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Ecological Condition of the Columbia River Estuary

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Ecological Condition of the Columbia River Estuary

an Environmental Monitoring and Assessment Program (EMAP) Report

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Executive Summary

The Columbia River estuary is a unique and important ecological resource. EPA's National Estuary Program (NEP) was established by Congress in 1987 in Clean Water Act amendments to improve the quality of estuaries of national significance. The Columbia River estuary is one of 28 estuaries in the NEP.

The overall quality of the Columbia River estuary, which forms the border between Washington and Oregon, is described in this report using data collected as part of the Western Environmental Monitoring and Assessment Program (EMAP). EMAP was initiated by EPA's Office of Research and Development (ORD) to estimate the current status and trends in the condition of nation's ecological resources. EMAP also examines associations between these indicators and natural and human-caused stressors. The coastal component of EMAP's monitoring and assessment tools are used to create an integrated and comprehensive coastal monitoring program of coastal ecosystems. Water column measurements are combined with information about sediment characteristics and chemistry, benthic organisms, and fish to describe the current estuarine condition.

Sampling began during the summer of 1999, with small estuaries of the Columbia River. In 2000, sampling continued with the larger Columbia River estuary. The boundary for the Columbia River estuary was head of tidal influence, so there were some freshwater components of this sampling effort. The Washington Department of Ecology (Ecology), and the Oregon Department of Environmental Quality (ODEQ) conducted all field sampling for this project in 1999-2000 with assistance from EPA Region 10 and the National Marine Fisheries Service (NMFS).

This project was designed to evaluate the overall condition of the Columbia River estuary. For water physical/chemical parameters, 7% of the area of the Columbia River estuary was in fair/poor condition, while nutrient indicators (nitrogen, phosphorus and chlorophyll a) showed a larger percent of the area (31-46%) in the fair/poor condition category. For sediment indicators, total organic carbon showed none of the areas was in poor condition, but for sediment contaminants approximately 16% of the Columbia River estuarine area was in poor condition. As for biological indicators (chemicals in fish tissue and percent *Corbicula*), for chemicals in fish tissue, 39% of the area was in fair/poor condition. An even higher percent of the Columbia River estuary (66%) was in poor condition using percent *Corbicula*, a non-indigenous species, as an indictor.

In 2006, we evaluated the ecological condition of the estuaries of Oregon and Washington (Hayslip, et al., 2006). The percent area in fair/poor condition for every indicator we evaluated was higher in the Columbia River estuary. The only exception was for chemicals in fish tissue where we found 47% of the area for estuaries of Oregon and Washington in fair/poor condition and 39% in the Columbia River estuary in fair/poor condition.

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Photo: Boat used by the Oregon Department of Environmental Quality for Columbia River estuary Sampling.

I. INTRODUCTION

Estuaries are bodies of water that receive freshwater and sediment from rivers and saltwater and sediment from the oceans. They are transition zones between the fresh water of a river and the salty environment of the sea. This interaction produces a unique environment that supports wildlife and fisheries and contributes substantially to the ecology and economy of coastal areas.

Recent studies have shown that growth of the human population is concentrated in the coastal areas (Culliton, 1990). This population growth in the coastal areas is a principal driver for many ecosystem stresses such as habitat loss, pollution, and nutrient enhancement. These stressors can affect the sustainability of coastal ecological resources (Copping and Bryant, 1993). Increased globalization of the economy is a major influence in the introduction of exotic species into port and harbors. Major environmental policy decisions at local, state and federal levels will determine the future for estuarine conditions of the western U.S. Information on the ecological condition of estuaries is essential to these policy decisions.

EPA's National Estuary Program (NEP) was established by Congress in 1987 to improve the quality of estuaries of national significance. The Clean Water Act Section 320 directs EPA to work collaboratively with locals to develop a plan (called Comprehensive Conservation and Management Plans) for attaining or maintaining water quality in an estuary. The Columbia River estuary is one of 28 estuaries in the NEP. The Lower Columbia River Estuary Partnership's (LCREP's) *Comprehensive Conservation and Management Plan, Volume 1* (LCREP, 1999) identifies actions that can be conducted in the study area to improve water quality and habitat in the Columbia River estuary.

The Columbia River estuary extends downstream from the Bonneville Dam at river mile 146 to the mouth of the Columbia River. The overall quality of Columbia River estuary, which forms the border between Washington and Oregon, is described in this report using data collected as part of the Western Environmental Monitoring and Assessment Program (EMAP). In EPA Region 10, Western EMAP is a cooperative effort between the Environmental Protection Agency (EPA) Office of Research and Development (ORD), EPA Region 10, the Washington Department of Ecology (Ecology), the Oregon Department of Environmental Quality (ODEQ), the National Oceanographic and Atmospheric Administration (NOAA) and others. Much of this report is based on work by ODEQ (Sigmon, 2004), Ecology (Wilson and Partridge, 2007) and EPA ORD (Nelson, 2005 and U.S. EPA, 2004).

A. Background

EMAP (Environmental Monitoring and Assessment Program) was initiated by EPA's Office of Research and Development (ORD) to estimate the current status and trends in the condition of nation's ecological resources. EMAP also examines associations between these indicators and natural and human-caused stressors. This information will assist the EPA and States/Tribes as the Clean Water Act (CWA) directs them to develop programs that evaluate, restore and maintain the chemical, physical and biological integrity of the Nation's waters. The data collected during this survey can also be used to examine the relationships between environmental stressors and the condition of ecological resources

The coastal component of Western EMAP applies EMAP's monitoring and assessment tools to create an integrated and comprehensive coastal monitoring program along the west coast. Water column measurements are combined with information about sediment characteristics and chemistry, benthic organisms, and fish to describe the current estuarine condition. Sampling began during the summer of 1999, with small estuaries of the Columbia River. In 2000, sampling continued with the larger Columbia River estuary. The boundary for the Columbia River estuary was head of tidal influence, so there were some freshwater components of this sampling effort. This report provides a summary of the data from 1999-2000 sampling for the Columbia River estuary.

B. Objectives

The overall objectives of this project are:

- to describe the current ecological condition of the Columbia River estuary based on a range of indicators of environmental quality using a statistically based survey design;
- to establish a baseline for evaluating how the conditions of the estuarine resources change in the future;
- to develop and validate improved methods for use in future coastal monitoring and assessment efforts in the western coastal states;
- to transfer the technical approaches and methods for designing, conducting and analyzing data from statistically based environmental assessments to the states and others;
- to work with the states and others to build a strong program of water monitoring which will lead to better management and protection of western estuaries.

II. METHODS

The Washington Department of Ecology (Ecology), and the Oregon Department of Environmental Quality (ODEQ) conducted all field sampling for this project in 1999-2000 with assistance from EPA Region 10 and the National Marine Fisheries Service (NMFS).

The goal of EMAP is to develop ecological monitoring and assessment methods that advance the science of measuring environmental resources to determine if they are in an acceptable or unacceptable condition. Two major features of EMAP are:

- the probability-based selection of sample sites and
- the use of ecological indicators.

A. **Design** - How to Select Estuarine Sites to Sample

Environmental monitoring and assessments are typically based on subjectively selected sampling sites. EMAP provides an alternative method of sample site selection for large-scale monitoring. Peterson (1999) compared subjectively selected localized lake data with EMAP probability-based sample selection and showed the results for the same area to be substantially different. The primary reason for these differences was lack of regional sample representativeness of subjectively selected sites. Coastal studies have been plagued by the same problem. A more objective approach is needed to assess overall estuarine quality on a regional scale.

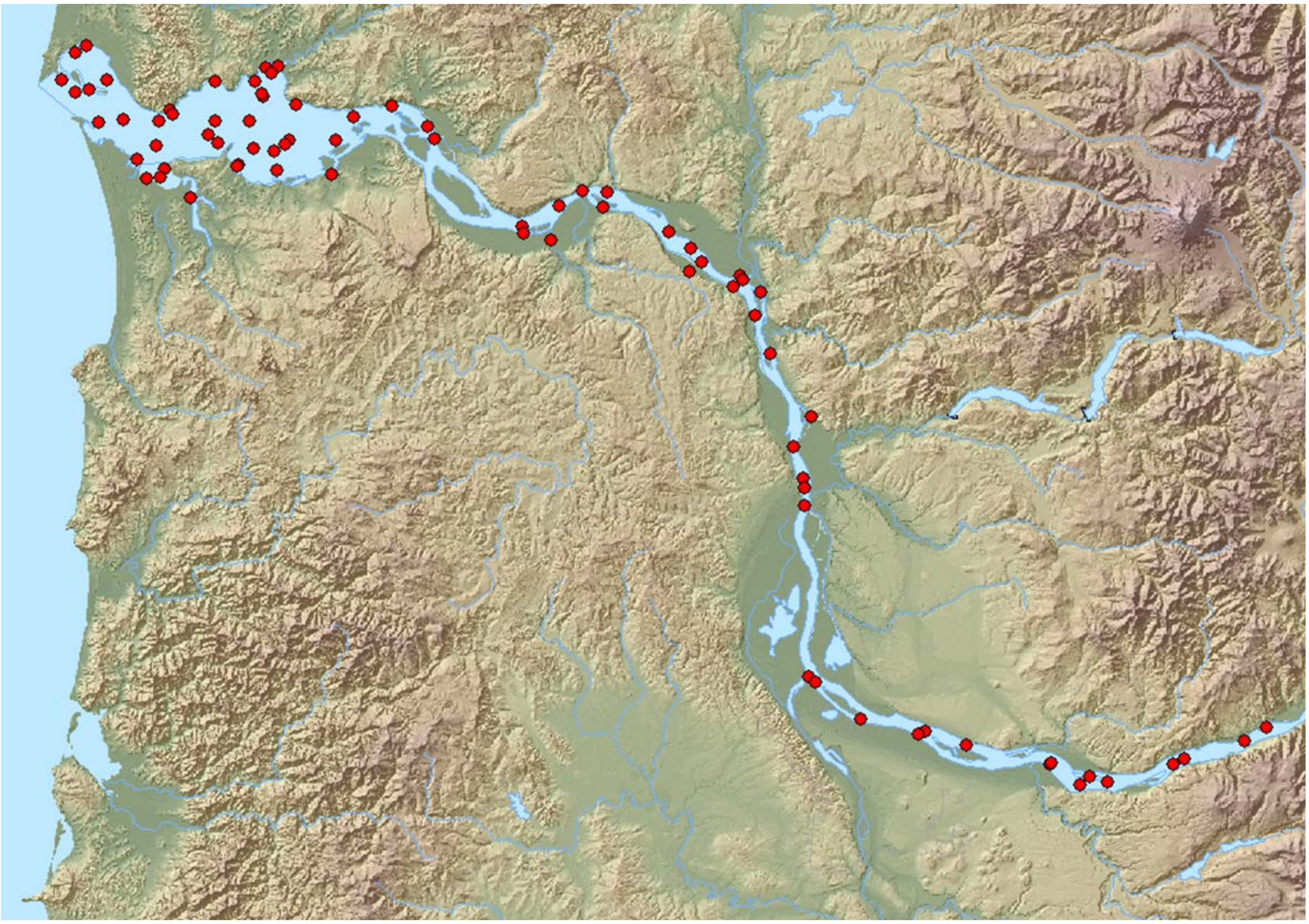
In addition, it is generally impossible to completely census an extensive resource, such as the set of all estuaries on the west coast. A more practical approach to evaluating resource condition is to sample selected portions of the resource using probability-based sampling.

Designing a probability-based survey begins with creating a list of all units of the target population
from which to select the sample and selecting a random sample of units (places to collect data) from this list. The list or map that identifies every unit within the population of interest is termed the sampling frame.

Studies based on random samples of the resource rather than on a complete census are termed sample or probability-based surveys. Probability-based surveys offer the advantages of being affordable and of allowing extrapolations to be made of the overall condition of the resource based on the random samples collected. These methods are widely used in national programs such as forest inventories, consumer price index, labor surveys, and such activities as voter opinion surveys.

A probability-based survey design provides an approach to selecting samples in such a way that they provide valid estimates for the entire resource of interest, in this case the Columbia River estuary. Therefore, the results in this document will be reported in terms of the percent of estuarine area of the Columbia River estuary. The sampling frame for the EMAP Western Coastal Program was developed from USGS 1:100,000 scale digital line graphs. Additional details are described in Diaz-Ramos (1996), Stevens (1997), and Stevens and Olsen (1999).

The assessment of condition of small estuaries conducted in 1999 was the first phase of a two-year comprehensive assessment of all estuaries of the states of Washington and Oregon. The complete assessment requires the integrated analysis of data collected from the small estuarine systems in 1999 and the larger estuarine systems in 2000 (**Map 1**). The intent of the design is to be able to combine data from all stations for analysis. The West Coast sampling



Map 1. Columbia River estuary EMAP Sampling Locations, 1999-2000.

frame was constructed as a GIS coverage that included the total area of the estuarine resource of interest. The estuarine area of the Columbia River represented by this report is 611 square kilometers (or 236 square miles).

For the state of Washington, the 1999 design included 12 sites in the tributary estuaries of the Columbia River located within Washington State. The Oregon 1999 design included 17 sites in the tributary estuaries of the Columbia River located within Oregon. A total of 29 sites were sampled in tributary estuaries of the Columbia River in 1999.

In 2000, the design included only the main channel area of the Columbia River. The Columbia River system was split into two subpopulations: the lower, saline portion and the upper, more freshwater portion, with a total of 20 and 30 sites, respectively (Appendix 1).

All sites from both states and for both years (79 sites) were combined for analysis in this report to represent the entire 611 square kilometers of the Columbia River estuary of Oregon and Washington.

B. **Indicators** - What to Assess at Each Selected Site

The objective of the Clean Water Act is to restore and maintain the chemical, physical and biological integrity of the Nation's waters. Therefore, in order to assess the nation's waters, it is important to measure chemical (including sediment chemistry and fish tissue contaminants), physical (such as water clarity, and silt-clay content) and biological (fish and invertebrate communities, and toxicity testing) conditions. Coastal EMAP uses ecological indicators to quantify these conditions. Indicators are measurable characteristics of the environment, both abiotic and biotic, that can provide information on ecological resources.

There is a great deal of information collected as part of Coastal EMAP. **Table 1** shows the selected core EMAP coastal indicators. For a list of the chemical analytes for sediment and tissue samples, see Appendix 2. In the following section, we will give an overview of the methods for those indicators that we describe in the results and discussion sections of this report. Additional detailed information on field data collection and laboratory analysis methods is available in the "Environmental Monitoring and Assessment Program (EMAP): National Coastal Assessment Quality Assurance Project Plan (U.S. EPA, 2001).

Indicator	Rationale
Water Column Indicators	
Water Clarity	Clear waters are valued by society and contribute to the maintenance of healthy and productive ecosystems. Light penetration into estuarine waters is important for submerged aquatic vegetation which serves as food and habitat for the resident biota.
Dissolved oxygen	Dissolved oxygen (DO) in the water column is necessary for all estuarine life. Low levels of oxygen (hypoxia) or lack of oxygen (anoxia) often accompany the onset of severe bacterial degradation, sometimes resulting in the presence of algal scums and noxious odors. In severe cases, low DO can lead to the death of large numbers of organisms.
Dissolved nutrients (Nitrogen and Phosphorus)	Dissolved inorganic nitrogen and dissolved inorganic phosphorus are necessary and natural nutrients required for the growth of phytoplankton. However, excessive dissolved nutrients can result in large, undesirable phytoplankton blooms.
Total Suspended Solids	Total suspended solids (TSS) refers to the matter that is suspended in water. TSS can be a useful indicator of the effects of runoff from construction, agricultural practices, logging activity, discharges, and other sources.
Sediment Indicators	
Silt-Clay Content	The percentage of particles present in bottom sediments that are silt and clay is an important factor determining the composition of the biological community. It is an important factor in the adsorption of contaminants to sediment particles and therefore for the exposure of organisms to contaminants.
Sediment contaminants	A wide variety of metals and organic substances are discharged into estuaries from urban, agricultural, and industrial sources in the watershed. The contaminants adsorb onto suspended particles that settle to the bottom, disrupt the benthic community and can concentrate in the tissue of fish and other organisms.
Sediment toxicity testing	A standard direct test of toxicity is to measure the survival of amphipods (commonly found, shrimp-like benthic crustaceans) exposed to sediments for 10 days under laboratory conditions.
Biological Indicators	
Benthic organisms	The organisms that inhabit the bottom substrates of estuaries are collectively called benthic macroinvertebrates or benthos. These organisms are an important food source for bottom-feeding fish, shrimp, ducks, and marsh birds. Benthic organisms are sensitive indicators of human-caused disturbance and serve as reliable indicators of estuarine environmental quality. We also examine which species are Non-Indigenous species (NIS) also called non-native species.
Fish-tissue contaminants	Chemical contaminants may enter an organism in several ways: uptake from water, sediment, or previously contaminated organisms. Once these contaminants enter an organism, they tend to build up. When fish consume contaminated organisms, they may “inherit” the levels of contaminants in the organisms they consume. This same “inheritance” of contaminants occurs when other biota (such as birds) consume fish with contaminated tissues.

