LOWER COLUMBIA RIVER

BI-STATE PROGRAM

RECONNAISSANCE SURVEY OF THE LOWER COLUMBIA RIVER

TASK 4: REVIEW OF BIOLOGICAL INDICATORS TO SUPPORT RECOMMENDATIONS ON A BIOLOGICAL MONITORING APPROACH

FEBRUARY 1992

Prepared By:

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In Association With:

EVS CONSULTANTS

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Final Report

RECONNAISSANCE SURVEY OF THE LOWER COLUMBIA RIVER TASK 4: REVIEW OF BIOLOGICAL INDICATORS TO SUPPORT RECOMMENDATIONS ON A BIOLOGICAL MONITORING APPROACH

by

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in association with

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February 1992

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EXECUTIVE SUMMARY

The Lower Columbia River Bi-State Program was formed at the direction of the legislatures from the states of Oregon and Washington to assess environmental conditions of the lower Columbia River from Bonneville Dam (RM 146) to the mouth of the river. The Bi-State Steering Committee subdivided the first year of the program into seven tasks. Each task addresses separate, but interrelated, objectives. The primary objective of Task 4 is to make recommendations on the biological indicators that would be most useful in a future, long-term monitoring program on the lower Columbia River. This report focuses on the characterization of habitats and biological communities in the lower Columbia River, reviews biological indicators, and provides a preliminary list of candidate indicators for potential use in a monitoring program These indicators could be use to assess the overall health of the ecology of the lower Columbia River and to monitor the quality of water and sediment in relation to anthropogenic contaminants.

The lower Columbia River can be characterized as a highly dynamic system consisting of a freshwater riverine reach and an estuarine/marine reach. The composition and distribution of the biota is strongly influenced by substrate type, river flow characteristics, and salinity. The freshwater reach is dominated by sand habitats, which is reflected in the low diversity of benthic invertebrates residing in those habitats. The estuary/marine reach is dominated by sands and mud, but is physically more stable with more diverse habitats and therefore more taxa.

Biological indicators of water and sediment quality were divided into exposure and response indicators. Candidate exposure indicators include bioaccumulation and biomarkers. Candidate response indicators include individual-, population-, and community-level indicators using fish and benthic invertebrates. Water and sediment bioassays also are considered to have strong potential for use in a monitoring program.

Numerous endpoints can be used for both exposure and response indicators and thus numerous options can be considered. Because of the combination of varying habitat and associated biological communities in the lower Columbia River, and the wide range of potential contaminants, no single indicator or approach will work at all locations. Final recommendations will be made upon assessing field data on contaminants, their spatial distribution and associated

biological communities. The indicators presented in this report will be evaluated after the data regarding the recently completed reconnaissance survey are available to make final recommendations of applicable biological indicators.

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1.0 INTRODUCTION

The Lower Columbia River Bi-State Program was formed at the direction of the legislatures from the states of Oregon and Washington to assess environmental conditions in the lower Columbia River from Bonneville Dam at River Mile (RM) 146 to the mouth of the river. The states formed an Interstate Agreement that directs a four-year program to characterize water quality in the lower Columbia River, identify water quality problems, determine whether beneficial uses are impaired, and develop solutions to problems found in the river. The goal of the first year is to establish the technical framework for determining the environmental health of the lower Columbia River This program is funded by the Washington Department of Ecology, Oregon Department of Environmental Quality, public ports in Washington and Oregon, and the Northwest Pulp and Paper Association.

To achieve the first year objectives, the Bi-State Committee subdivided the program into seven tasks. These tasks include: 1) initial data review and synthesis; 2) inventory and characterization of pollutants; 3) review of physical and hydrological characteristics; 4) biological indicators and monitoring approach; 5) identification of beneficial uses and sensitive areas; 6) planning and implementation of screening surveys; and 7) establishment of technical framework and recommendations for future study. This report presents the results of Task 4.

2.0 OBJECTIVES

This report consists of three separate but interrelated objectives: 1) use available information to characterize the major habitats and biological communities in the lower Columbia River, 2) compile and review literature on biological indicators, and 3) develop a candidate list of biological indicators that could be used in an environmental monitoring program in the lower Columbia River. Final recommendations of biological indicators will be made based upon data collected during the field reconnaissance survey

3.0 APPROACH

The following steps are being taken to accomplish the objectives of Task 4:

1. Develop a detailed work plan

2. Compile and review pertinent literature and interview scientists with experience in the Columbia River and/or biological indicators

3. Characterize habitats and communities of the lower Columbia River using historical data

4. Select candidate biological indicators

5. Collect additional field data

6. Reassess biological indicators

7. Identify major ecological zones of the lower Columbia River

8. Provide final recommendations of biological indicators that would be most useful and applicable for long-term water quality monitoring in the lower Columbia River.

The planned products of Task 4 include four reports; a detailed work plan, a report titled "Review of Biological Indicators to Support Recommendations on a Biological Monitoring Approach" (present report), a Report on Testing, and a Final Report. The detailed work plan was completed and presented to the Committee on August 30, 1991. The second report (this report) is the initial report on biological indicators and includes three main parts: the first part is a review of habitats and biological communities of the lower Columbia River; the second section presents a review of potential biological indicators, and the third presents preliminary recommendations of candidate biological indicators. The third report, Report on Testing, will provide a preliminary summary of the field and laboratory investigation in relation to the selection of biological indicators for the lower Columbia River. The Final Report will integrate information from all previous reports and summarize findings and recommendations.

The discussion of biological indicators is based on a literature review that included agency documents and published literature Individuals who have extensive experience in the use of biological indicators under a wide variety of conditions, including conditions similar to those of the Columbia River were interviewed. They were selected from the Scientific Resource Panel, academia, state and federal government agencies, and other consulting firms. All contacts were documented and contact sheets area included as Appendix B.

The different habitat types present in the lower Columbia River and the geographic extent of those habitats were defined based on information compiled in Tasks 1, 2 and 5. The key elements used to delineate habitat types were salinity, current speed, and substrate grain size. Information from the biological characterization was integrated with the review of biological indicators to select candidate biological indicators for use on the lower Columbia River. Criteria for selecting biological indicators included biological relevance, sensitivity to substances of concern, ease of interpretation, and the availability of established procedures.

4.0 HABITATS AND BIOLOGICAL COMMUNITIES

The objective of this section is to provide a basic description of habitats that occur in the lower Columbia River and the biological communities that use those habitats. This information will be used to determine which individual taxa, populations, and communities are most appropriate for use in biological monitoring in the Columbia River.

4.1 LOWER COLUMBIA RIVER HABITATS

Habitats can be defined on a variety of environmental scales ranging from the surface of a sand grain to an entire ocean. For the purpose of characterizing biological communities in the lower Columbia River, habitats were defined on a broad scale based on gross differences in major chemical and physical characteristics, specifically salinity, flow, and sediment grain size. Salinity was considered to be the dominant factor differentiating habitats and communities. Based on average conditions, the lower Columbia River was divided into three salinity regimes: marine (salinity >20 ppt), estuarine (0.5 to 20 ppt), and freshwater (<0.5 ppt). The distribution of pelagic (residing in the water column) organisms was considered to be controlled primarily by salinity, but also, to a more limited extent, by flow velocities. Pelagic habitats were classified more qualitatively as either high flow (e.g., main channel) or low flow (e.g., protected bays, sloughs) areas. In addition, the fringing marsh communities were differentiated on the basis of the average salinity of the nearshore waters. The water-column and marsh habitats were defined as follows:

Marine pelagic: (high flow and low flow)
Estuarine pelagic: (high flow and low flow)
Riverine pelagic: (high flow and low flow)
Estuarine marsh: estuarine salinities, intertidal marsh
Riverine marsh: freshwater, fringing marsh

The distribution of benthic (dwelling on or in bottom sediments) organisms, respond to differences in the characteristics of the substrates. Salinity was used to divide the study area into major reaches. The variable found to be most useful in classifying benthic habitats within each of the major reaches was sediment grain size. Sediments were classified as predominantly fine-grained (<63 um; muds or muddy sands), predominantly coarse-grained (63 to 2000 um; fine to coarse sand), or very coarse-grained (>2 mm; gravel and cobble). Based on these categories, six benthic habitat types were defined:

Marine sands: marine salinities, sand substrate, high flow
Estuarine sands. estuarine salinities, sand substrate, high flow
Estuarine muds: estuarine salinities, muddy substrate, low flow
Riverine gravel: freshwater, gravel substrate, high flow
Riverine sands: freshwater, sand substrate, high flow
Riverine muds: freshwater, muddy substrate, low flow

4.2 HABITAT DISTRIBUTIONS

For the purpose of describing the general distribution of habitats within the lower 146 miles of the river, information is presented by river reach (segment), as defined in Task 3. A summary of habitat types by river segment is presented in Table 1.

4.2.1 River Segment 1 (Entrance to RM 38)

The greatest number of habitat types occur in the first river segment, encompassing the Columbia River estuary. All of the pelagic and benthic habitats defined for this study are found here, with the exception of the riverine gravel habitat. Salinity, substrate, current patterns, and current speed vary widely depending on location, tidal cycle, and river flow. The entrance to the lower Columbia River (RM 0 to 5) is the area of highest salinity because of the intrusion of oceanic water masses and is characterized as marine habitat. Salinities range from 17 to 25 ppt depending on river flow (Simenstad et al. 1990). The entrance is also characterized by strong currents (both tidal and river currents), wave action, deep water, and coarse sand substrates.

Estuarine benthic and pelagic habitats are typically found from inside the river mouth, which includes the peripheral bays near the entrance of the river, to about RM 20. Salinities vary widely (from 0.5 to 20 ppt), depending on the degree of mixing between the freshwater and oceanic strata. Mixing is a function of the strength of the river currents in relation to the tidal currents; maximum mixing occurs when river currents are weak compared to tidal currents (Jay and Sherwood 1990). The main channel and shoals within this region are characterized by fine to coarse sand substrates. Both tidal and river currents tend to be strong and periodically erode bottom sediments, but there is an overall accumulation of sands within this region of the river. Wave and current energies are lower in peripheral bays (e.g., Baker,

Table 1. Habitat types identified in each river segment in the lower Columbia River.