Table 1. Selected Coastal EMAP Indicators

1. Field Methods

Detailed descriptions of the field methods are available in the "Environmental Monitoring and Assessment Program (EMAP): National Coastal Assessment Quality Assurance Project Plan 2001-2004" (U.S. EPA, 2001). The discussion below is a very brief summary of the methods used for the indicators that will be evaluated in this report.

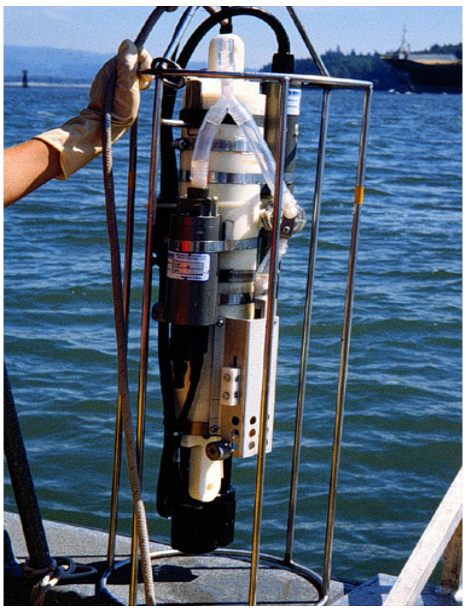


Photo: Example of water sampler

Water Column

Water depth, salinity, conductivity, temperature, pH and DO data were collected using an electronic instrument called a Conductivity Temperature Depth recorder (CTD), which takes measurements from the surface to the bottom of the water column. Photosythetically available radiation (PAR) was measured with LiCor® PAR sensors. The CTD and underwater PAR sensor were mounted for water column profiling. Water quality indicators were recorded with the CTD at discrete depth intervals, depending on the total station depth (**Table 2**).

Total Depth (m)	Sample Depth Increment
< 1.5	Mid-depth
≤ 2	Every 0.5m
> 2 and < 10	0.5m, Every 1m, 0.5 off bottom
> 10	0.5m, Every 1m up to 10m, Every 5m to 0.5m off bottom

Table 2. Station Total Depth and CTD Sampling Depths.

Near-bottom measurements were taken after a three minute delay in case the sediment surface had been disturbed. Data were recorded for descending and ascending profiles. Secchi depth was recorded as the water depth at which a standard 20cm diameter black-and-white Secchi disc could be seen during ascent.

Discrete water samples were collected with bottles at one to three depths, which corresponded with the CTD and PAR measurement depths (**Table 3**). Water grab samples were analyzed for dissolved nutrients [forms of Nitrogen (Nitrate, Nitrite, Ammonium), and Phosphorus], Total Suspended Solids and Chlorophyll *a*.

Total Depth (m)	Discrete Sample depth
< 1.5	Mid-depth
≥ 1.5 to < 2	0.5m 0.5m off bottom
≥ 2	0.5m Mid-depth 0.5m off bottom

Table 3. Station Depth and Discrete Water Sampling Depths.

Sediment

Sediment samples were collected with a 0.1-m^2 Van Veen grab sampler. All sediment sampling gear was decontaminated and rinsed with site water prior to sample collection. Acceptable grabs were ≥ 7 cm penetration, not canted, not overflowing, not washed out, and had an undisturbed sediment surface. Water overlying the sediment grab, if present, was siphoned off without disturbing the surface. The top 2-3 cm of sediment were removed with a stainless steel spoon and transferred to a decontaminated container. Sediments from a minimum of three grabs were composited to collect approximately 6 liters of sediment. Most sites required from 6 to 9 grabs. Once adequate sediment was collected, it was homogenized and transferred to clean jars, stored on wet ice and later refrigerated or frozen until analysis.

Benthic Invertebrates

Sediment samples to enumerate the benthic infauna were collected using a 0.1-m^2 Van Veen grab sampler. After collection, infauna were sieved through nested 1.0-mm and 0.5-mm mesh sieves using site water supplied by an adjustable flow hose. Material caught on the screens was fixed with 10% phosphate-buffered formalin. Samples were re-screened and preserved with 70% ethanol within two weeks of field collection. The 0.5 mm fraction was archived, and the 1.0 mm fraction was shipped for sorting and taxonomic identification.

Fish Trawls

Bottom trawls were conducted using a 16-foot otter trawl with a 1.25-inch mesh net. Trawls were intended to retrieve demersal fishes (fish living on or near the bottom) and benthic invertebrates. Trawling was performed after water quality and sediment sampling were completed. Fish were obtained by hook-and-line techniques at sites where trawling was not feasible due to safety and/or logistical concerns. The catch was brought on board, put alive into wells containing fresh site water and immediately sorted and identified. Information was recorded on species, fish length and number of organisms. All fish not retained for tissue chemistry or to study their diseased tissue (histopathology) were returned to the estuary.

Fish Tissue

From the fish caught, several species of flatfish (demersal soles, flounders, and dabs) were designated as target species for the analyses of chemical contaminants in whole-body fish tissue. These flatfish are common along the entire U.S. Pacific Coast and are intimately associated with the sediments. Where the target flatfish species were not collected in sufficient numbers, perchiform (see list below) species were collected. These species live in the water column but feed primarily or opportunistically on the benthos. In cases where neither flatfish species nor perches were collected, other species that feed primarily or opportunistically on the benthos were collected for tissue analysis. The target species analyzed for tissue contaminants were:

Pleuronectiformes (flatfish)
Citharichthys sordidus - Pacific sanddab
Citharichthys stigmaeus - speckled sanddab
Platichthys stellatus - starry flounder
Pleuronectes isolepis - butter sole
Pleuronectes vetulus - English sole
Psettichthys melanostictus - sand sole

Perciformes (perchiform fish)
Cymatogaster aggregata - shiner perch
Embiotoca lateralis - striped sea perch

Other
Leptocottus armatus - Pacific staghorn sculpin

Target species were used for whole-body tissue contaminant analyses. Individuals of a single species (ideally 5-10 fish) were combined for a single composite sample. Approximately 200-300 grams of tissue (wet weight) is needed to complete all analysis, but a minimum of 50 grams of tissue is required for mercury analysis.

2. Laboratory Methods

The detailed quality assurance/quality control (QA/QC) program and laboratory methods for the Western Coastal EMAP program are outlined in “Environmental Monitoring and Assessment Program (EMAP): National Coastal Assessment

Quality Assurance Project Plan 2001-2004" (U.S. EPA, 2001). The methods are described briefly below.

Water

Discrete water samples were analyzed by the state environmental labs (Oregon DEQ and Ecology/University of Washington).

Sediment Chemistry

Sediment samples for chemical analysis were taken from the same sediment composite used for the sediment toxicity tests. Approximately 250-300 ml of sediment was collected from each station for analysis of the organic pollutants and another 250-300 ml for analysis of the total organic carbon (TOC) and metals (Appendix 2). The analytical methods are those used in the NOAA NS&T Program (Lauenstein, 1993) or documented in the EMAP-E Laboratory Methods Manual (U.S. EPA, 1994a).

Fish Tissue

Organic and metal contaminants were measured in the whole-body tissues of the species of fish listed above (Section II.B.1). Chemical residues in fish tissue (Appendix 5) were determined for each of the composited tissue samples. Quality control procedures for the tissue analysis were similar to those described above for sediments and followed the procedures detailed in U.S. EPA (1994a and 2001), including the use of certified reference materials, spikes, duplicates, and blanks.

Sediment Physical Parameters

Sediment silt-clay and TOC were analyzed by the State labs (Oregon and Washington). Grain size analysis was by dry- and wet sieving. Sediment digestion for TOC analysis was by acidification and combustion.

Amphipod Sediment Toxicity Tests

The 10-day, solid-phase toxicity test with the marine amphipod *Ampelisca abdita* was used to evaluate potential toxicity of sediments from all sites. Mortality, and emergence from the sediment during exposure were the exposure criteria used. All bioassay tests were performed within 28 days of field collection using the benthic amphipod *Ampelisca abdita*. Amphipod toxicity tests were performed with the species *Hyalella azteca* for the freshwater sites in the Columbia in 2000. Procedures followed the general guidelines provided in ASTM Protocol E-1367-92 (ASTM 1993) and the EMAP-E Laboratory Methods Manual (U.S. EPA, 1994a).

Benthic Invertebrates

Benthic infauna data were processed according to protocols described in the EMAP lab method manual (U.S. EPA, 1994a). Both indigenous and exotic organisms were identified to the lowest practical taxonomic level (species where possible).

3. Data Analysis Methods

In this report, the primary method for evaluating indicators for sites selected using the EMAP probability design is the cumulative distribution function (CDF). A CDF is a graph that shows the distribution of indicator or parameter data accumulated over the entire “population” of concern. The “population” in this report is generally the total area of the Columbia River estuary.

The EMAP statistical design allows for extrapolation from data collected at specific sites to the entire “population,” in this case the Columbia River estuary.

For example, if an indicator value above 3 is considered “impaired,” then **Figure 1** (CDF) shows that approximately 60 percent of the area of the Columbia River estuary exceed that threshold (and the other 40% of the estuary area is below 3).

The EMAP design also allows for the calculation of confidence intervals for CDFs. For example, we could say that 60% of the area of the Columbia River estuary exceed some threshold, plus or minus 8%. However, for ease of reading the CDFs, we did not include the confidence intervals for the graphs in this document.

The CDF below is just an introductory example. The 50% line marked on all of the CDFs in this report, including the one below, is just a marker and not an ecologically important criterion.

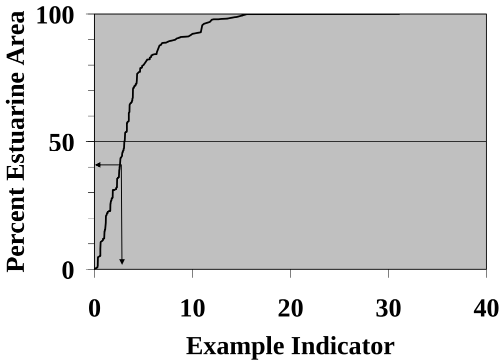


Figure 1. Example Cumulative Distribution Function (CDF).

III. RESULTS

In this section of the report we will describe the results from the data collected using the EMAP protocols (described in Section II) from nearly 80 randomly selected sites in the Columbia River estuary (Map 1). We are able to present only a portion of the indicators that were generated from the field data due to the large volume of information that was collected. Additional indicators are summarized in the Appendices. In Section IV, we will then compare these results to established benchmarks (where available) to make conclusions about whether the Columbia River estuary is in good, fair or poor condition.

A. Water Physical/Chemical Parameters

1. Water Clarity

Light Transmissivity

The extent of light transmittance or attenuation at a given water depth is a function of the amount of ambient light and water clarity, with the latter affected by the amount of dissolved and particulate constituents in the water. Light transmissivity, the percent of light transmitted at 1m, in the Columbia River estuary ranged from 0 to 87.6 percent (median 16.8 percent) across the 68 stations where light transmissivity was measured (**Figure** 2).

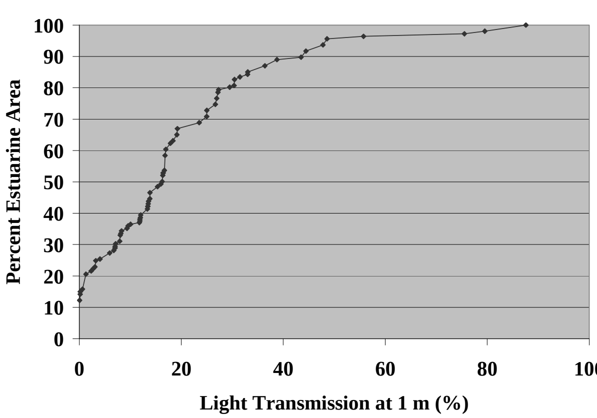


Figure 2. CDF of Water Clarity.

Secchi Depth

Secchi Depth is a measure of cloudiness or turbidity. It is the greatest depth to which light can penetrate underwater. Secchi depth in the Columbia River estuary ranged from 0.1 meters to 3.5 meters (median 1.5 meters) across the 78 stations where Secchi depth was measured (**Figure 3**).

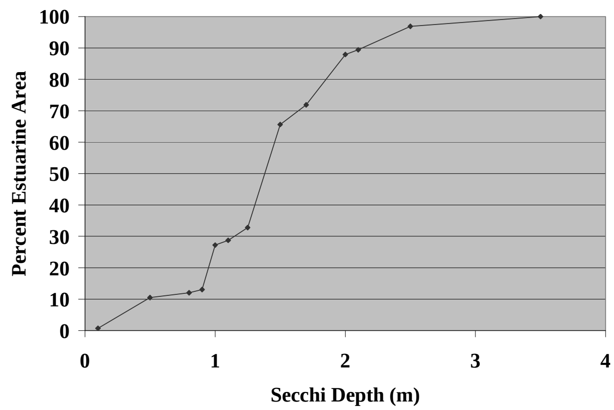


Figure 3. CDF of Secchi Depth.

2. Dissolved Oxygen

Dissolved oxygen is necessary for all estuarine life. Dissolved oxygen (DO) concentrations in the bottom water for the Columbia River estuary ranged from 2.9 mg/L to 11.5 mg/L (median 8.4), across the 79 stations of the total estuarine where bottom dissolved oxygen concentrations were measured (**Figure 4**).

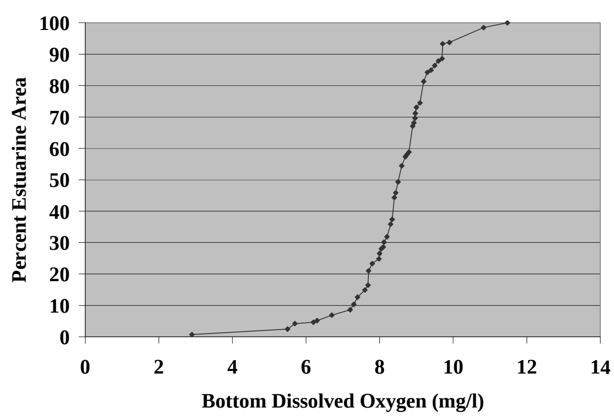


Figure 4. CDF of Bottom Dissolved Oxygen.

Surface dissolved oxygen (DO) concentrations in the Columbia River estuary ranged from 3.4 mg/L to 11.2 mg/L (median 8.8 mg/l) across the 79 stations where surface dissolved oxygen concentrations were measured (**Figure 5**).

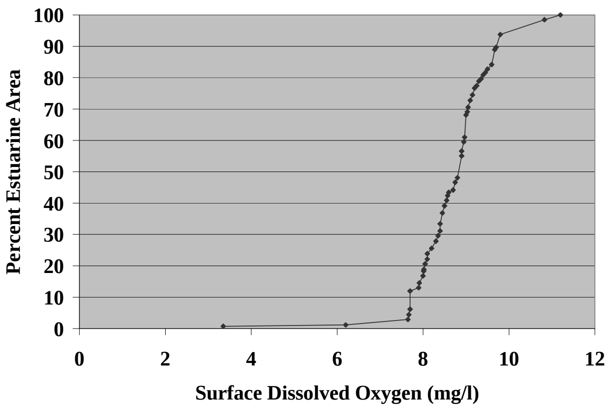


Figure 5. CDF of Surface Dissolved Oxygen.

3. Nutrients

Nutrients are chemical substances used by organisms for maintenance and growth that are critical for survival. Plants require a number of nutrients. Of these, nitrogen and phosphorus are of particular concern in estuaries for two reasons: they are two of the most important nutrients essential for the growth of aquatic plants, and the amount of these nutrients being delivered to estuaries is increased by many human activities.

Eutrophication is a condition in which high nutrient concentrations stimulate excessive algal blooms, which then deplete oxygen as they decompose. Estuaries with insufficient mixing may become hypoxic (low in oxygen) and under the worst conditions, the bottom waters of an estuary turn anoxic (without oxygen).

Nutrient concentrations were measured at the surface, middle and bottom of the water column at 79 stations. The following graphs represent the mean of the three depths at each station.

Total Dissolved Inorganic Nitrogen

Total dissolved inorganic nitrogen concentrations ranged from 20.6 to 283.7 µg/L for the sites sampled. The three depths showed a similar distribution, but bottom and midwater samples generally had higher total nitrogen concentrations than did the surface samples. About half of the estuary area had less than 150 µg/L total dissolved inorganic nitrogen (**Figure 6**) for the mean of the three depths at each station.