Habitat Type	Segment 1	Segment 2	Segment 3	Segment 4
Bottom				
Marine sands	X			
Estuarine sands	X			
Estuarine muds	X			
Estuarine marsh	X			
Riverine gravel				X
Riverine sands	X	X	X	X
Riverine muds	X	X	X	X
Riverine marsh	X	X	X	X
Water Column				
Marine pelagic	X			
Estuarine pelagic	X			
Riverine pelagic	X	X	X	X

Trestle, and Youngs Bays) and protected shoreline areas than in the main channels. Commensurate with the lower physical energy, bottom substrates in these areas are characterized by silts, clays, and very fine sands. Marsh habitats are found in the intertidal areas of the bays and protected shorelines.

Freshwater habitats commence near RM 20 and continue throughout the remaining upstream reaches of the river Typically, salinities are below 0.5 ppt, however, under low river flow and incoming neap tide conditions, intrusion of saline water has been measured as far upstream as RM 30 in the main channel (Jay and Sherwood 1990). The main channel areas in the freshwater region of River Segment 1 are subject to river currents of varying velocities depending on water flow and tidal cycles. Sediments in the main channels of the freshwater habitats in Segment 1 tend to be coarse sands Currents and substrates are strongly modified by the presence of many land margins and shallow areas. Cathlamet Bay forms a large, principally freshwater bay with an extensive system of islands, shoals, and marshes. Sediments in Cathlamet Bay tend to be very fine sands or muds. Grays Bay is also considered a freshwater habitat, but exposure to prevailing winds contributes to the presence of coarser sand substrates. Fine substrates are confined to the more sheltered areas near the mouth of the Grays River.

4.2.2 River Segment 2 (RM 38 to RM 72)

Habitats found within this reach of the river are entirely freshwater and include riverine sand, mud, marsh, and pelagic habitats. River flows are variable and continue to be influenced by tidal cycles. Flow reversals have been noted as far upstream as RM 72 (Snyder and McConnell 1970), which is the upstream boundary of Segment 2. The river channel in this segment is split by low-lying islands (most notably Puget Island), forming sloughs and backwater channels. In the main channel, substrates are dominated by fine to coarse sands.

Coarser sands are found in the upstream areas and finer sands tend to occur in the downstream portion of the main channel where currents are slowed by tidal effects and the presence of islands. Finer sediments (e.g., silts) are found in sloughs and backwater channels. In the vicinity of the Cowlitz River, volcanic material from Mt. St. Helens contributes to the fine sediments in backwater channels (e.g., Carrolls Channel). Marsh habitats are found around island perimeters and near the mouths of smaller streams, and are characterized by mud substrates.

4.2.3 River Segment 3 (RM 72 to RM 102)

Segment 3 extends from the Kalama River to the mouth of the Willamette River. Habitats include riverine sand, mud, marsh, and pelagic habitats. This segment of the river consists principally of fine to coarse sand substrates and is characterized by strong river currents and tidal cycles. River channel sediments in this reach are not stable and under higher flow conditions are transported downstream Coarse sands occur in the main channel and finer sands are distributed in the shallow areas adjacent to the main channel. Silts and clays are only found in sloughs, backwater channels, and in fringing marshes.

4.2.4 River Segment 4 (RM 102 to RM 146)

This segment of the river extends from just above the mouth of the Willamette River to the Bonneville Dam. All riverine benthic habitats are found in this segment including gravel, sand, mud, and marsh habitats in addition to the pelagic habitat. The river meanders slightly and the majority of the main channel in this segment is split by low-lying sand islands (e g., Government, Reed, and Hamilton Islands). River flow in this segment is mainly a function of water released at the dam and tends to be less variable than in other river segments. However, tidal influences on water surface elevation have been identified as far upstream as the Bonneville Dam. Flow reversals in the river can extend as far upstream as RM 72, during periods of high tide and low river discharge. Tidal influence, however, is limited and does not have a profound effect on the biota in River Segment 4.

Main channel flows, particularly immediately downstream of the dam, tend to be high velocity. Moderation of flow velocity occurs in backwater channels and sloughs. Substrate types in this reach are the most diverse. The main channel substrates are comprised of gravel and cobble for approximately six miles downstream of the dam. Basaltic bedrock is exposed in some high scour areas below the dam. Downstream sediments are predominantly medium and coarse sands. In protected channels, backwater, and fringing marsh areas, sediments are finer and include silts and clays.

4.3 BIOLOGICAL COMMUNITIES OF THE LOWER COLUMBIA RIVER

This section presents a general overview of the major biological communities that reside in the lower Columbia River. There is a general lack of seasonal data for the lower Columbia River, so this report does not attempt to identify seasonal differences in communities. Characteristic biological communities occur within each of the defined habitats. For this study, descriptions of biological communities are limited to the dominant (numerically abundant) taxa identified in Tasks 1 and 5: fish, epibenthic and benthic invertebrates, and plants. For the purposes of this report, benthic invertebrate refers to any invertebrate that is predominantly associated with the bottom. Epibenthic refers to any benthic invertebrate that is mainly associated with the sediment surface. Pelagic refers to the water column (i.e., pelagic) and demersal refers to bottom dwelling (i.e., benthic). There are limited data describing the biological components of the lower Columbia River and therefore the following discussion is base upon minimal data, particularly in the freshwater reaches

4.3.1 Fish Communities

Bottom and Jones (1990) listed 81 species of fish occurring in the lower Columbia River, which included anadromous (13 species), resident marine and estuarine (50 species, combined), and freshwater (18 species) fishes. A complete listing of the species identified during past studies of the river is available in the Task 1 report.