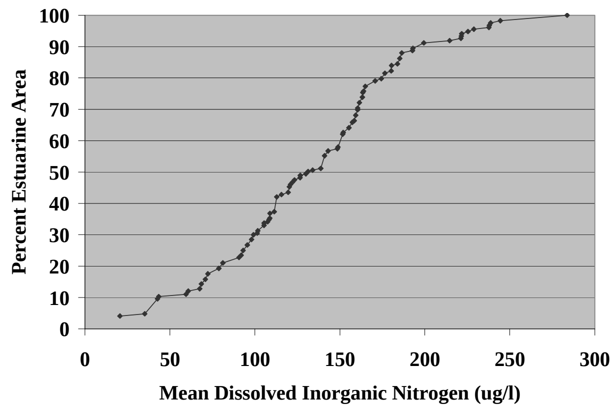


Figure 6. CDF of Total Dissolved Inorganic Nitrogen.

Soluble Phosphorus

Soluble phosphorus concentrations ranged from 0 to 34.4 µg/L (**Figure 7**). About half of the estuarine area had soluble phosphorus concentrations less than 16 µg/L for the mean of the three depths at each station.

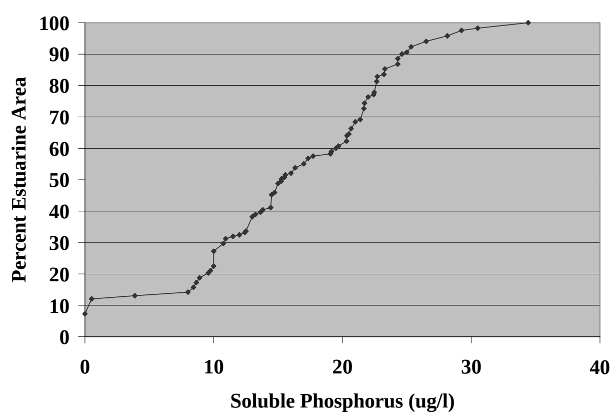


Figure 7. CDF of Soluble Phosphorus.

Chlorophyll *a*

Phytoplankton are microscopic plants common to estuarine waters. Phytoplankton are primary producers of organic carbon and form the base of the estuary food chain. One procedure for determining the abundance of phytoplankton is to measure the amount of the photosynthetic pigment chlorophyll *a* that is present in water samples. Chlorophyll is a pigment common to all photosynthetic algae, and its amount in the water is in relation to the algal concentration. Chlorophyll *a* concentrations ranged from 0 to 14.5 µg/L (**Figure 8**). About one-half of the estuary area had less than 4 µg/L for the mean of the three depths at each station.

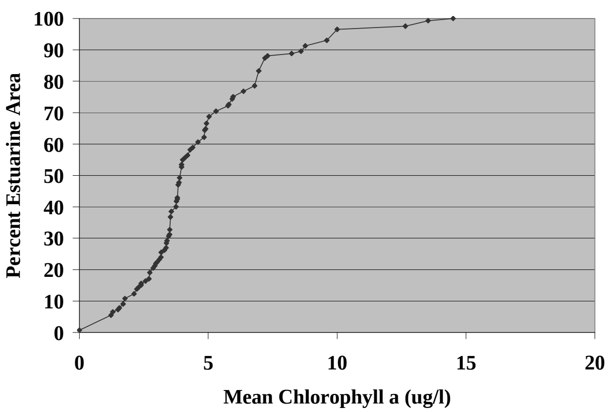


Figure 8. CDF of Mean Chlorophyll a.

Nitrogen to Phosphorus Ratio

The relationship between nitrogen and phosphorus (N:P ratio) can provide insights into which of these nutrients is limiting. Molar nitrogen to phosphorus ratios (N:P) ranged from 0 to 179 (**Figure 9**) for the mean of the three depths at each station. Thirty-seven percent of the estuary area had N:P < 16, which may indicate that production of phytoplankton at these sites is nitrogen-limited.

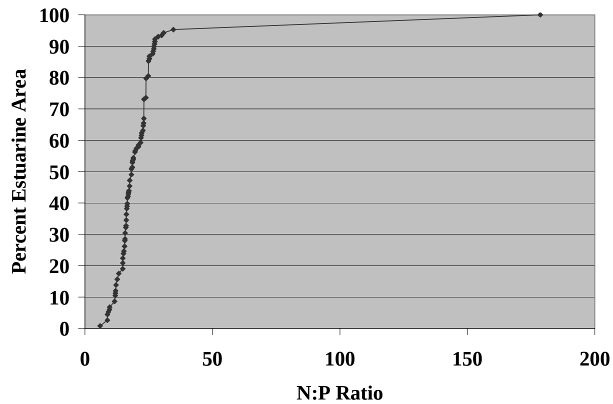


Figure 9. CDF of N:P Ratio.

4. TSS

Suspended materials include soil particles (clay and silt), algae, plankton, and other substances. Total suspended solids (TSS) refer to the matter that is suspended in water. The solids in water have different attributes and sizes.

Total suspended solids often increase sharply during and immediately following rainfall, especially in developed watersheds, which typically have relatively high proportions of impervious surfaces such as rooftops, parking lots, and roads. The flow of stormwater runoff from impervious surfaces rapidly increases stream velocity, which increases the erosion rates of streambanks and channels (U.S. EPA, 1993).

Some of the physical effects of above normal suspended materials include:

- clogged fish gills, inhibiting the exchange of oxygen and carbon dioxide,
- reduced resistance to disease in fish,
- reduced growth rates,
- altered egg and larval development,
- fouled animal filter-feeding systems, and
- hindered ability of aquatic predators from spotting and tracking down their prey.

Higher concentrations of suspended solids can also serve as carriers of toxins, which readily cling to suspended particles. Total Suspended Solids in the Columbia River estuary ranged from .6 mg/L to 140 mg/L (mean 10.3 mg/L) across the 79 stations where TSS was measured (**Figure 10**).

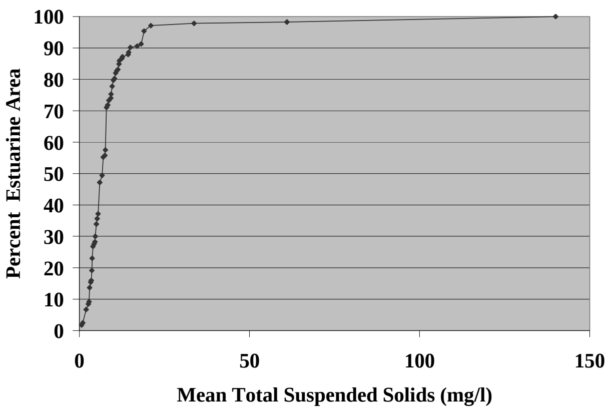


Figure 10. CDF of Total Suspended Solids.

Photo: Sediment sampling by Washington Department of Ecology.

B. Sediment Characteristics

Sampling of sediment was conducted at 77 stations, representing 98% of the area of the Columbia River estuary. Silt-clay content and total organic carbon (TOC) are descriptors of the characteristics of the sediments. For contaminants in the sediments, the section below compares the concentrations of metals and organic chemicals in those sediment samples to state sediment standards, where available, and to sediment quality guidelines. See Appendix 4 for additional details.

The sediment quality guidelines used here are concentrations that have shown adverse effects on organisms in laboratory experiments. They are divided into ERLs (Effects Range-Low) and ERMs (Effects Range-Median) and are described more completely in Long, 1995. ERM guidelines were calculated as the 50th percentile concentrations associated with toxicity or other adverse biological effects in a database compiled from saltwater studies conducted throughout North America. The ERL guidelines were calculated as the 10th percentile of that dataset. However, since much of the Columbia River estuary is freshwater (salinity <5 psu), we will also use the Threshold Effect Concentration (TEC), the concentration below which adverse effects are not expected to occur (for more detailed discussion see MacDonald et al., 2000). TECs were derived for common chemicals of concern in freshwater sediments. TECs provide a reliable basis for classifying freshwater sediments as toxic.

In this section of the report we will be using the ERLs, ERMs and TECs as descriptors, since a single exceedance may or may not indicate poor estuarine condition. In Section IV, we will examine sites with multiple exceedances, which may indicate poor estuarine condition.

1. Silt-Clay Content

The proportion of fine grained materials (silt and clay) in the estuarine sediments ranged from 0 to 93%, with a mean of 7.9% fines, across the 77 stations where silt-clay content was measured (**Figure 11**). If sediment samples with less than 20% fines are considered predominantly sand, then sandy sediments make up 89% of the estuarine area. If samples with more than 80% fines are considered muddy, then muddy sediments cover 3% of the estuarine area.

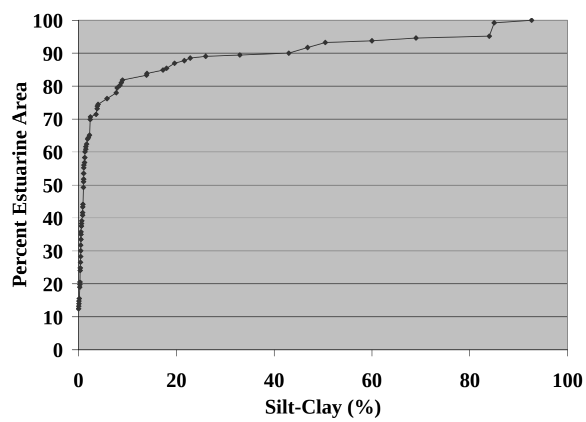


Figure 11. CDF of Percent Silt-Clay.

2. Total Organic Carbon

Total Organic Carbon (TOC) is the amount of organic matter within the sediment. TOC can be an important food source for deposit-feeding benthos. Silty sediments high in TOC are more likely than sandy sediments, or sediments low in TOC, to have contaminants adsorbed to them. TOC concentrations in the Columbia River estuary ranged from 0% to 2.2% (**Figure 12**) across the 77 stations where TOC was measured.

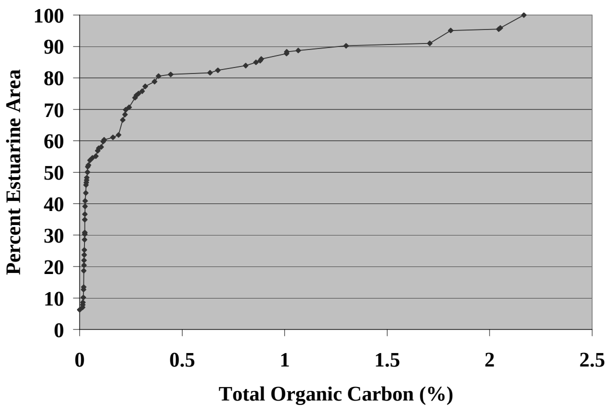


Figure 12. CDF of Total Organic Carbon.

3. Metals

Sediment samples were collected from 77 sites, representing 98% of the estuarine area, and were analyzed for metals. **Table 4** describes the minimum, maximum and the percent of estuarine area exceeding the ERMs, ERLs, and TECs.

Chromium, copper and nickel exceedances of the ERL or TEC will not be included in any aggregate sediment contaminant indicator. This is because the ERL and TEC for chromium are less than the average concentration found in the Earth's crust and in marine shales (100 and 90 ppm, respectively, Krauskopf and Bird, 1995). The ERL and TEC for copper are also less than the average concentration in the Earth's crust and in shale (55 and 45 ppm, respectively). Also, the ERL and ERM values for nickel are not based on a strong correlation between concentration and effect (Long, 1995). Finally, the ERL, ERM and TEC concentrations for nickel are within the range of concentrations found in common rock types that make up the earth's crust.

Analyte	units	Min. detected	Max.	% area analyte detected	Fresh-water TEC [1]	% area exceeds TEC	Estuarine ERL[2]	% area exceeds ERL	Estuarine ERM[2]	% area exceeds ERM
Arsenic	mg/kg	0.69	20.8	92	9.8	4.8	8.2	7.2%	70	0
Cadmium	mg/kg	0.09	0.9	80	0.99	0	1.2	0	9.6	0
Chromium	mg/kg	15.3	89.8	100	not used	N/A	not used	N/A	370	0
Copper	mg/kg	8.3	59	100	not used	N/A	not used	N/A	270	0
Lead	mg/kg	1.5	25.9	100	36	0	46.7	0	218	0
Mercury	mg/kg	0.0049	0.2	94	0.18	<1	0.15	1.4%	0.71	0
Nickel	mg/kg	15.1	49.2	100	not used	N/A	not used	N/A	not used	N/A
Selenium	mg/kg	0.13	0.46	10	N/A	N/A	N/A	N/A	N/A	N/A
Silver	mg/kg	0.13	0.98	40	N/A	N/A	1	0	3.7	0
Zinc	mg/kg	54	147	100	121	11.1	150	0	410	0
PAH, total	µg/kg	1	59878	39	1610	<1	4022	<1	44792	<1
PCB, total	µg/kg	0.8	13	15	60	0	22.7	0	180	0
DDT, total	µg/kg	0.27	7.2	13	5.3	<1	1.58	6	46.1	0
DDE	µg/kg	0.27	3.9	11	3.2	<1	2.2	<1	27	0
dieldrin	µg/kg	1.5	1.8	3	1.9	0	N/A	N/A	N/A	N/A
lindane	µg/kg	1.3	2.7	6	2.4	4.7	N/A	N/A	N/A	N/A

Table 4. Selected Chemicals in Sediments of the Columbia River estuary (N/A = criterion not available for comparison).

[1] Macdonald, et al., 2000.

[2] Long, et al., 1995.

4. Polynuclear aromatic hydrocarbons (PAHs)

Polynuclear aromatic hydrocarbons (PAHs) are petroleum or coal combustion by-products often associated with elevated levels of tumors in fish. The PAHs of low molecular weight are relatively easy to degrade, whereas those with higher molecular weights are resistant to decomposition. The low molecular weight PAHs are acutely toxic to aquatic organisms, whereas the high molecular weight PAHs are not. However, several high molecular weight PAHs are known to be carcinogenic.

Total PAH

Total PAHs ranged in concentration from below detection to 59,878 ppb (ng/g dry weight), and were detected in 39% of the estuarine area (**Figure 13**). The TEC of 1610 µg/kg, the ERL of 4022 µg/kg and the ERM of 44792 µg/kg were all exceeded at only one site representing less than 1% of the area.

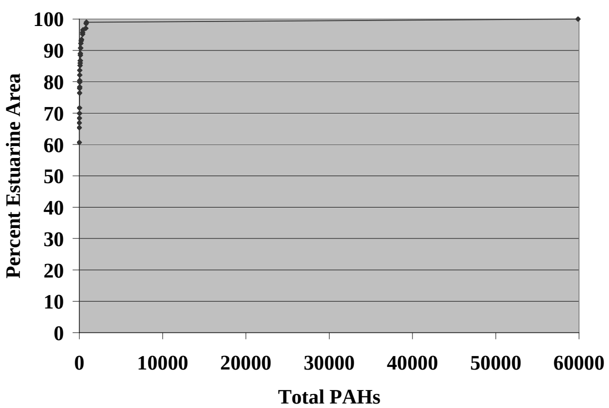


Figure 13. CDF of Total PAHs.

5. Polychlorinated Biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are a group of toxic, persistent chemicals formerly used in electrical transformers and capacitors. They often accumulate in sediments, fish, and wildlife, and are detrimental to the health of these organisms.

The sediment quality guidelines and standards for PCBs are based on a different analytical method than that used to analyze the EMAP sediments* so the "total PCB" concentrations using the two methods will not yield the same result. The EMAP totals are of the 21 PCB congeners measured, so the concentrations are biased low. The comparison is useful to highlight areas that are impacted by PCBs, but it is important to keep in mind that if identical methodology were used, additional sites might show exceedances.

*The EMAP PCB analyte list includes the most common congeners, which are not necessarily the most toxic. Because the EMAP total PCB concentration is a sum of only the 21 congeners that were measured, it is important to remember that it **is biased low**. There are approximately 114 PCB congeners that are found in commercial mixtures (Frame et al, 1996) although some are found only rarely. In addition, quality assurance review following EMAP PCB analysis indicated low precision for the results at the individual congener level due to interferences. However, the review also concluded that it was acceptable to use the EMAP total PCBs as general indicators of sediment contamination.

EMAP total* PCB concentrations ranged from below detection to 13 µg/kg. PCBs were detected in 15% of the estuarine area (**Table 5**). The TEC of 60 µg/kg, the ERL of 22.7 µg/kg and the ERM of 180 µg/kg were not exceeded.

6. Pesticides

Not all of the pesticides measured in the sediment have criteria to use for comparison. DDT and DDE have TECs, ERLs and ERMs. Only dieldrin and lindane have TECs. Endosulfan sulfate, hexachlorobenzene, DDT and DDE were found in more than 10% of the estuarine area (**Table 5**). Forty-three percent of the estuarine area had no pesticides detected in the sediments.

Pesticide	Min. detected	Max. detected	% of area with detected analyte
aldrin	0.5	1.4	7
chlordane	all ND	all ND	0
dieldrin	1.5	1.8	3
endosulfan I	all ND	all ND	0
endosulfan II	1.75	1.75	<1
endosulfan sulfate	1.25	11.8	12
endrin	2.7	2.7	<1
heptachlor	0.6	3.6	17
heptachlor epoxide	1.3	3.3	<1
Hexachlorobenzene	0.65	4.6	11
Lindane	1.3	2.7	6
Mirex	all ND	all ND	0
trans nonachlor	1.1	1.1	<1
DDT, total	0.27	7.2	13
44'-DDE	0.27	3.9	11

Table 5. % of Estuarine Area with Pesticides Detected in the Sediments.

DDT

Total DDT was detected in 13% of the estuarine area, with concentrations ranging from below detection to 7.2 µg/kg (**Figure 14**). The ERL of 1.58 µg/kg was exceeded in 6% of the area, the TEC of 5.3 µg/kg was exceeded in less than 1% of the area, but the ERM was not exceeded.

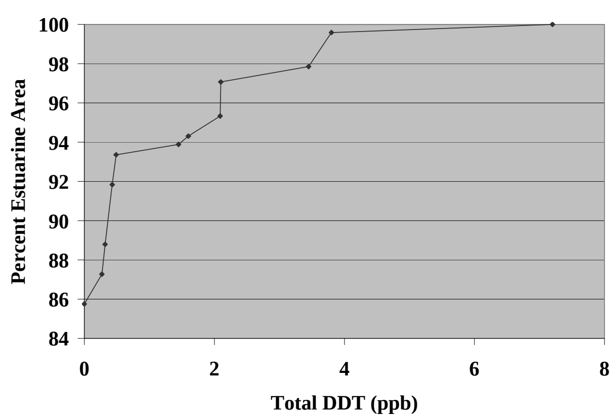


Figure 14. CDF of Total DDT.

In a separate EMAP study of the ecological condition of the continental shelf, the Washington State Department of Ecology (Partridge, 2007) found that DDTs were detected in the offshore locations near the mouth of the Columbia. Detectable concentrations of DDTs occur closer to shore near the Columbia River and get deeper and farther from shore going northward, with none in the 30-120 m depth band in the northern half of the Olympic Coast National Marine Sanctuary.

The DDT breakdown product 4,4'-DDE was detected in 11% of the estuarine area with concentrations ranging from below detection to 3.9 µg/kg. The ERL of 2.2 µg/kg and the TEC of 3.2 µg/kg were exceeded in less than 1% of the area but the ERM was not exceeded.

C. Toxicity

1. Acute sediment toxicity tests

Toxicity testing uses biological organisms, in this case either the marine amphipod *Ampelisca abdita* or the freshwater amphipod *Hyallela azteca*, to determine toxicity. Toxicity is a measure of the degree to which a chemical or mixture of chemicals in the sediments will harm living things. Eighty percent of the estuarine area had over 90% survival rate of the test organisms (*Ampelisca abdita* or *Hyallela azteca*) when they were exposed to sediments in the laboratory (i.e., 80% of the area had less than 10% mortality of test organisms in the lab).

D. Chemicals in Fish Tissue

Chemicals were measured in tissue from whole fish in the Columbia River estuary. The values in the TSC column in **Table 6** were used to indicate concentrations that may be harmful to the fish. The Toxic Tissue Screening Concentration (TSC) is a product of U.S. EPA's water quality criterion (WQC) and bioconcentration factor (BCF) per respective chemical (TSC=WQC*BCF). The BCFs are from the U.S. EPA (1986). For chemicals not listed in the EPA document, BCFs were calculated based on Dyer, 2000, unless otherwise noted.

1. Metals

<u>**Inorganic Arsenic**</u>

Fish tissue was analyzed for total arsenic (inorganic and organic). Since an arsenic TSC is applicable for only inorganic arsenic, an estimate of the percentage of the total arsenic that is inorganic arsenic in fish tissue (2%) was made based on other studies of marine fish species.

Arsenic was detected in fish tissue in 72.7% of the estuarine area, with concentrations detected in fish tissue ranged from .15 mg/kg to 29.8 mg/kg (**Figure 15**). The TSC of 1.6 mg/kg was exceeded in 1.1% of the estuarine area.

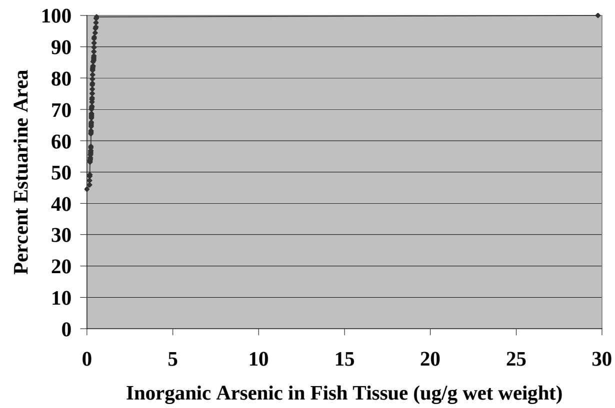


Figure 15. CDF of Inorganic Arsenic in Fish Tissue.

Tissue Analyte	Units (wet weight)	Minimum Detected	Maximum	% Estuarine Area with Analyte Detected	TSC[1]	% of total estuarine area exceeding TSC[1]
METALS						
Inorganic Arsenic	mg/kg	0.15	29.77	72.7	1.6	1.1
Cadmium[2]	mg/kg	0.01	0.16	52.3	0.083	1.1
Lead[2]	mg/kg	0.05	0.97	35.1	0.059	2.5
Mercury	mg/kg	0.01	0.26	96.7	0.06	31.8
Selenium	mg/kg	0.11	0.57	88.0	0.56	2.1
Silver	mg/kg	0.01	0.28	44.1	0.37	0.0
Zinc	mg/kg	7.84	39.06	100.0	20	49.6
PESTICIDES						
DDT, total	µg/kg	15.64	493.64	76.3	54	41.1

Table 6. Selected Contaminants in Fish Tissue in the Columbia River estuary.

[1] TSC source except where noted: Dyer, S. D., White-Hull, C.E., and Shephard, B.K., 2000, Assessments of Chemical Mixtures via Toxicity Reference Values Overpredict Hazard to Ohio Fish Communities, Environ. Sci. Technol. 34, 2518-2524.

[2] Shephard, B., 2007, in prep

Mercury

In most (96.7%) of the estuarine area, mercury was detected in fish tissue. The concentrations detected in fish tissue ranged from .01 mg/kg to .26 mg/kg (**Figure 16**). The TSC of .06 mg/kg was exceeded in 31.8% of the area.

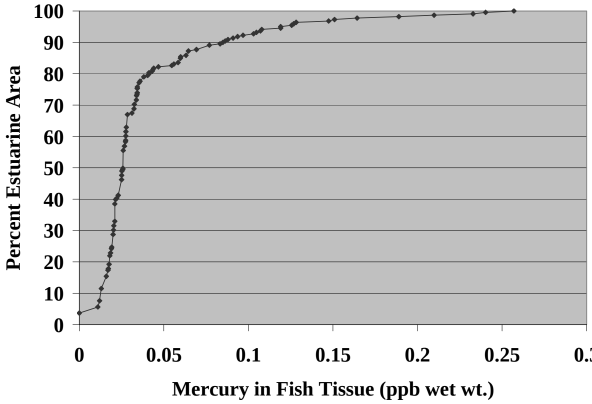
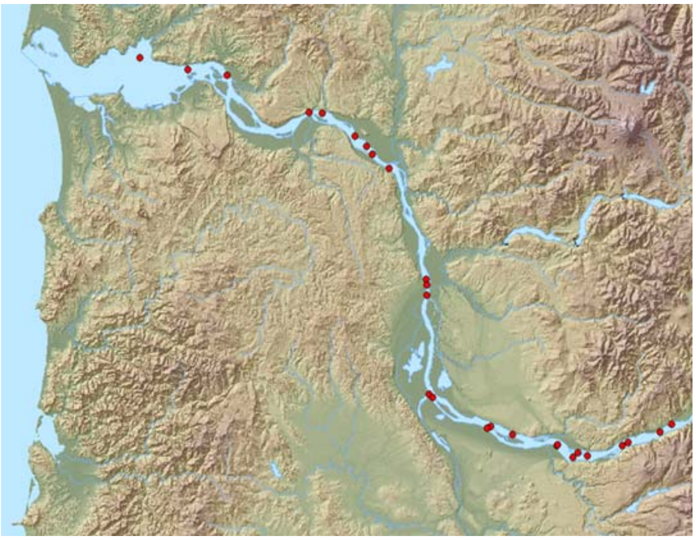


Figure 16. CDF of Mercury in Fish Tissue.

Map 2 shows the sites in the Columbia River estuary where mercury in fish tissue exceeds the TSC.



Map 2. Sites with Mercury in Fish Tissue exceeding the TSC.

Zinc

Zinc was detected in fish tissue in 100% of the estuarine area. The concentrations ranged from 7.8 mg/kg to 39.0 mg/kg (**Figure 17**).

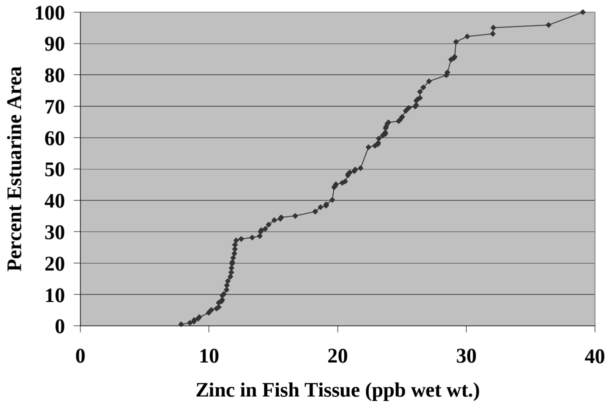
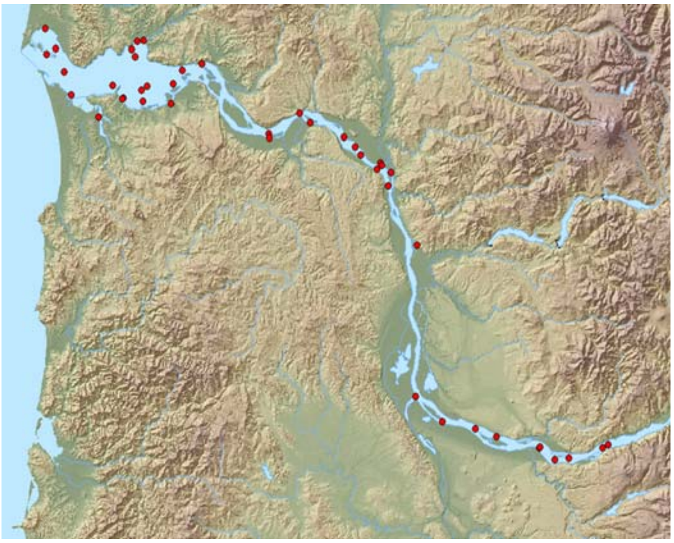


Figure 17. CDF of Zinc in Fish Tissue.

The TSC of 20 mg/kg was exceeded in 49.6% of the area. **Map 3** shows the sites where the TSC for zinc is exceeded.



Map 3. Sites with Zinc in Fish Tissue exceeding the TSC.

2. Pesticides

DDT

In 76.3% of the estuarine area, DDT was found in the fish tissue analyzed. The concentrations detected ranged from 15.64 µg/kg to 494 µg/kg (**Figure 18**).

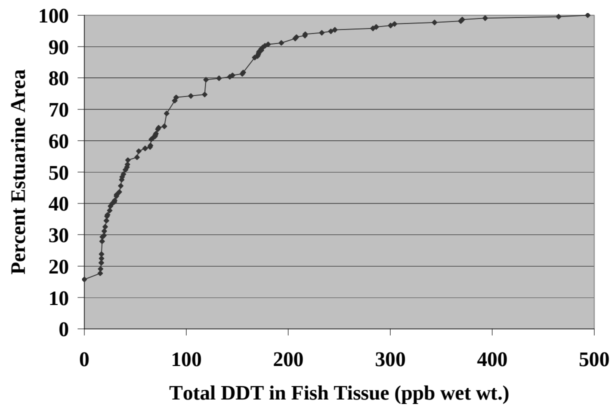
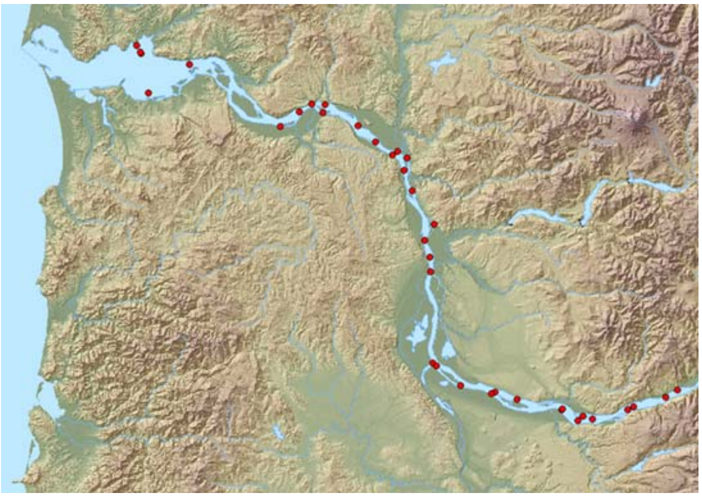


Figure 18. CDF of DDT in Fish Tissue.

The TSC of 54 µg/kg was exceeded in 41.1% of the area. **Map 4** shows the sites where the TSC for DDT is exceeded. These results confirm the findings of the Bi-State report (Tetra Tech, 1993) which concluded that DDT was distributed in fish tissue samples collected throughout the lower Columbia River.



Map 4. Sites with DDT in Fish Tissue exceeding the TSC.

E. Benthic Invertebrates

Benthic invertebrates were sampled at 77 sites, representing 98% of the Columbia River estuary. Benthic invertebrate abundance and diversity are good indicators of environmental health. See Appendix 6 for additional information on the benthic invertebrate community.

1. Benthic abundance

Benthic invertebrate abundance is the number of organisms per unit area. It ranged from 2 to over 8000 organisms per $0.1m^2$, with a mean of 364 organisms per $0.1m^2$.

2. Benthic species richness/diversity

There were 102 species found overall in 1999-2000. Of these, 44 were found at only 1 site, while an additional 16 were found at two sites. Six species were found at 15 or more sites. *Corbicula fluminea,* a non-indigenous species, was found at the most sites (56) representing 73% of the area of the Columbia River estuary. Benthic species richness (the number of different taxa found at each site) ranged from 1 to 30, with a mean of 6 species.

The salinity of the waters sampled was quite varied. Since benthic invertebrates have varying tolerances to salinity, we divided the sites into two groups using the bottom salinity measurements:

Freshwater, with < 5psu, and
Intermediate, with > 5 and < 25 psu.

Seventy percent of the area was freshwater, and 30% was of intermediate salinity. The Columbia River estuary sites were all either freshwater or intermediate. It should be noted that while some of the some of species may have been found at very few sites, they can be extremely abundant locally.

At the freshwater sites, 78 species were found. Of these, 40 were found at only 1 site, and an additional 10 were found at two sites. Seven species were found at 10 or more sites of the freshwater sites. *Corbicula fluminea* was found in 94% of the freshwater estuarine area.

At the intermediate sites, 48 species were found. Of these, 20 were found at only 1 site, and an additional 8 were found at two sites. Only two species were found at 7 or more sites. *Corbicula fluminea* was found in 26% of the intermediate estuarine area.

Figure 19 shows the most common species for each of the two salinity categories: freshwater and intermediate. The most common freshwater species was *Corbicula fluminea*, a non-indigenous species. The most common intermediate species was *Paranemertes californica*, which did not occur at all at freshwater sites.