Fish populations vary as a function of life cycles of individual fish species, salinity, and flow. In addition, Bottom et al. (1984) and Bottom and Jones (1990) found that the distribution of fish abundance within habitats or broad salinity zones in the lower Columbia River was influenced by prey density. The main food items of demersal fish assemblages are benthic and epibenthic invertebrates. Based on these factors, the dominant fish species identified in the lower Columbia River were divided into four general fish assemblages (Simenstad et al. 1990): anadromous, marine, estuarine, and freshwater. The taxa of each assemblage are presented in Table 2.

4.3.2 Epibenthic Invertebrates

Epibenthic organisms occur throughout the Columbia River. These invertebrates live on or just above the bottom sediments and are important prey organisms for fish, marine mammals, and birds. Epibenthic taxa identified in the river consist primarily of crustaceans including species of Ostracoda, Copepoda (harpacticoids, cyclopoids, calanoids), Branchiopoda (cladocerans). The calanoid and harpacticoid copepods in addition to cladocerans were among the major prey of most fish species including juvenile salmonids, American shad, starry flounder, staghorn sculpin, longfin–smelt, surf smelt, and Pacific herring (Jones et al. 1990).

Data available on the epibenthic communities in the lower Columbia River were limited to habitat studies conducted in the estuary (Jones et al. 1990; Simenstad et al. 1990; Fox et al. 1984). Data were not available characterizing the epibenthic communities of River Segments 2, 3, and 4.

4.3.3 Benthic Invertebrates

Benthic invertebrates occur throughout the Columbia River. These invertebrates typically live in the bottom sediments. The benthic invertebrate communities in the river are characterized by many taxa, including Arthropoda (Crustacea and Insecta), Annelida (Polychaeta and Oligochaeta), Mollusca (Bivalvia and Gastropoda), Nematoda, Nemertea (Rhynchocoela), and

Table 2. Dominant fish assemblages in the lower Columbia River (Simenstad et al., 1990).

Species	Scientific Name	Marine	Anadromous	Estuarine	Freshwater
Assemblage 1					
Pacific herring	*Clupea harengus pallasi*	X			
Northern anchovy	*Engraulis mordax*	X			
Surf smelt	*Hypomesus pretiosus*	X			
Whitebait smelt	*Allosmerus elongatus*	X			
Pacific sand lance	*Ammodytes hexapterus*	X			
Assemblage 2					
American shad	*Alosa sapidissima*		X		
Chinook salmon	*Oncorhynchus tshawytscha*		X		
Coho salmon	*Oncorhynchus kisutch*		X		
Steelhead	*Oncorhynchus mykiss*		X		
Eulachon	*Thaleichthys pacificus*		X		
Longfin smelt	*Spirinchus thaleichthys*		X		
Pacific lamprey	*Lampetra tridentata*		X		
River lamprey	*Lampetra ayresi*		X		
Assemblage 3					
Sand sole	*Psettichthys melanostictus*			X	
English sole	*Parophrys vetulus*			X	
Starry flounder	*Platichthys stellatus*			X	
Pacific staghorn sculpin	*Leptocottus armatus*			X	
Pacific tomcod	*Microgadus proximus*			X	
Snake prickleback	*Lumpenus sagitta*			X	
Shiner perch	*Cymatogaster aggregata*			X	
White sturgeon	*Acipenser transmontanus*			X	
Three-spine stickleback	*Gasterosteus aculeatus*			X	
Assemblage 4					
Large-scale sucker	*Catostomus macrocheilus*				X
Peamouth	*Mylocheilus caurinus*				X
Prickly sculpin	*Cottus asper*				X
Sand roller	*Percopsis transmontana*				X
Leopard dace	*Rhinichthys falcatus*				X
Northern squawfish	*Ptychocheilus oregonensis*				X

Platyhelminthes (Turbellaria). Benthic amphipods (*Corophium salmonis*, *C. spinicorne*, and *Eogammarus confervicolus*) and mysids (*Archaeomysis grebnitzkii*) were also among the major prey of most fish species occurring in the lower Columbia River.

Several studies have been conducted characterizing the benthic communities in River Segment 1, but only limited data were available identifying the dominant invertebrates in River Segments 2, 3, and 4. Based on the available information, dominant benthic invertebrates in each river segment were identified. The invertebrate communities were further characterized by habitat type (e.g., amphipods were dominant in the marine sands as well as the estuarine sand and mud habitats). The following community characterizations are based on a limited distribution of sampling stations, and as such do not preclude the presence of other dominant taxa. For example, in River Segment 3, Chironomidae (Insecta) larvae were found only in the riverine sands habitat, but sampling was limited to a few stations and it is likely that this species also occurs in the riverine mud habitats in this river segment.

4.3.4 Macroalgae

Benthic macroalgae are typically found on the sediments of tidal mudflats. These multi-celled algae (>0.5 mm) are important components of the food-chain that supports the epibenthic and benthic invertebrate communities (Fox et al. 1984). Single-celled algae (<0.5 mm), or micro-algae, are another important and abundant part of the benthic food-chain, and may in fact play a larger role than macroalgae. However, identification and characterization of the microalgal communities in the lower Columbia River were not components of this study. Data characterizing the macroalgae communities of the lower Columbia River were limited to studies of the estuary (Simenstad et al. 1990; Fox et al. 1984). Data were not available identifying macroalgae in River Segments 2, 3, or 4.