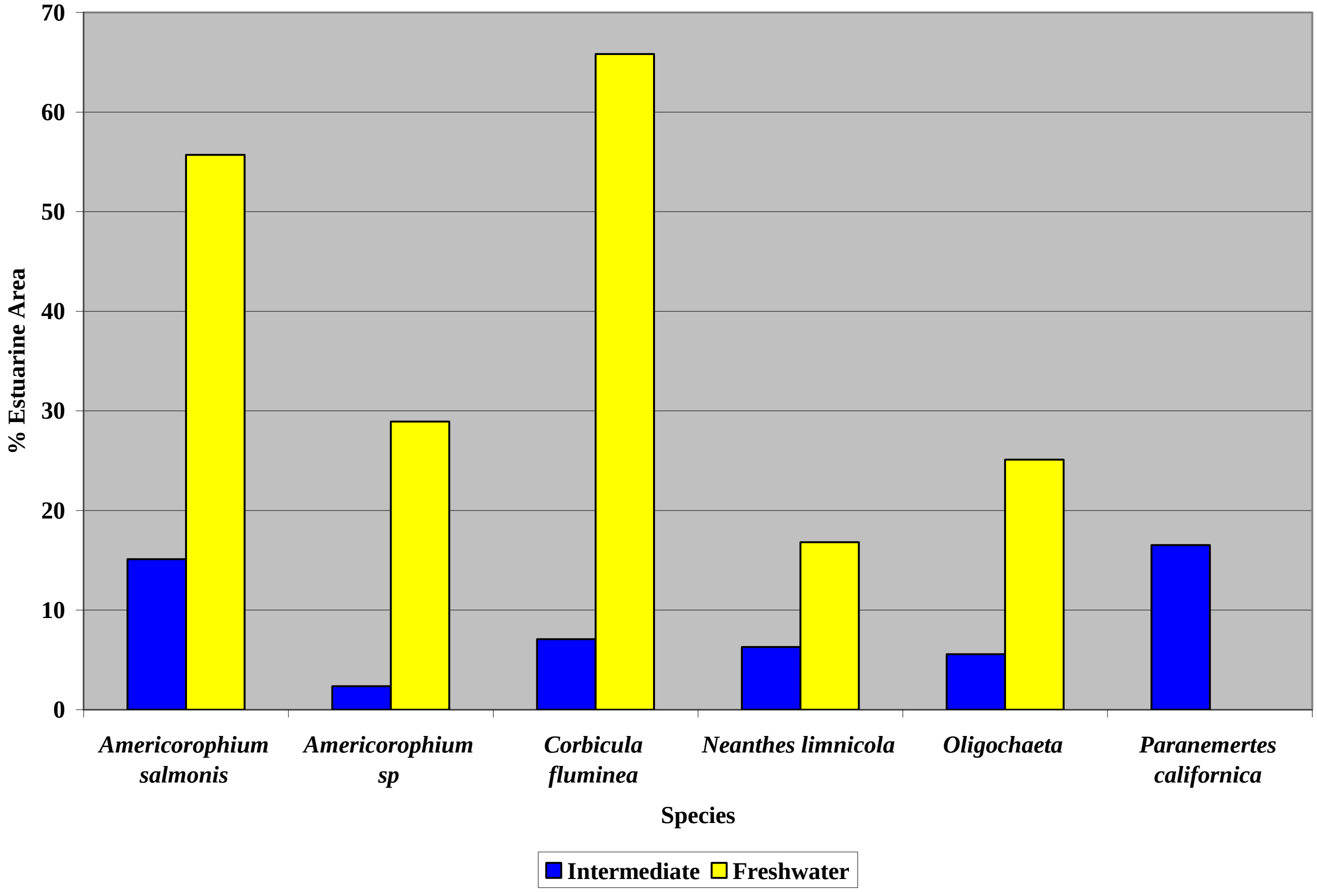


Figure 19. Most Common Benthic Invertebrates (for each of the two salinity categories: freshwater and intermediate).

F. Fish

Fish sampling was conducted at 51 sites, representing 405 square kilometers (66% of the estuarine area of the Columbia River estuary). Starry flounder (*Platichthys stellatus*) was the most commonly occurring species; it was found in over 60% of the estuarine area sampled for fish. Of the total 21 fish species found, 10 species were found at only one site. It should be noted that while some of the species may have been found at very few sites, they can be extremely abundant locally.

An additional 5 species were found at 5 or fewer sites. Only 2 species (Starry flounder and Three-spine stickleback) were found at 10 or more sites. Appendix 7 lists all of the fish species found.

Due to the varying tolerances of fish to salinity, we divided the sites into two groups (the same as for the benthic invertebrates) using the bottom salinity measurements:

- Freshwater, with < 5psu, and
- Intermediate, with ≥ 5 and ≤ 25 psu.

Sixty-six percent of the estuarine area sampled for fish sites was in the freshwater category, and 34% was intermediate. Of the 21 fish species found overall in 1999-2000, 8 were found in the intermediate and 16 in the freshwater sites (**Figure 20**). Only 3 species were found in both freshwater and intermediate sites. See Appendix 7 for additional details.

Freshwater sites had bottom salinities of less than 5 psu and surface salinities between 0.01 psu and 3.4 psu. Of the 16 species found at freshwater sites, 13 of these species were found only at freshwater sites. Unique freshwater species included American Shad, Crappies, Northern Pikeminnow, Peamouth, Three-spine stickleback, and Sand roller.

Intermediate sites had bottom salinities between 5 psu and 25 psu and surface salinities from 2.7 psu to 24.9 psu. Of the 8 species found at intermediate sites, 5 were found only at the intermediate sites. Unique intermediate species included: Californian anchovy, White spotted greenling, Pacific tomcod, English sole and Longfin smelt. **Figure 21** shows the most common species for each of the two salinity categories: freshwater and intermediate.

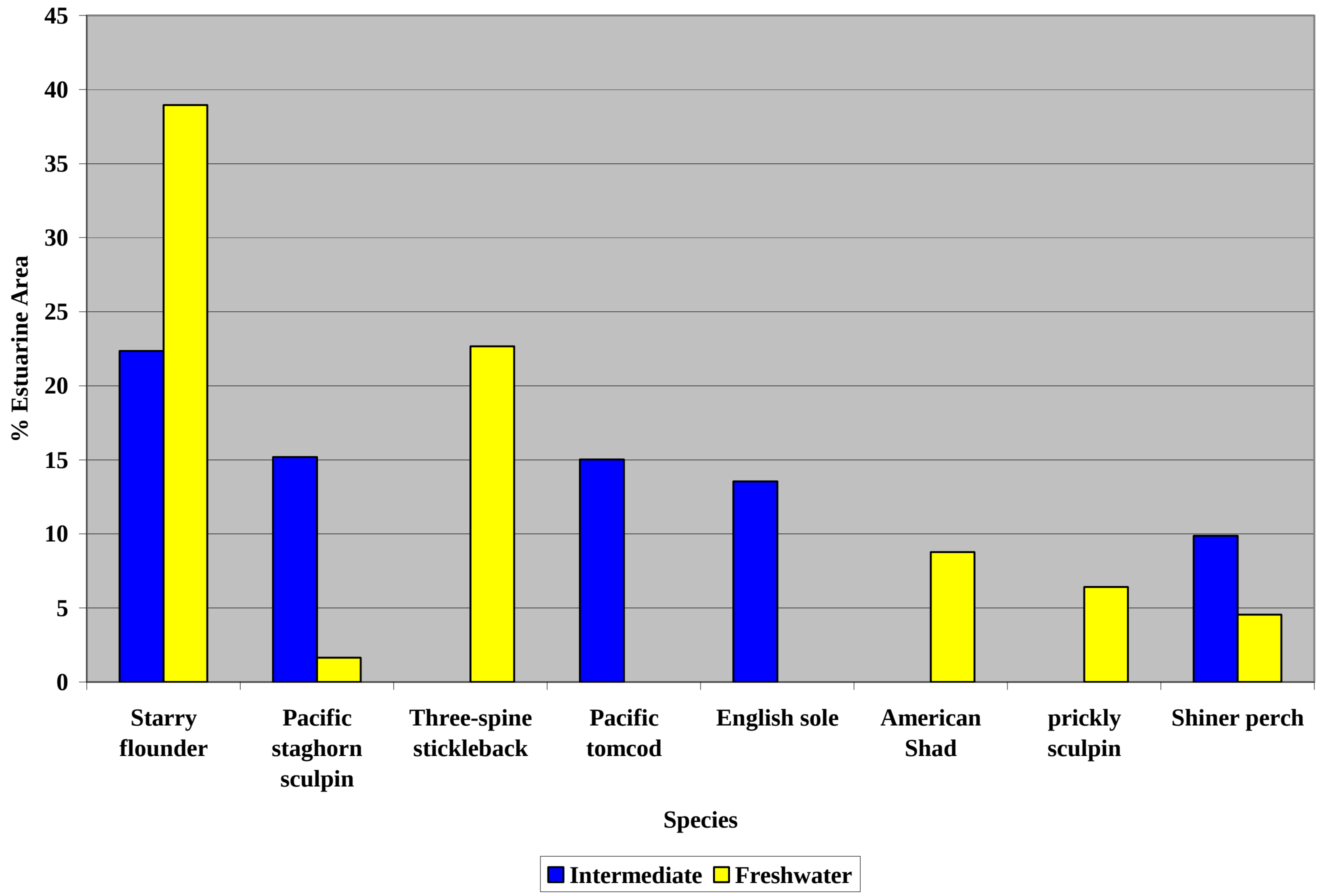


Figure 20. Most Commonly Found Fish at Intermediate and Freshwater Sites.

IV. CONCLUSIONS

Photo: English Sole, a target fish species.

Most historic assessments of estuary quality have focused on describing the chemical quality of estuaries and, occasionally, impacts to sport fisheries. However, the goal of the Clean Water Act is to maintain and restore the physical, chemical and biological integrity of the nation's waters. In this assessment we try to address this issue by incorporating direct measurements of physical, chemical and biological condition of estuaries.

To assess whether or not a specific metric indicates good or poor condition, a benchmark, standard or target is needed for comparison. Not all parameters or indicators have benchmarks developed. Therefore, we will only interpret those indicators that have benchmarks or targets developed that are relevant to the Columbia River estuary. This is sometimes a difficult task, as the Columbia River estuary is often freshwater in character, so some estuarine benchmarks or targets may not be appropriate.

In addition, for some indicators, such as dissolved oxygen, there is a single benchmark. Above this benchmark, estuarine conditions are determined to be good, but below it conditions may range from fair to poor. However, for other indicators, such as sediment contaminants, we have benchmarks that allow us to determine which sites are in good, fair and poor condition.

The National Estuary Program Coastal Condition Report (NEPCCR) also assessed the condition of the Columbia River estuary along with the other estuaries covered by National Estuary Program (U.S.EPA, 2006). We will compare our results with the NEPCCR only for those indicators where we use different benchmarks. The NEPCCR uses benchmarks developed for national scale assessments, which in some cases are different from the more local benchmarks that we use in this report.

A. Water Physical/Chemical Indicators

Dissolved Oxygen

Low dissolved oxygen (DO) concentrations are stressful to many estuarine organisms. These low levels most often occur in bottom waters and affect the organisms that live in the sediments. Low levels of oxygen (hypoxia) or lack of oxygen (anoxia) often accompany the onset of severe bacterial degradation, sometimes resulting in the presence of algal scums and noxious odors. However, in some estuaries, low levels of oxygen occur periodically and may be a part of the natural ecology. Therefore, although it is easy to show a snapshot of the conditions of the nation's estuaries concerning oxygen concentrations, it is difficult to interpret whether this snapshot is representative of typical summertime conditions or the result of natural physical and chemical processes.

The State of Oregon has a DO criterion (6.5 mg/L) for estuaries, which is a relatively high value compared to other estuarine criteria such as those used (5 mg/L) in the National Coastal Assessment (U.S. EPA, 2004). Oregon's DO criteria for freshwaters range from 6.5 mg/L to 11.0 mg/l, the later being for salmonid spawning waters. The State of Washington's DO criteria for Salmonid rearing and migration is 6.5 mg/L. Therefore, we rated dissolved oxygen good or fair/poor using the following criteria (**Table 7):**

Good: > 6.5 mg/L
Fair/Poor: ≤ 6.5 mg/L

Less than seven percent of estuarine area was in poor condition, having a bottom DO concentration below 6.5 mg/L. Approximately 93% of the area of the estuaries was in good to fair condition, having bottom DO concentrations above 6.5mg/L (**Figure 25**).

	Good	Fair/Poor
Dissolved Oxygen	> 6.5 mg/L	< 6.5 mg/L
Chlorophyll a	< 5 µg/L	> 5 µg/L
Dissolved Inorganic Nitrogen	<168 µg/L	>168 µg/L
Soluble Phosphorus	<22 µg/L	>22 µg/L

Table 7. Criteria for Assessing Water Physical/Chemical Indicators.

The NEPCCR (U.S. EPA, 2006) reported 99% of the area of the Columbia River estuary as being in good condition for dissolved oxygen. This is a higher percent than our conclusions (93%) because we used the State of Oregon's dissolved oxygen criterion (6.5 mg/L) for estuaries.

Nutrients

Some nutrient inputs (such as nitrogen and phosphorus) are necessary for healthy, functioning estuarine ecosystems. When excess nutrients from various sources, such as sewage and fertilizers, are introduced into an estuary, the concentration of nutrients will increase beyond natural background levels. Elevated nutrients can lead to excess plant production, and thus, to increased phytoplankton production, which can decrease water clarity and lower concentrations of dissolved oxygen.

To assess whether a site was in good or fair/poor condition (Table 7), we used the suggested criteria for nitrogen (dissolved inorganic nitrogen), phosphorus (soluble phosphorus) and chlorophyll a that were developed based on a case study in the Yaquina estuary in Oregon. We used the 75th percentile value proposed for the less saline part of the estuary for nitrogen and phosphorus (Table 7). These values are very similar to those from the 75th percentile of reference conditions of larger rivers in the Western Mountain ecoregion from the Western EMAP study (Herlihy pers com). For chlorophyll a, we used the mean value from the less saline area in Yaquina bay study (Brown et al, 2007), which is the same as the value used in the National Coastal Assessment.

For nitrogen, 31% of the estuarine area was considered in fair/poor condition, and 69% was in good condition (**Figure 25**). In contrast, the NEPCCR reported that the 100% of the Columbia River estuary was in good condition for nitrogen. This is because they used the National Coastal Assessment (NCA) benchmark for nitrogen, while we used benchmarks based on work in Yaquina bay and Western EMAP data, which we believe to be more appropriate for the Columbia River estuary.

For phosphorus, 32% of the estuarine area was considered in fair/poor condition, and 68% was in good condition (**Figure 25**).The NEPCRR had a consistent result, concluding that 70% of the Columbia River estuary was in good condition for phosphorus. This is because the numbers developed for Yaquina bay and the NCA numbers are similar.

For Chlorophyll *a*, 42% of the area was in fair/poor condition and 58% was in good condition (**Figure 25)**.

Figure 21 shows the percent of the Columbia River estuary where all three nutrient indicators (nitrogen, phosphorus and chlorophyll a) are all rated as good, or all 3 are rated poor or some mix of good and poor condition.

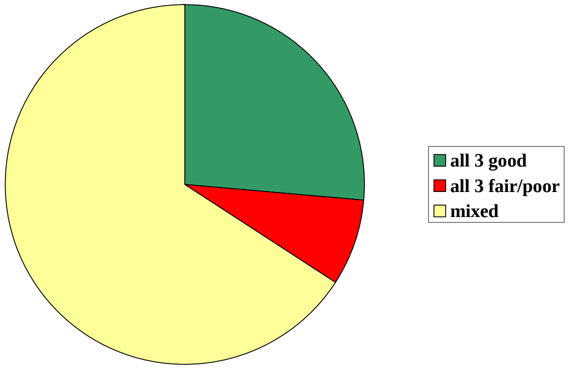


Figure 21. Percent of estuarine area with all 3 nutrient indicators in good or poor or mixed condition.

B. Sediment Characteristics

In this section, we assess sediment characteristics with two indictors: total organic carbon (TOC) and sediment contamination.

The 3.5% level was found by Hyland, 2005, to be associated with decreased benthic abundance and biomass. None of the estuarine area has total organic carbon content greater than 3.5%. The National Coastal Assessment Program (U.S. EPA, 2004) uses concentrations above 2% and above 5% TOC to indicate fair and poor habitat, respectively. Using these values, 1.4% of the area is in fair condition (above 2%) and none is in poor condition (above 5%).

To assess the degree of sediment contamination, the sediment concentrations of contaminants were compared with the Effects Range-Median (ERM) and Effects Range-Low (ERL), (Long, 1995) and the Threshold Effect Concentration (TEC), (MacDonald et al., 2000). A station with a concentration exceeding an ERM is classified as being in poor condition. Stations with three or more concentrations exceeding either the ERL or TEC were classified as being in fair condition.

For this comparison, nickel, copper, and chromium exceedances that were within background ranges were excluded. Less than 1% of the estuarine area exceeded an ERM indicating a poor sediment condition (**Figure 22**). In 5% of the area, no ERMs were exceeded, but more than 3 ERLs or TECs were exceeded, indicating a fair rating for sediment contamination (**Figure 22**).