4.3.5 Aquatic Vascular Plants

Aquatic vascular plants are found along the riverbanks and marsh islands of the lower Columbia River. The dominant aquatic plant communities in the river are affected by salinity and elevation (frequency of inundation) and are typically characterized by several species.

Dominant vascular plants in the marsh communities of River Segment 1 were characterized during habitat studies of the estuary, but only limited data were available identifying the dominant vascular plants in River Segments 2, 3, and 4. Dominant aquatic plants in each river segment were identified based on available information. As with the benthic macroinvertebrate community characterizations, the aquatic vascular plant community characterizations presented below do not preclude the presence of other dominant taxa.

Biological communities are presented by river segment and habitat type. Data indicate that Segments 2, 3, and 4 are characterized by similar habitats and biological communities, therefore, these three river segments are discussed together.

4.4 DOMINANT BIOLOGICAL COMMUNITY DISTRIBUTIONS

Dominant biological communities for each habitat type are presented by river segment.

4.4.1 River Segment 1 (Entrance to RM 38)

4.4.1.1 Fish Communities.

Anadromous Fish--Anadromous fish are found in all pelagic habitat types in River Segment 1. Juvenile and adult fish use the various estuary habitats for spawning, nursery, and foraging during different life stages. The most abundant anadromous species are American shad, chinook salmon, and longfin smelt

Marine Habitat (Entrance to RM 5)--Marine fishes are found in areas of the river influenced by ocean water. All species of marine fish are associated with the pelagic habitat. The dominant marine species occurring in River Segment 1 were Pacific herring and northern anchovy.

Estuarine Habitat (RM 5 to RM 20)--The greatest number of fish species were found in the estuarine habitats. In general, greater fish densities were found in low flow areas within estuarine habitats. The most abundant estuarine species identified in River Segment 1 included shiner perch, Pacific staghorn sculpin, white sturgeon, and starry flounder. Most species were observed in the shallow embayments of Baker Bay, Trestle Bay, and Youngs Bay.

Riverine Habitat (RM 20 to RM 38)--Most of the resident freshwater species found in the riverine habitats of River Segment 1 are associated with the bottom. The riverine backwater channels and bays have greater fish densities than the main channel areas. Peamouth and prickly sculpin are two of the more abundant freshwater species. White sturgeon are also abundant in the riverine habitats of Segment 1.

4.4.1.2 ***Epibenthic Invertebrates.*** Epilithic invertebrate data are presented in Table 3.

Marine Sands Habitat--The marine sands habitat was dominated by copepods. Harpacticoid copepods were the most abundant taxa and included ***Microarthridion littorale, Scottolana canadensis***, and *Tachidius triangularis* *Eurytemora affinis* was the most abundant calanoid copepod. Only one cyclopoid copepod (*Oithona similis*) was abundant in the marine sands habitat. Ostracods and cladocerans were not found in this habitat, but these subclasses are primarily freshwater organisms (Pennak 1978) and therefore are not expected to be abundant in the more saline portions of River Segment 1.

Estuarine Sand and Mud Habitats--Although epibenthic samples were collected from both sand and mud habitats in River Segment 1, the relationship of substrate type to dominant taxa was not presented in the data available for review. As in the marine habitat, the most abundant and diverse taxa found in the estuarine habitats were copepods. Dominant harpacticoid and calanoid copepod taxa in the estuarine habitat were the same as in the marine habitat. Cyclopoid copepods were more taxonomically diverse in the estuarine habitats than in the marine habitat. *Cyclops* spp. were the most abundant. Cladocerans (*Bosmina longirostis* and *Daphnia* spp.) were also found in the estuarine habitats. Although they are primarily freshwater organisms, it is likely that downriver flows contribute to their distribution in the estuarine habitats. Ostracods were not found in the estuarine habitats, but it is likely that some freshwater species are also present in this reach of the river as a result of downriver flows.

Riverine Sand and Mud Habitats--In Segment 1, the most diverse epibenthic communities were found in the riverine reaches, although no information was available to differentiate characteristic community members by substrate type. The dominant species in this habitat were the same as those found in the estuarine habitats. In addition, abundant species occurring in this reach of the river that were not found in the estuarine or marine habitats included the ostracod ***Limnocythere*** spp. and the harpacticoid copepod ***Attheyella*** spp.

4.4.1.3 ***Benthic Invertebrates.*** River Segment 1 of the Columbia River is characterized by marine sands, estuarine sand and mud, and riverine sand and mud habitats. All of the dominant benthic macroinvertebrate taxa identified in the lower Columbia River occurred in River Segment 1. Based on data presented in Holton (1984), Simenstad et al. (1984), Jones et al. (1990), and Fox et al. (1990), dominant benthic taxa were identified for this river segment and are presented in Table 4

Marine Sands Habitat--The marine sands habitat was dominated by several species of Arthropoda (crustaceans), Annelida (polychaetes), and Nemertea (Rhynchocoela). Platyhel-

Table 3. Characteristic epibenthic taxa of the benthic habitat types occurring in River Segment 1 of the lower Columbia River.