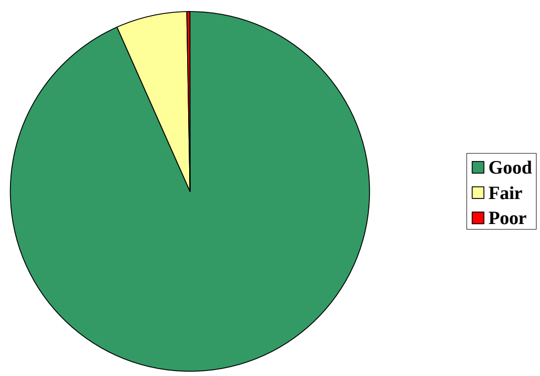
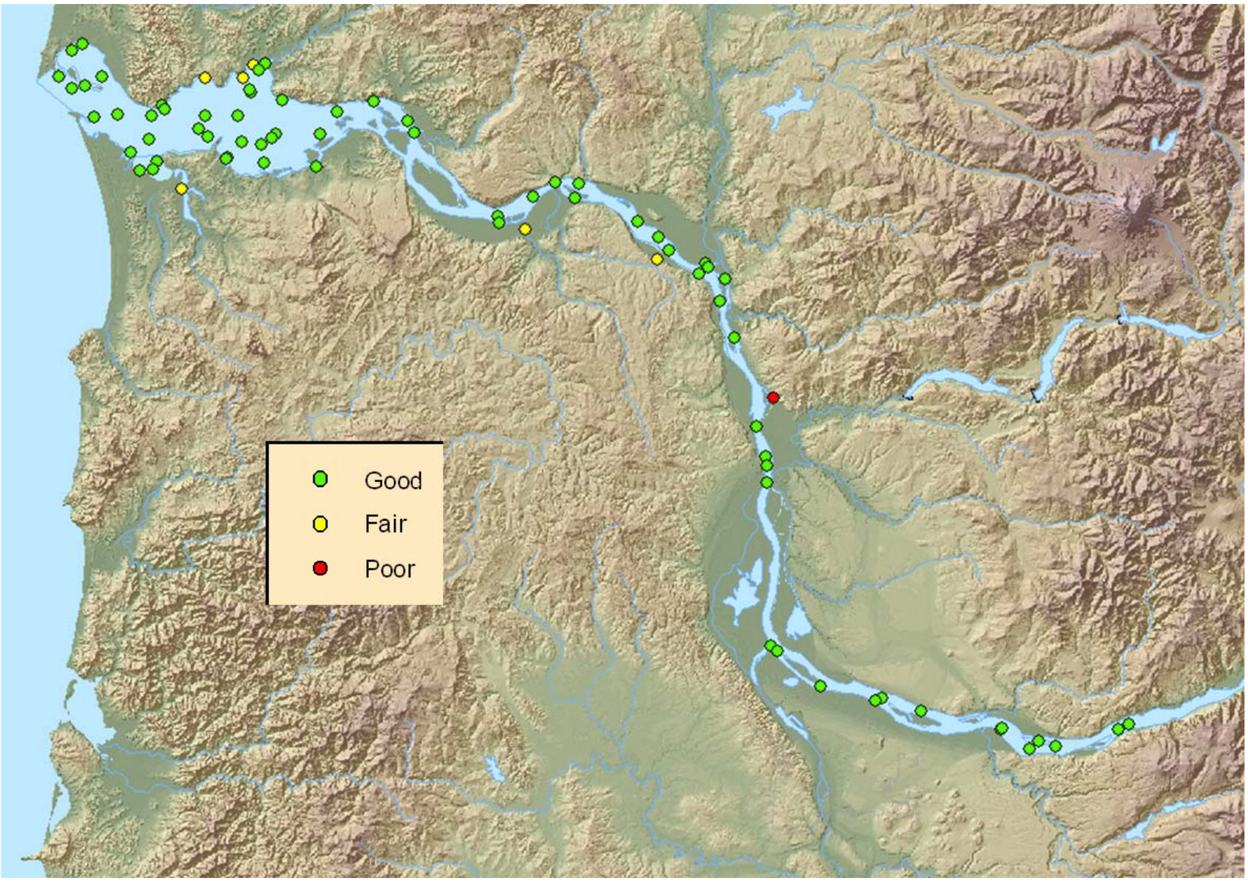


Figure 22. Summary of Sediment Contamination.

Map 5 shows the locations where sediment condition is good (green dots), fair (yellow dots) and poor (red dot).



Map 5. Map of sediment contaminant condition summary.

C. Chemicals in Fish Tissue

The Toxic Tissue Screening Criteria (TSC) are tissue residue levels that, when exceeded, may be harmful to fish. We evaluated the TSC for arsenic, cadmium, DDT, lead, mercury, selenium and zinc. In the Columbia River estuary, 4.6% of the estuarine area had 4 of these chemicals exceeding the TSC (at the same site, which indicates a likely poor condition), 13.7% had 3 chemicals above the TSC, 20.6% had 2 and 61.0 % have one or zero above the TSC, indicating good conditions (**Figure 23**).

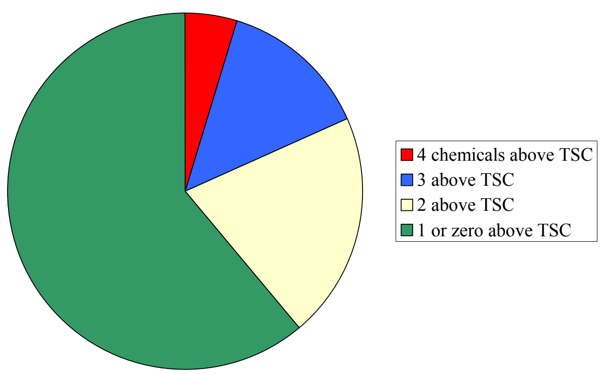


Figure 23. Summary of Chemicals in Fish Tissue.

It is difficult to compare our results to the NEPCCR fish tissue contaminants results. The benchmark that the NEPCCR uses is the EPA Advisory Guidance values for fish consumption by humans using whole-fish contaminant concentrations. They found that 46 percent of all stations sampled where fish were rated poor. However, since the fish collected in this study were not targeted to fish that people actually eat, we believe that using a more ecological based benchmark is more appropriate.

D. Benthic Invertebrates

Benthic indices combine data about the benthic invertebrate community to assess the condition of the waterbody. However, there is no benthic index that has been developed for the Columbia River estuary. Many of the indices that have been developed are either for completely freshwater systems or for much more saline estuarine systems and neither would be appropriate to use for the Columbia River estuary.

Invasive species represent a threat to the fundamental ecological integrity of aquatic ecosystems throughout the U.S. (Lee and Thompson, 2003). *Corbicula fluminea* is a non-indigenous clam species that occurs in both fresh and marine waters. Metrics using *Corbicula* have been proposed for rivers (Kerans and Karr, 1994). Therefore, we will use a single metric, the percent of the total number of taxa that are *Corbicula fluminea* (% corbicula) as a very rough assessment of the condition of the benthic invertebrate community in the Columbia River estuary. By definition, zero percent is what the historic level of any non-indigenous species (such as corbicula) would have been (27 of the estuarine area had zero Corbicula); however, we used a cut-point of 10% as a background level for % corbicula. **Figure 24** shows more than in 66% of the estuarine area, 10% of the total taxa are *Corbicula* indicating poor conditions.

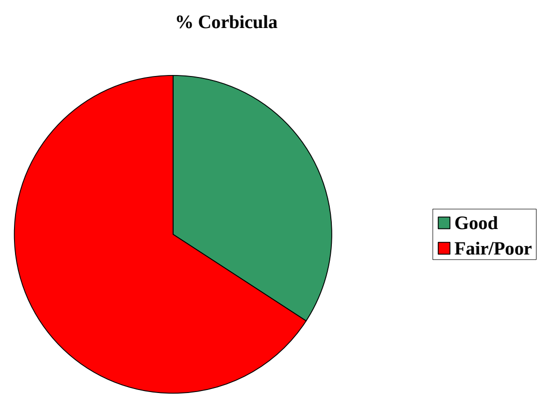


Figure 24. Percent Corbicula

E. Summary

This project was designed to evaluate the overall condition of the Columbia River estuary. For dissolved oxygen, 7% of the area of the Columbia River estuary was in fair/poor condition, while nutrient indicators (nitrogen, phosphorus and chlorophyll a) showed a larger percent of the area (31-46%) in the fair/poor condition category (**Figure 25**). For sediment indicators, total organic carbon showed none of the areas was in poor condition, but for sediment contaminants approximately 16% of the Columbia River estuarine area was in poor condition (**Figure 25**). As for biological indicators (chemicals in fish tissue and % corbicula), for chemicals in fish tissue, 39% of the area was in fair/poor condition (**Figure 25**). An even higher percent of the Columbia River estuary (66%) was in poor condition using percent *Corbicula* as an indictor (**Figure 25**).

In 2006, we evaluated the ecological condition of the estuaries of Oregon and Washington (Hayslip, et al., 2006). The percent area in fair/poor condition for every indicator we evaluated was higher in the Columbia River estuary. The only exception was for chemicals in fish tissue where we found 47% of the area for estuaries of Oregon and Washington in fair/poor condition and 39% in the Columbia River estuary in fair/poor condition.

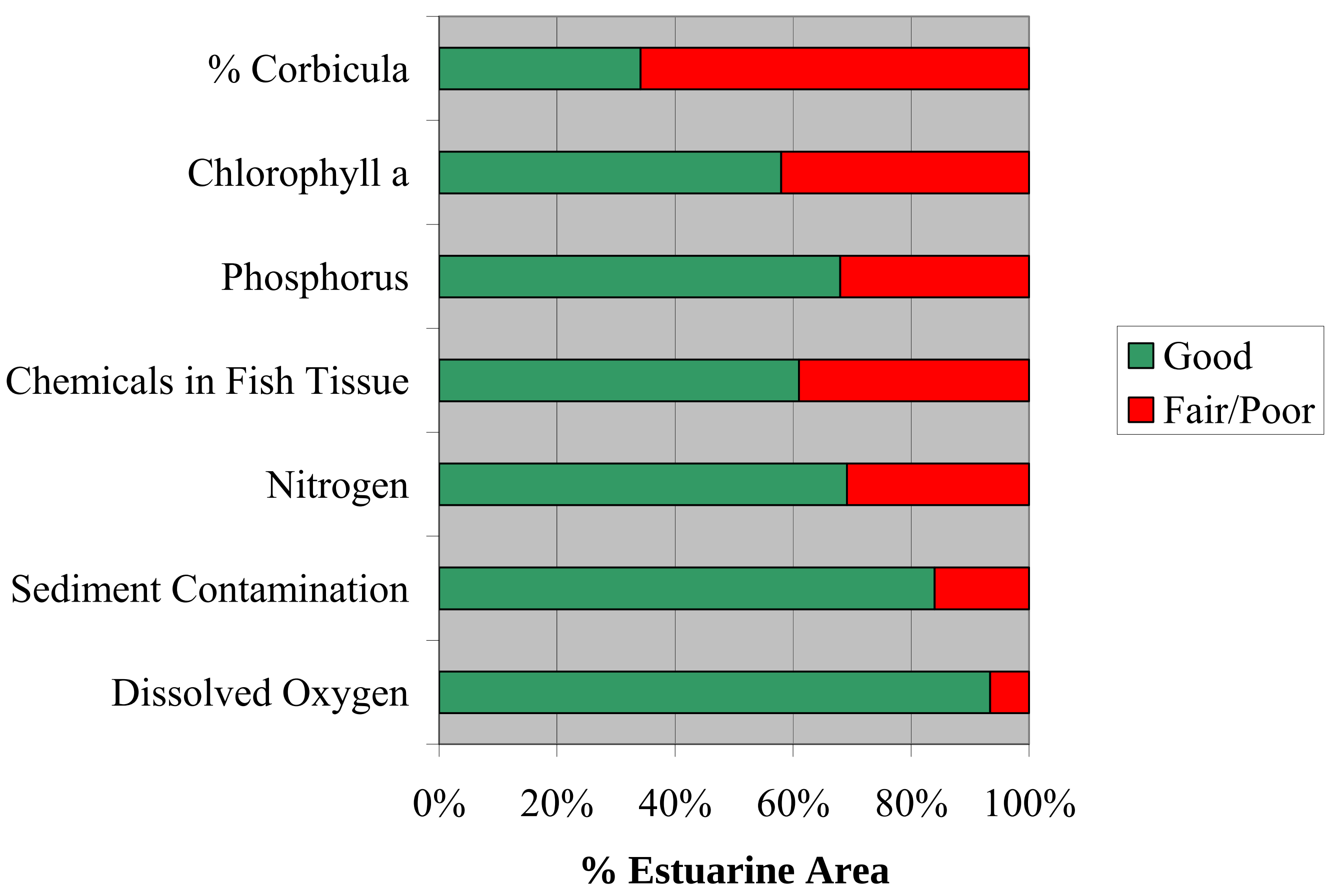


Figure 25. Overall Condition of Columbia River Estuarine Area for Selected Indicators.

V. REFERENCES

American Society for Testing and Materials (ASTM). 1993. Guide for conducting 10-day static sediment toxicity tests with marine and estuarine amphipods. ASTM Standard Methods Volume 11.04, Method Number E-1367-92. ASTM, Philadelphia, PA.

Brown, C.A., W.G. Nelson, B.L. Boese, T.H. DeWitt, P.M. Eldridge, J.E. Kaldy, H. Lee II, J.H. Power, and D.R. Young. 2007. An Approach to Developing Nutrient Criteria for Pacific Northwest Estuaries: A Case Study of Yaquina Estuary, Oregon. USEPA Office of Research and Development, National Health and Environmental Effects Laboratory, Western Ecology Division. EPA/600/R-07/046.

Copping, A. and B.C. Bryant. 1993. Pacific Northwest Regional Marine Research Program, Vol. 1. Research Plan, 1992-1996. Office of Marine Environmental and Resource Programs, University of Washington, Seattle.

Culliton, T.J., M.A. Warren, T.R. Goodspeed, D.G. Remeer, C.M. Blackwell, and J.J. McDonough, III. 1990. 50 Years of Population Change along the Nation's Coasts, 1960-2010. NOAA, Office of Oceanography and Marine Assessment, National Ocean Service, Coastal Trends Series, Rockville, MD. 41 pp.

Diaz-Ramos, S., D.L. Stevens, Jr., and A.R. Olsen. 1996. EMAP Statistics Methods Manual. EPA/620/R-96/002. Corvallis, OR: U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory.

Dyer, S.C., C.E. White-Hull, and B.K. Shephard. 2000. Assessments of Chemical Mixtures via Toxicity Reference Values Overpredict Hazard to Ohio Fish Communities. Environ. Sci. Technol. 2000(34):251-2524.

Hayslip, G., L. Edmond, V. Partridge, W. Nelson, H. Lee, F. Cole, J. Lamberson , and L. Caton. 2006. Ecological Condition of the Estuaries of Oregon and Washington. EPA 910-R-06-001. U.S. Environmental Protection Agency, Office of Environmental Assessment, Region 10, Seattle, Washington.

Herlihy, A. 2008. Personal communication.

Hyland, J.L., L. Balthis, I. Karakassis, P. Magni, A.N. Petrov, J.P. Shine, O. Vestergaard, and R.M. Warwick. 2005. Organic carbon content of sediments as an indicator of stress in the marine benthos. Mar. Ecol. Progr. Ser. 295:91-103.

Kerans, B.L. and J.R. Karr. 1994. A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. Ecological Applications: 4:768-785.

LCREP (Lower Columbia River Estuary Partnership). 1999. *Comprehensive Conservation and Management Plan, Volume 1.* Lower Columbia River Estuary Partnership, Portland, OR.

Long, E.R., D. MacDonald, S. Smith, and F. Calder. 1995. Incidence of Adverse Biological Effects Within Ranges of Chemical Concentrations in Marine and Estuarine Sediments. Environmental Management 19(1):81-97.

Lee II, H. and B. Thompson, 2003. How Invaded Is Invaded? U.S. EPA. Proceedings of the Third International Conference on Marine Bioinvasions, La Jolla, California, March 16-19, 2003, p. 80.

Macdonald, D.D., Ingersoll, C.G., and Berger, T. A., 2000, Development and Evaluation of Consesus-Based Sediment Quality Guidelines for Freshwater Ecosystems, Arhives of Environmental Contamination Toxicology, 39, 20-31.

Nelson, W.G., H. Lee II, J.O. Lamberson, V. Engle, L. Harwell, and L.M. Smith. 2005. Condition of estuaries of western United States for 1999: A statistical summary. Office of Research and Development, National Health and Environmental Effects Research Laboratory. EPA/620/R-04/200.