Taxa	Habitat Types				
	Marine sands	Estuarine sands	Estuarine muds	Riverine sands	Riverine muds
Phylum ARTHROPODA					
Class CRUSTACEA					
Subclass OSTRACODA					
Limnocythere spp.				P	P
Subclass COPEPODA					
Harpacticoida					
Attheyella spp.				A	A
Bryocamptus spp.				P	P
Ectinosoma spp.	P				
Microarthridion littorale	A	A	A	A	A
Scottolana canadensis	A	A	A	A	A
Tachidius spp.	P	P	P	P	P
Tachidius triangularis	A	A	A	A	A
Cyclopoida					
Cyclops bicuspidatus thomasi		P	P	P	P
Cyclops vernalis		P	P	P	P
Oithona similis	A	A	A	A	A
Paracyclops fimbriatus poppei				P	P
Calanoida					
Acartia clausi	P	P	P		
A longiremis	P	P	P		
Centropages abdominalis	P	P	P		
Eurytemora affinis	A	A	A		
Pseudocalanus elongatus	P	P	P		
Subclass BRANCHIOPODA					
Cladocera					
Bosmina longirostris		P	P	P	P
Daphnia galeata mendotae		P	P	P	P
D. parvula		P	P	P	P
D. pulex		P	P	P	P
D. rosea		P	P	P	P
D retrocurva		P	P	P	P

A: Species abundant.
P: Species present but not abundant.

Table 4. Characteristic taxa of the benthic habitat types occurring in River Segment 1 of the lower Columbia River.

Taxa	Habitat Type				
	Marine sands	Estuarine sands	Estuarine muds	Riverine sands	Riverine muds
Phylum ARTHROPODA					
Class CRUSTACEA					
<u>Amphipoda</u>					
Corophium salmonis		A	A	A	A
Eogammarus confervicolus		A			P
E washingtonianus	P				
Eohaustorius estuarius		A			
Mandibulophoxus uncirostratus	P				
Monoculodes spinipes	P				
Grandiphoxus milleri	A	A			
<u>Decapoda</u>					
Callianassa spp.			P		
Cancer magister	A	P	P		
Crangon franciscorum	A	P			
Pacifastacus trowbridgii					P
<u>Mysidacae</u>					
Archaeomysis grebnitzkii	A				
Neomysis kadiakensis	P				
N mercedis	P				
<u>Cumacea</u>					
Hemileucon spp.			P		
<u>Isopoda</u>					
Gnorimosphaeroma oregonensis		P			
Saduria entomon		P			
Class INSECTA					
<u>Diptera</u> (larvae)					
Ceratopogonidae				P	A
Chironomidae				P	A
Phylum ANNELIDA					
Class POLYCHAETA					
Eteone spp.		P	P		
Hobsonia florida			A		
Mediomastus spp.			P		
Neanthes limnicola		A	A		
Nepthys californiensis		P			
Paraonella platybranchia	A				
Polydora ligni			P		
Pseudopolydora kempi			A		
Pygospio elegans			P		
Spio butleri		P			

Table 4. (Continued)

Taxa	Habitat Type				
	Marine sands	Estuarine sands	Estuarine muds	Riverine sands	Riverine muds
Phylum ANNELIDA (cont.)					
Class POLYCHAETA (cont.)					
Spio filicornis	A				
Class OLIGOCHAETA		A	A		A
Phylum MOLLUSCA					
Class BIVALVIA					
Anodonta oregonensis				P	
A wahlamentensis				P	
Corbicula manilensis				A	A
Macoma balthica			A		
Mya arenaria	P	P	P		
Class GASTROPODA					
Ancyclidae					P
Fluminicola virens					A
Goniobasis plicifera					A
Hydrobia spp.					P
Phylum NEMATODA	P	P	P	P	P
Phylum NEMERTEA (RHYNCHOCOELA)	A	A	P	P	P
Phylum PLATYHELMINTHES					
Class TURBELLARIA	P	P	A	P	P

A: Species abundant.
P: Species present but not abundant.

minthes and Nematoda species were also present in the marine habitat, but these species were not as abundant as the other taxa. Crustaceans were the most taxonomically diverse group and included amphipods, decapods, and mysids *Paraphoxus milleri* (*Gondiphocus grandis*) was the most abundant amphipod species and the mysid *Archeomysis grebnitzkii* was the primary mysid species found in the marine sands habitat. Decapods (Dungeness crab and sand shrimp) were also abundant in the entrance to the river. Two polychaetes (*Paraonella platybranchia* and *Spio filicornis*) were characteristically common in the marine sands habitat, and nemerteans occurred throughout this marine area.

Bivalves, nematodes, and turbellarians (flatworms) were present in the marine sands habitat of River Segment 1, but at reduced densities.

Estuarine Sand Habitats--Commonly occurring taxa in the estuarine sands habitat included Arthropoda (crustaceans), Annelida (polychaetes and oligochaetes), and Nemertea (Rhynchocoela). Less abundant taxa included species of Mollusca, Nematoda, and Platyhelminthes. In general, the estuarine sand habitats were dominated by amphipods, including *Paraphoxis milleri*, *Corophium salmonis*, *Eogammarus confervicolus*, and *Eohaustorius estuarias*. Amphipod communities occurred primarily in the sandy substrates of channels and shoals. Decapods and isopods were also present in the estuarine sands, but were not as abundant as the amphipods. Sand shrimp (*Crangon franciscorum*), which were abundant in the marine sands habitat, are known to migrate upriver into the estuarine reach to about RM 20. Secondary species of importance in the estuarine sand habitats included isopods, nematodes, and flatworms. Nematodes and flatworms had also been identified in the marine sands habitat.