Peterson, S.A., N.S. Urquhart, and E.B. Welch. 1999. Sample representativeness: a must for reliable regional lake condition estimates. Environmental Science and Technology 33:1559-1565.

Partridge, V.. 2007. Condition of Coastal Waters of Washington State, 2000-2003: A Statistical Summary. Washington State Department of Ecology, Olympia, WA. Publication 07-03-051. www.ecy.wa.gov/biblio/0703051.html.

Sigmon, C.L.T., L. Caton, G. Coffeen, and S. Miller. 2004. Draft – Coastal Environmental Monitoring and Assessment Program. The Condition of Oregon Estuaries in 1999, A Statistical Summary. Oregon Department of Environmental Quality, Laboratory. Portland, Oregon. DEQ04-LAB-0046-TR.

Stevens, D.L., Jr. 1997. Variable density grid-based sampling designs for continuous spatial populations. Environmetrics 8:167-195.

Stevens, D. L., Jr., and A.R. Olsen. 1999. Spatially restricted surveys over time for aquatic resources. J. of Agricultural, Biological and Environmental Statistics 4:415-428.

Tetra Tech. 1993. Reconnaissance survey of the lower Columbia River. Task 7 conclusions and recommendations. Prepared for Lower Columbia River Bi-State Committee. Tetra Tech, Inc., Redmond, WA. 270 pp. + appendix (TC 8526-07).

U.S. EPA. 1993. Volunteer estuary monitoring: A methods manual. US Environmental Protection Agency Report EPA 842-B-93-004. Washington, D.C.: Office of Water. 176 pp.

U.S. EPA. 1994a. Environmental Monitoring and Assessment Program (EMAP): Laboratory method manual – estuaries, Volume 1: Biological and physical analysis. United States Environmental Protection Agency, Office of Research and Development. Environmental Monitoring and System Laboratory, Cincinnati, OH. EPA/600/4-91/024.

U.S. EPA. 2001. Environmental Monitoring and Assessment Program (EMAP): National Coastal Assessment Quality Assurance Project Plan 2001-2004. United States Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, FL. EPA/620/R-01/002.

U.S. EPA. 2004. National Coastal Condition Report II. United States Environmental Protection Agency, Office of Research and Development/Office of Water. Washington D.C. EPA620-R-03-002.

U.S. EPA. 2006. National Estuary Program Coastal Condition Report. United States Environmental Protection Agency, Office of Research and Development/Office of Water. Washington D.C. EPA-842/B-06/001.

Wilson, S., and V. Partridge. 2007. Condition of Outer Coastal Estuaries of Washington State, 1999: A Statistical Summary. Washington State Department of Ecology, Olympia, WA. Publication 07-03-012. www.ecy.wa.gov/biblio/0703012.html

VI. APPENDICES

Appendix 1. Site location information.

STATE	YEAR	ESTUARY NAME	EMAP Station ID	LATITUDE	LONGITUDE
OREGON	2000	COLUMBIA RIVER, RIVER MILE 51.4	OR00-0001	46.18642	-123.181
OREGON	2000	COLUMBIA RIVERRIVER MILE 49.2	OR00-0002	46.16893	-123.216
OREGON	2000	COLUMBIA RIVERRIVER MILE 53.2	OR00-0003	46.18787	-123.141
OREGON	2000	COLUMBIA RIVER, RIVER MILE 45.9	OR00-0004	46.14234	-123.275
OREGON	2000	COLUMBIA RIVER, RIVER MILE 59.2	OR00-0005	46.14628	-123.036
OREGON	2000	COLUMBIA RIVER, RIVER MILE 61.5	OR00-0006	46.12905	-122.999
OREGON	2000	COLUMBIA RIVER, RIVER MILE 62.9	OR00-0007	46.1142	-122.978
OREGON	2000	COLUMBIA RIVER	OR00-0008	46.10204	-122.915
OREGON	2000	COLUMBIA RIVER, RIVER MILE 66.2	OR00-0009	46.0889	-122.923
OREGON	2000	COLUMBIA RIVER, RIVER MILE 69	OR00-0010	46.05742	-122.887
OREGON	2000	COLUMBIA RIVER, RIVER MILE 72.5	OR00-0011	46.01564	-122.858
OREGON	2000	COLUMBIA RIVER, RIVER MILE 80.2	OR00-0012	45.91205	-122.81
OREGON	2000	COLUMBIA RIVER, RIVER MILE 82.8	OR00-0013	45.87721	-122.793
OREGON	2000	COLUMBIA RIVER, RIVER MILE 83.6	OR00-0014	45.86531	-122.788
OREGON	2000	COLUMBIA RIVER, RIVER MILE 85.1	OR00-0015	45.84555	-122.786
OREGON	2000	COLUMBIA RIVER, RIVER MILE 99	OR00-0016	45.6517	-122.763
OREGON	2000	COLUMBIA RIVER, RIVER MILE 99.7	OR00-0017	45.64532	-122.751
OREGON	2000	COLUMBIA RIVER	OR00-0018	45.60626	-122.675
OREGON	2000	COLUMBIA RIVER, RIVER MILE 109.4	OR00-0019	45.59698	-122.569
OREGON	2000	COLUMBIA RIVER	OR00-0020	45.59403	-122.582
OREGON	2000	COLUMBIA RIVER, RIVER MILE 112.6	OR00-0021	45.5839	-122.502
OREGON	2000	COLUMBIA RIVER, RIVER MILE 119.9	OR00-0022	45.56827	-122.366
OREGON	2000	COLUMBIA RIVER, RIVER MILE 119.9	OR00-0023	45.56863	-122.363
OREGON	2000	COLUMBIA RIVER, RIVER MILE 138.8	OR00-0024	45.62269	-122.018
OREGON	2000	COLUMBIA RIVER, RIVER MILE 136.6	OR00-0025	45.605	-122.053
OREGON	2000	COLUMBIA RIVER	OR00-0026	45.55558	-122.3
OREGON	2000	COLUMBIA RIVER, RIVER MILE130.8	OR00-0027	45.5745	-122.165
OREGON	2000	COLUMBIA RIVER, RIVER MILE 123.1	OR00-0028	45.54575	-122.315
OREGON	2000	COLUMBIA RIVER, RIVER MILE 125.3	OR00-0029	45.55037	-122.271
OREGON	2000	COLUMBIA RIVER, RIVER MILE 131.6	OR00-0030	45.58123	-122.149
OREGON	2000	COLUMBIA RIVER	OR00-0031	46.27134	-124.045
OREGON	2000	COLUMBIA RIVER	OR00-0032	46.2592	-124.021
OREGON	2000	COLUMBIA RIVER, RIVER MILE 3.8	OR00-0033	46.22675	-123.978
OREGON	2000	COLUMBIA RIVER	OR00-0034	46.24636	-123.865
OREGON	2000	COLUMBIA RIVER	OR00-0035	46.28297	-123.793
OREGON	2000	COLUMBIA RIVER	OR00-0036	46.23201	-123.939
OREGON	2000	COLUMBIA RIVER	OR00-0037	46.242	-123.859
OREGON	2000	COLUMBIA RIVER	OR00-0038	46.23394	-123.88
OREGON	2000	COLUMBIA RIVER	OR00-0039	46.23854	-123.79

STATE	YEAR	ESTUARY NAME	EMAP Station ID	LATITUDE	LONGITUDE
OREGON	2000	COLUMBIA RIVER	OR00-0040	46.26919	-123.713
OREGON	2000	COLUMBIA RIVER	OR00-0041	46.20529	-123.882
OREGON	2000	COLUMBIA RIVER	OR00-0042	46.22234	-123.797
OREGON	2000	COLUMBIA RIVER	OR00-0043	46.24003	-123.732
OREGON	2000	COLUMBIA RIVER, RIVER MILE 21.4	OR00-0044	46.26385	-123.658
OREGON	2000	COLUMBIA RIVER, RIVER MILE 25.7	OR00-0045	46.25365	-123.562
OREGON	2000	COLUMBIA RIVER, RIVER MILE 14.5	OR00-0046	46.21268	-123.781
OREGON	2000	COLUMBIA RIVER	OR00-0047	46.22227	-123.665
OREGON	2000	COLUMBIA RIVER, RIVER MILE 28.8	OR00-0048	46.2683	-123.502
OREGON	2000	COLUMBIA RIVER, RIVER MILE 32.5	OR00-0049	46.24906	-123.44
OREGON	2000	COLUMBIA RIVER, RIVER MILE 33.5	OR00-0050	46.23561	-123.427
OREGON	1999	YOUNGS BAY, RIVER MILE 8.3	OR99-0001	46.113	-123.547
OREGON	1999	CATHLAMET BAY	OR99-0002	46.12633	-123.434
OREGON	1999	YOUNGS BAY	OR99-0003	46.10801	-123.519
OREGON	1999	CATHLAMET BAY	OR99-0004	46.13026	-123.403
OREGON	1999	YOUNGS BAY	OR99-0005	46.10038	-123.536
OREGON	1999	CATHLAMET BAY	OR99-0006	46.12473	-123.413
OREGON	1999	YOUNGS BAY	OR99-0007	46.1014	-123.523
OREGON	1999	MARSH ISLAND CREEK	OR99-0008	46.13569	-123.353
OREGON	1999	CATHLAMET BAY	OR99-0009	46.11381	-123.447
OREGON	1999	CATHLAMET BAY	OR99-0010	46.11322	-123.448
OREGON	1999	CATHLAMET BAY	OR99-0011	46.11171	-123.409
OREGON	1999	YOUNGS RIVER	OR99-0012	46.08924	-123.49
OREGON	1999	KNAPPA SLOUGH	OR99-0013	46.11229	-123.355
OREGON	1999	BRADBURY SLOUGH	OR99-0014	46.10196	-123.086
OREGON	1999	WALLACE SLOUGH	OR99-0015	46.0805	-123.163
OREGON	1999	CLATSKANIE RIVER	OR99-0016	46.07717	-123.136
OREGON	1999	RINEARSON SLOUGH	OR99-0017	46.07408	-123.021
WASHINGTON	1999	BAKER BAY	WA99-0038	46.18577	-124.006
WASHINGTON	1999	BAKER BAY	WA99-0039	46.18082	-124.016
WASHINGTON	1999	BAKER BAY	WA99-0040	46.16402	-123.584
WASHINGTON	1999	GRAYS RIVER	WA99-0041	-99.99	99.99
WASHINGTON	1999	BAKER BAY	WA99-0042	46.15784	-123.599
WASHINGTON	1999	GRAYS BAY	WA99-0043	46.181	-123.426
WASHINGTON	1999	GRAYS BAY	WA99-0044	46.17998	-123.419
WASHINGTON	1999	GRAYS BAY	WA99-0045	46.17716	-123.422
WASHINGTON	1999	GRAYS BAY	WA99-0046	46.17232	-123.436
WASHINGTON	1999	GRAYS BAY	WA99-0047	46.16495	-123.43
WASHINGTON	1999	COWLITZ RIVER	WA99-0048	46.05688	-122.553
WASHINGTON	1999	CARROLLS CHANNEL	WA99-0049	46.05073	-122.528
WASHINGTON	1999	MARTIN SLOUGH	WA99-0050	45.56797	-122.472

Appendix 2. Chemicals measured in sediments and fish tissues.

CHEMICAL CATECORY	CHEMICALS	
Polynuclear Aromatic Hydrocarbons (PAHs)		
	Acenaphthene	2-methylnaphthalene
	Anthracene	1-methylnaphthalene
	Benz(a)anthracene	1-methylphenanthrene
	Benzo(a)pyrene	2,6-dimethylnaphtalene
	Biphenyl	Naphthalene
	Chrysene	Naphtalene(C1-C4)
	Chrysene(C1-C4)	Phenanthene
	Dibenz(a,h)anthracene	Pyrene
	Dibenzothiophene	Benzo(b)fluoranthene
	Dibenzothiophene(C1-C3)	Acenaphthylene
	2,6-dimethylnaphthalene	Benzo(k)fluoranthene
	Fluoranthene	Benzo(g,h,i)perylene
	Fluorene	Ideno(1,2,3-c,d)pyrene
	Fluorene(C1-C3)	2,3,5-trimethylnaphthalene
PCB Congeners		
	PCB No. Compound Name	PCB No. Compound Name
	8 2,4'-dichlorobiphenyl	126 3,3,4,4',5-pentachlorobiphenyl
	18 2,2',5-trichlorobiphenyl	128 2,2',3,3',4,4'-hexachlorobiphenyl
	28 2,4,4'-trichlorobiphenyl	138 2,2',3,4,4',5'-hexachlorobiphenyl
	44 2,2',3,5'-tetrachlorobiphenyl	153 2,2',4,4',5,5'-hexachlorobiphenyl
	52 2,2',5,5'-tetrachlorobiphenyl	170 2,2',3,3',4,4',5-heptachlorobiphenyl
	66 2,3',4,4'-tetrachlorobiphenyl	180 2,2',3,4,4',5,5'-heptachlorobiphenyl
	101 2,2',4,5,5'-pentachlorobiphenyl	187 2,2',3,4',5,5',6-heptachlorobiphenyl
	105 2,3,3',4,4'-pentachlorobiphenyl	195 2,2',3,3',4,4',5,6-octachlorobiphenyl
	110/77 2,3,3',4',6-pentachlorobiphenyl	206 2,2',3,3',4,4',5,5',6-nonachlorobiphenyl
	3,3',4,4'-tetrachlorobiphenyl	209 2,2'3,3',4,4',5,5',6,6'-decachlorobiphenyl
	118 2,3,4,4',5-pentachlorobiphenyl	
DDT and its metabolites		
	2,4'-DDD	4,4'-DDE
	4,4'-DDD	2,4'-DDT
	2,4'-DDE	4,4'-DDT
Chlorinated pesticides other than DDT		
	Aldrin	Heptachlor
	Alpha-Chlordane	Heptachlor epoxide
	Dieldrin	Hexachlorobenzene
	Endosulfan I	Lindane (gamma-BHC)
	Endosulfan II	Mirex
	Endosulfan sulfate	Toxaphene
	Endrin	Trans-Nonachlor
Trace Elements		
	Aluminum	Manganese (sediment only)
	Antimony (sediment only)	Mercury
	Arsenic	Nickel
	Cadmium	Selenium
	Chromium	Silver
	Copper	Tin
	Iron	Zinc
	Lead	
Other Measurements		
	Total organic carbon (sediments)	

Appendix 3. Summary statistics for water chemistry and habitat indicators. Total estuarine area is 611 square kilometers.

Indicator	Units	N	Mean	95% Confidence	Median	Minimum	Range of Detected Values	Variance	Standard Deviation	Standard Error
Water Clarity - Light Transmissivity at 1m	%	68	21.163	18.221	16.824	0.073	0.0732 - 87.590	293.152	17.122	0.744
Secchi Depth	m	79	1.563	0.678	1.500	0.100	0.1000 - 3.5000	0.410	0.640	0.026
Dissolved Oxygen - Bottom	mg/l	79	8.333	1.221	8.439	2.900	2.900 - 11.474	1.327	1.152	0.047
Dissolved Oxygen - Surface	mg/l	79	8.655	0.903	8.750	3.350	3.350 - 11.200	0.726	0.852	0.035
Chlorophyll a	µg/l	79	4.885	2.966	3.967	ND*	1.230 - 14.500	7.834	2.799	0.114
Mean Orthophosphate Phosphorus	µg/l	79	17.703	8.089	19.500	ND*	0.530 - 34.429	58.258	7.633	0.310
Mean Total Dissolved Nitrogen	µg/l	79	141.827	58.416	148.500	20.600	20.600 - 283.729	3038.336	55.121	2.241
Mean Nitrogen to Phosphorus Ratio	ratio	75	19.950	20.883	16.647	5.986	5.986 - 178.619	386.987	19.672	0.823
Total Suspended Solids	mg/l	79	10.373	21.937	6.000	0.667	0.667 140.00	428.482	20.700	0.842

*ND = not detected
Summary statistics were calculated with non-detects set to zero.

Appendix 4. Summary statistics for sediment characteristics. Total estuarine area is 611 square kilometers.

Indicator	Units	N	Mean	95% Confidence	Median	Detection Frequency(%) **	Range of Detected Results	Variance	Standard Deviation	Standard Error
Aldrin	ng/g dry wt	77	0.075	0.096	0.000	6.490	0.5 - 1.400	0.069	0.263	0.011
Aluminum	µg/g dry wt	77	62970.320	64166.728	67600.000	100.000	13000 - 78800.000	220058940.269	14834.384	609.175
Antimony	µg/g dry wt	77	0.057	0.070	0.000	15.580	0.14 - 0.980	0.027	0.165	0.007
Arsen	µg/g dry wt	77	3.686	3.993	2.700	94.810	0.69 - 20.800	14.449	3.801	0.156
Cadmium	µg/g dry wt	77	0.177	0.192	0.122	84.410	0.09 - 0.854	0.033	0.182	0.007
Chlordane	ng/g dry wt	77	0.000	ND*	ND*	ND*	ND*	0.000	0.000	0.000
Chromium	µg/g dry wt	77	33.622	34.813	29.800	100.000	15.3 - 89.800	218.022	14.766	0.606
Copper	µg/g dry wt	77	19.469	20.254	16.600	100.000	8.35 - 59.000	94.724	9.733	0.400
DDE	ng/g dry wt	77	0.093	0.123	0.000	14.280	0.27 - 3.900	0.143	0.378	0.016
DDT – Total	ng/g dry wt	77	0.225	0.290	0.000	15.580	0.27 - 7.200	0.638	0.799	0.033
Dieldrin	ng/g dry wt	77	0.054	0.077	0.000	2.600	1.5 - 1.800	0.083	0.288	0.012
Endosulfan I	ng/g dry wt	77	0.000		0.000	ND*	ND*	0.000	0.000	0.000
Endosulfan II	ng/g dry wt	77	0.018	0.032	0.000	1.300	1.75 - 1.750	0.031	0.175	0.007
Endosulfan Sulfate	ng/g dry wt	77	0.631	0.787	0.000	14.280	1.25 - 11.800	3.767	1.941	0.080
Endrin	ng/g dry wt	77	0.027	0.049	0.000	1.300	2.7 - 2.700	0.073	0.270	0.011

Indicator	Units	N	Mean	95% Confidence	Median	Detection Frequency(%) **	Range of Detected Results	Variance	Standard Deviation	Standard Error
Heptachlor	ng/g dry wt	77	0.467	0.540	0.000	22.080	0.6 - 3.600	0.816	0.903	0.037
Heptachlor Epox	ng/g dry wt	77	0.019	0.034	0.000	2.600	1.3 - 3.300	0.035	0.188	0.008
Hexachloro-benzene	ng/g dry wt	77	0.410	0.497	0.000	10.390	0.65 - 4.600	1.184	1.088	0.045
Iron	µg/g dry wt	77	37501.853	38189.131	35266.667	100.000	27700 - 75200.000	72618329.658	8521.639	349.942
Lead	µg/g dry wt	77	9.422	9.758	8.720	100.000	1.47 - 25.900	17.399	4.171	0.171
Lindane	ng/g dry wt	77	0.136	0.181	0.000	3.900	1.3 - 2.700	0.319	0.565	0.023
Manganese	µg/g dry wt	77	658.128	669.755	626.000	100.000	437 - 1390.000	20785.404	144.171	5.920
Mercury	µg/g dry wt	77	0.028	0.030	0.014	98.700	0.0049 - 0.239	0.001	0.030	0.001
Mirex	ng/g dry wt	77	0.000	ND*	0.000	ND*	ND*	0.000	0.000	0.000
Nickel	µg/g dry wt	77	27.546	28.077	26.650	100.000	15.1 - 49.200	43.380	6.586	0.270
PAH –High Molecular Weight	ng/g dry wt	77	47.975	62.070	0.000	0.760	35.060- 3293.475	30544.351	174.769	7.177
PAH – Low Molecular Weight	ng/g dry wt	77	16.356	28.518	0.000	0.760	20.780 - 3574.433	22739.918	150.798	6.193
PAH – Total	ng/g dry wt	77	155.445	353.906	0.000	1.000	36.360 59878.200	6055243.337	2460.740	101.050
PCB – EMAP Total	ng/g dry wt	77	0.428	0.545	0.000	0.800	12.990 13.000	2.106	1.451	0.060
Selenium	µg/g dry wt	77	0.034	0.043	0.000	10.390	0.13 - 0.460	0.012	0.110	0.005
Silt and Clay – Percent	%	77	7.850	19.183	1.030	89.600	.05 – 92.66	327.241	18.090	0.743

Indicator	Units	N	Mean	95% Confidence	Median	Detection Frequency(%) **	Range of Detected Results	Variance	Standard Deviation	Standard Error
Silver	µg/g dry wt	76	0.102	0.119	0.000	61.840	0.013 - 0.980	0.046	0.214	0.009
Tin	µg/g dry wt	77	1.315	1.360	1.355	85.710	0.455 - 2.500	0.310	0.557	0.023
Total Organic Carbon	ng/g dry wt	77	0.227	0.261	0.031	0.014	97.400 2.167	0.183	0.427	0.018
Toxaphene	ng/g dry wt	77	0.000	ND*	0.000	ND*	ND*	0.000	0.000	0.000
Trans Nonachlor	ng/g dry wt	77	0.026	0.039	0.000	1.100	1.300 1.100	0.028	0.167	0.007
Zinc	µg/g dry wt	77	86.134	87.819	79.200	100.000	54.8 - 147.000	436.523	20.893	0.858

*ND = not detected
**Detection frequency refers to the percent of individual samples analyzed, not to the percentage of the area.
Summary statistics were calculated with non-detects set to zero.

Appendix 5. Summary statistics for contaminants in fish tissue. Total estuarine area is 611 square kilometers.

	Units	N	Mean	95% Confidence	Median	Detection Frequency**	Range of Detected Values	Variance	Standard Deviation	Standard Error
Aldrin	ng/g wet wt.	69	ND*	ND*	ND*	ND*	ND*	0.000	0.000	0.000
Alumuminum	µg/g wet wt.	70	29.472	32.156	14.118	100.000	0.531 - 182.834	1043.694	32.306	1.366
Arsenic	µg/g wet wt.	70	0.536	0.790	0.238	65.700	0.153 - 29.767	9.314	3.052	0.129
Cadmium	µg/g wet wt.	70	0.015	0.017	0.009	51.400	0.010 - 0.156	0.000	0.021	0.001
Chlordane	ng/g wet wt.	69	0.236	0.300	0.000	13.000	2.023 - 4.855	0.589	0.767	0.032
Chromium	µg/g wet wt.	70	0.259	0.277	0.169	100.000	0.067 - 1.200	0.048	0.218	0.009
Copper	µg/g wet wt.	70	0.913	0.959	0.878	90.000	0.214 - 3.730	0.304	0.551	0.023
DDE	ng/g wet wt.	69	66.104	72.818	29.000	88.400	12.000 - 405.444	6520.557	80.750	3.418
DDT – Total	ng/g wet wt.	70	76.988	84.872	29.771	85.700	15.640 - 493.644	9004.572	94.892	4.014
Dieldrin	ng/g wet wt.	69	0.420	0.579	0.000	15.900	0.940 - 29.574	3.690	1.921	0.081
Endosulfan 1	ng/g wet wt.	69	0.224	0.283	0.000	11.600	2.890 - 4.896	0.508	0.713	0.030
Endosulfan 2	ng/g wet wt.	69	1.317	1.622	0.000	30.000	2.090 - 54.126	13.396	3.660	0.155
Endosulfan Sulfate	ng/g wet wt.	69	ND*	ND*	ND*	ND*	ND*	0.000	0.000	0.000
Endrin	ng/g wet wt.	69	1.408	1.790	0.000	30.000	0.788 - 75.702	21.071	4.590	0.194
Heptachlor	ng/g wet wt.	69	ND*	ND*	ND*	ND*	ND*	0.000	0.000	0.000
Heptachlor Epoxide	ng/g wet wt.	69	0.085	0.127	0.000	5.800	1.044 - 8.928	0.258	0.508	0.021
Hexachlorobenzene	ng/g wet wt.	69	0.171	0.219	0.000	8.700	1.445 - 4.095	0.327	0.572	0.024

	Units	N	Mean	95% Confidence	Median	Detection Frequency**	Range of Detected Values	Variance	Standard Deviation	Standard Error
Iron	µg/g wet wt.	70	50.318	54.871	27.251	100.000	5.207 - 395.500	3003.012	54.800	2.318
Lead	µg/g wet wt.	70	0.055	0.063	0.000	37.100	0.054 - 0.968	0.010	0.102	0.004
Lindane	ng/g wet wt.	69	ND*	ND*	ND*	ND*	ND*	0.000	0.000	0.000
Mercury	µg/g wet wt.	70	0.046	0.049	0.033	97.100	0.011 - 0.257	0.001	0.039	0.002
Mirex	ng/g wet wt.	69	ND*	ND*	ND*	ND*	ND*	0.000	0.000	0.000
Nickel	µg/g wet wt.	70	0.187	0.308	0.000	12.900	0.085 - 13.169	2.146	1.465	0.062
PCB - EMAP total	ng/g wet wt.	70	52.399	58.678	16.821	91.400	2.050 - 691.176	5711.810	75.577	3.197
Selenium	µg/g wet wt.	70	0.251	0.260	0.268	87.100	0.105 - 0.572	0.012	0.112	0.005
Silver	µg/g wet wt.	70	0.021	0.025	0.000	35.700	0.008 - 0.280	0.003	0.054	0.002
Tin	µg/g wet wt.	41	0.020	0.024	0.000	14.600	0.072 - 0.295	0.002	0.046	0.003
Toxaphene	ng/g wet wt.	69	ND*	ND*	ND*	ND*	ND*	0.000	0.000	0.000
Trans Nonachlor	ng/g wet wt.	69	2.015	2.441	0.000	58.600	0.440 - 46.066	26.314	5.130	0.217
Zinc	µg/g wet wt.	70	17.942	18.512	17.316	100.000	7.838 - 39.060	47.081	6.862	0.290

* ND = Not Detected
**Detection frequency refers to the percent of individual samples analyzed, not to the percentage of the area. This is different from Table 6.
Summary statistics were calculated with non-detects set to zero.

Appendix 6. Benthic invertebrate species from 1999-2000. Species are identified as Native (N) or Non-Indigenous (NIS) species, or blank where it unknown. Freshwater sites have <5 psu bottom salinity and Intermediate sites have ≥5 psu and ≤ 25 psu bottom salinity.

Species	Native(N)/Non-Indigenous (NIS)	# of Total sites	Found at intermediate sites	Found at freshwater sites
Acarina		2		1
Actiniidae		1	1	1
Agraylea sp		2		2
Americorophium salmonis	N	54	9	45
Americorophium sp		18	1	17
Americorophium spinicorne	N	11	3	8
Archaeomysis grebnitzkii	N	6	5	1
Barantolla nr americana	N	1	1	
Bivalvia sp 1		3		3
Caecidotea racovitzai	NIS	3		3
Ceratopogonidae		2		2
Chironomidae		24	1	23
Chironomus sp		2		2
Cladopelma sp		1		1
Clavidae		1		1
Coenagrionidae		1		1
Coleoptera		1		1
Corbicula fluminea	NIS	59	3	56
Corixidae		1		1
Corophiidae		13		13
Crangon franciscorum		5	2	3
Crangon sp		1	1	
Crangonyx floridanus subgroup		1		1
Cricotopus sp		1		1
Cryptochironomus sp		5		5
Cryptomya californica	N	2	2	
Cyclopidae		1		1
Cytherideidae		1		1
Demicryptochironomus sp		1		1
Dicrotendipes sp		3		3
Diptera		2	1	1
Dubiraphia sp		1		1
Eogammarus confervicolus CMPLX	N	3	2	1
Eogammarus sp		1		1
Eohaustorius estuarius	N	9	4	5
Eohaustorius washingtonianus	N	1	1	

Species	Native(N)/Non-Indigenous (NIS)	# of Total sites	Found at intermediate sites	Found at freshwater sites
Ephydridae		1		1
Epoicocladius sp		1		1
Eteone columbiensis	N	5	5	
Fluminicola virens	N	4		4
Gastropoda		1		1
Gastropoda sp 3		1		1
Gastropoda sp 4		3		3
Gomphidae		5		5
Grandidierella japonica	NIS	3	3	
Grandifoxus grandis		1	1	
Helisoma sp		1		1
Heteromastus sp		1	1	
Hexagenia sp		4		4
Hirudinea		6		6
Hobsonia florida	NIS	6	2	4
Hyalella azteca		1		1
Hydrobiidae		9		9
Juga plicifera	N	1		1
Lampetra ayresi		1		1
Macoma balthica	N	7	5	2
Magelona pitelkai	N	1	1	
Manayunkia speciosa	NIS	5		5
Mediomastus sp		2	1	1
Monoporeia affinis	N	5		5
Mya arenaria	NIS	3	2	1
Mytilidae		1	1	
Narpus sp		1		1
Neanthes limnicola	N	18	5	13
Neanthes sp		6	3	3
Nemertea		2		2
Neomysis mercedis	N	3		3
Neotrypaea sp		1	1	
Nephtys caecoides	N	1	1	
Nephtys californiensis	N	4	4	
Nephtys cornuta	N	1	1	
Nippoleucon hinumensis	NIS	2		2
Oligochaeta		31	4	27
Paralauterborniella sp		1		1
Paranemertes californica	N	7	7	
Paraonella platybranchia	N	1	1	
Pectinatella magnifica		1		1
Phaenopsectra sp		1		1
Physella sp		4		4

Species	**Native(N)/Non-Indigenous (NIS)**	**# of Total sites**	**Found at intermediate sites**	**Found at freshwater sites**
Polydora cornuta	NIS	2	2	
Polypedilum sp		1		1
Potamopyrgus antipodarum	NIS	10	1	9
Procladius sp		1		1
Pseudochironomus sp		1		1
Pseudodiaptomus forbesi	NIS	2		2
Pseudopolydora kempi	NIS	2	2	
Pseudopolydora sp		2	2	
Pygospio elegans		4	4	
Ramellogammarus oregonensis	N	1		1
Rhepoxynius stenodes		5	5	
Saduria entomon		5	3	2
Scolelepis sp		1	1	
Sialis sp		5		5
Siliqua sp		4	3	1
Sphaeriidae		1		1
Spio butleri	N	5	5	
Streblospio benedicti	NIS	1	1	
Tanytarsus sp		2		2
Tetrastemma candidum		4	3	1
Trichoptera		2		2
Typhloplanoidea		1		1
Uniramia		2	1	1

Appendix 7. Fish species from 1999-2000.

SCIENTIFIC NAME	COMMON NAME	# of SITES	% ESTUARINE AREA	SALINTY FOUND
Class Actinopterygii				
Order Clupeiformes				
Family Clupeidae				
Clupeidae sp	Herrings, shads, sardines, sardinellas, sprats, etc.	1	1.5	Freshwater
Alosa sapidissima	American Shad	6	8.8	Freshwater
Clupea pallasii	Pacific herring	1	.2	Freshwater
Family Engraulidae				
Engraulis mordax	Californian anchovy	1	3.5	Intermediate
Order Cypriniformes				
Family Cyprinidae				
Mylocheilus caurinus	Peamouth	2	2.9	Freshwater
Ptychocheilus oregonensis	Northern pikeminnow	2	3.3	Freshwater
Order Gadiformes				
Family Gadidae				
Microgadus proximus	Pacific tomcod	5	15.0	Intermediate
Order Gasterosteiformes				
Family Gasterosteidae				
Gasterosteus aculeatus	Three-spine stickleback	13	22.7	Freshwater
Order Osmeriformes				
Family Osmeridae				
Spirinchus thaleichthys	Longfin smelt	1	3.5	Intermediate
Order Perciformes				
Family Centrarchidae				
Pomoxis annularis	White Crappie	1	1.5	Freshwater
Pomoxis sp	Crappie	1	.2	Freshwater
Family Pholidae				
Pholis ornate	Saddleback gunnel	1	1.1	Intermediate
Family Embiotocidae				
Cymatogaster aggregata	Shiner perch	6	14.4	Freshwater, Intermediate
Order Percopsiformes				
Family Percopsidae				
Percopsis transmontana	Sand roller	1	1.5	Freshwater
Order Pleuronectiformes				
Family Pleuronectidae				
Platichthys stellatus	Starry flounder	34	61.3	Freshwater, Intermediate
Pleuronectes vetulus	English sole	6	13.5	Intermediate
Order Salmoniformes				
Family Salmonidae				
Oncorhynchus tshawytscha	Chinook salmon	1	1.9	Freshwater

SCIENTIFIC NAME	COMMON NAME	# of SITES	% ESTUARINE AREA	SALINTY FOUND
Order Scorpaeniformes				
Family Cottidae				
Artedius fenestralis	Padded sculpin	2	2.0	Freshwater
Cottus asper	Prickly sculpin	3	6.4	Freshwater
Leptocottus armatus	Pacific staghorn sculpin	8	16.8	Freshwater, Intermediate
Family Hexagrammidae				
Hexagrammos stelleri	Whitespotted greenling	1	1.8	Intermediate