The polychaete community was more diverse in the estuarine sand habitats than in the marine sands habitat, but these taxa were not as numerically dominant in the community as the amphipods. *Neanthes limnicola* was the most abundant polychaete in the estuarine sands habitat. Several other polychaetes were present in this habitat, preferring the sandy channels and shoals. Oligochaetes, as well as nemerteans, were abundant throughout the estuarine sand habitats.

Estuarine Mud Habitats--In the estuarine mud habitats, dominant taxa included Annelida (polychaetes and oligochaetes), Arthropoda (crustaceans), Mollusca (bivalves), and Platyhelminthes (turbellarians). Polychaetes were the most dominant taxa in this habitat. Although the number of polychaete taxa was not as great as that found in the estuarine sands habitat, polychaetes were more abundant in the estuarine muds habitat. *Hobsonia florida*, *Neanthes limnicola*, and *Pseudopolydora kempi* were the most abundant polychaetes and occurred primarily in the muddy substrates of the peripheral bays and tidal flats. Except for

Neanthes limnicola, which was also dominant in the estuarine sand habitats, these polychaetes were present only in the estuarine mud habitats. Several other, less abundant species of polychaetes were also present in the estuarine muds. Oligochaetes and the crustacean amphipod *Corophium salmonis*, which were also abundant in the estuarine sand habitats, were common throughout the muddy substrates of the estuarine reach. Other dominant taxa in this habitat included turbellarians and the bivalve *Macoma balthica.* These species occurred primarily in the peripheral bays

Less abundant species found in the estuarine mud habitats included crustacean decapods and cumaceans, and the bivalve *Mya arenaria* (soft-shell clam). Although Dungeness crab occur primarily in the marine sands habitat, this species is also present in the estuarine mud habitats during periods of low river flows. The cumacean *Hemileucon* spp. was only found in the muddy substrates of the peripheral bays in the estuarine reach of the river. Soft-shell clams were not abundant but were most common in the muddy, tidal flats and minor channels of the peripheral bays in the estuarine reach.

Riverine Sand Habitats--Arthropoda (crustaceans) and Mollusca (bivalves) were the dominant taxa found in the riverine sand habitats. The amphipod *Corophium salmonis*, which was also abundant in both estuarine habitat types, and Asiatic clam (*Corbicula manilensis*, an exotic species) were the most abundant species in the riverine sand habitats.

Other, less common bivalves present in the estuarine sand habitats included two species of freshwater mussels (*Anodonta* spp.) and one species of freshwater clam (*Pissidum* spp). Nematodes, nemerteans, and turbellarians were also present in the sand habitats of the fresh-water reach of River Segment 1, but these species were not abundant.

Riverine Mud Habitats--The most abundant taxa found in the riverine mud habitats included species of Arthropoda (crustaceans and insects) and Mollusca (bivalves and gastropods). As in the riverine sand habitats, *Corophium salmonis* and *Corbicula manilensis* were abundant in the riverine mud habitats. Larval forms of freshwater midges (Chironomidae) and biting midges (Ceratopogonidae; also known as "no-see-ums") were also commonly found in the muddy substrates. Although these dipterans were found only in the riverine mud habitats, it is likely that they are also present in the sandy substrates of the riverine habitat, and could, depending on the specific taxa, reside in the estuary. Gastropods were found only in the riverine mud habitats. The snails *Fluminicola virens* and *Goniobasis plicifera* were abundant in the muddy substrates of the freshwater bays.

Less abundant species of Mollusca found in the riverine mud habitats include freshwater limpets (Ancyclidae) and the freshwater clams *Pissidium* spp., which was also present in the riverine sand habitats. Red crayfish (*Pacifastacus trowbridgii*) were found only in the riverine mud habitats of River Segment 1. Nematodes and turbellaria, which were present or abundant in all other habitat types of River Segment 1, were also found in the riverine mud habitats. These taxa do not appear to be limited by salinity class or substrate type.

*4.4.1.4 **Macroalgae.*** Macroalgae are relatively rare in the estuary and their distribution is patchy. The green macroalga *Enteromorpha intestinalis*, eelgrass (*Zostera marina*), and rock-weed (*Fucus distichus*) were identified in River Segment 1. *Enteromorpha intestinalis* and *Fucus distichus* were associated with frequently inundated marsh sediments. Eelgrass was present on tidal sand flats in Baker and Trestle Bays but it was not widely distributed and its presence is considered rare in the estuary.

*4.4.1.5 **Aquatic Vascular Plants.*** Based on data presented in Fox et al. (1984) and Simenstad et al. (1984), dominant aquatic plants were identified for each of the two marsh habitat types (estuarine marshes and riverine marshes) in River Segment 1. The distribution of aquatic plants in each of these habitat types was further defined by elevation in the marsh. The vascular plants commonly found in the estuarine and riverine marshes are presented in Table 5.

Estuarine Marsh Habitats—In the estuarine marsh habitats, three species of vascular plants dominated the marsh areas that were frequently inundated. Creeping bentgrass, Lyngby's sedge, and common threesquare were the most abundant species and covered the largest areas of the lower-elevation marshes. Other plants more common to the frequently inundated marshes included quillwort, rush, small-flowered forget-me-not, and seaside arrow-grass.

More diverse communities of aquatic vascular plants were found in the less-frequently inundated areas (e.g. high marsh) of estuarine marsh habitat. As in the lower-elevation estuarine marshes, creeping bentgrass and Lyngby's sedge were abundant, but several other plants were also present and abundant in the higher marshes. These other, dominant plants found in the higher marshes included aster, baltic rush, wild pea, and pacific silverweed.

Riverine Marsh Habitats—In general, riverine marsh communities were more diverse and exhibited greater numbers of vascular plant species than the estuarine marsh communities. Frequently inundated areas of riverine marsh were dominated by eight species of vascular plants Water plantain, aster, Lyngby's sedge, tufted hairgrass, waterweed, common monkey—flower, wappato, and water parsnip were commonly found in the lower-elevation marsh areas of the riverine portion of River Segment 1. Lyngby's sedge was also dominant in the estuarine

Table 5. Characteristic aquatic vascular plants of the two marsh habitat types occurring in River Segment 1 of the lower Columbia River.

Species	Scientific Name	Habitat Type	
		Estuarine marsh	Riverine marsh
Creeping bentgrass	*Agrostis alba*	X	X
Water plantain	*Alisma plantago-aquatica*	X	X
Aster	*Aster* spp	X	X
Water stallwort	*Callitriche* spp		X
Yellow marshmarigold	*Caltha asarifolia*		X
Lyngby's sedge	*Carex lyngbei*	X	X
Tufted hairgrass	*Deschampsia caespitosa*		X
Common spikerush	*Eleocharis palustris*	X	X
Waterweed	*Elodea canadensis*		X
Swamp horsetail	*Equisetum fluviatile*		X
Horsetail	*Equisetum* spp.	X	X
Reed fescue	*Festuca arundinacea*	X	X
Boreal bog orchid	*Habenaria dilatata*		X
Quillwort	*Isoetes echinospora*	X	X
Baltic rush	*Juncus balticus*	X	X
Rush	*Juncus oxymeris*		X
Wild pea	*Lathyrus palustris*	X	
Plantain	*Littorella* spp.		X
Lotus	*Lotus corniculatus*		X
Skunk cabbage	*Lysichitum americanum*		X
Mint	*Mentha* spp.		X
Common monkey-flower	*Mimulus guttatus*		X
Small-flowered forget-me-not	*Myosotis laxa*	X	X
Wild parsley	*Oenanthe sarmentosa*	X	X
Reed canarygrass	*Phalaris arundinacea*		X
Mild water pepper	*Polygonum hydropiperoides*		X
Pacific silverweed	*Potentilla pacifica*	X	X
Buttercup	*Ranunculus* spp.		X
Curley-leaved dock	*Rumex crispus*	X	X
Wappato	*Sagittaria latifolia*		X
Common threesquare	*Scirpus americanus*	X	
Small-fruited bulrush	*Scirpus microcarpus*	X	
Bulrush	*Scirpus validus*		X
Water parsnip	*Sium sauve*		X
Seaside arrow grass	*Triglochin maritimum*	X	
Cattail	*Typha angustifolia*	X	
Broad-leaved cattail	*Typha latifolia*	X	X
Giant vetch	*Vicia gigantea*	X	

marsh habitats. Other plants more common to the frequently-inundated marsh habitats were plantain, buttercup, common spikerush, rush, and mild water pepper.

Community diversity in the less-frequently inundated riverine marshes was similar to that found in the frequently inundated riverine marshes. Several species of plants were commonly found throughout both the high and low elevations of riverine marsh, including water starwort, quillwort, small-flowered forget-me-not, and reed canarygrass. In the higher elevations of riverine marsh, creeping bentgrass, waterweed, lotus, common monkey-flower, Pacific silver-weed, wappato, and water parsnip were the most abundant species. Mint and skunk cabbage, which contributed highly to the percent cover of several riverine marsh islands, were found only in the higher elevation riverine marshes.

In both estuarine and riverine marshes, Lyngby's sedge was the most dominant vascular plant. Creeping bentgrass was also widely distributed between the two habitats. Other common species found in both estuarine and riverine marsh habitats included aster, pacific silverweed, and bulrush.

4.4.2 River Segments 2, 3, and 4 (RM 38 to RM 146)

4.4.2.1 Fish Communities. The fish communities of River Segments 2, 3, and 4 were characterized by freshwater and anadromous fish assemblages.

Anadromous Fish—Anadromous species were found in all habitat types in River Segments 2, 3, and 4. The most seasonally abundant anadromous species occurring in all three river segments are chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), chum salmon (*O. keta*), sockeye salmon (*O. nerka*), steelhead (*O. mykiss*), white sturgeon (*Acipenser transmontanus*), American shad (*Alosa sapidissima*), Pacific lamprey (*Lampetra tridentata*) and river lamprey (*L. ayresi*). These species may dominate the fish communities at various times of the year. Anadromous smelt and eulachon were also dominant in River Segment 2.

Riverine Habitat—Freshwater fish assemblages dominated River Segments 2, 3, and 4. Dominant resident species included prickly sculpin (*Cottus asper*), sand roller (*Percopsis transmontana*), peamouth (*Mylocheilus caurinus*), northern squawfish (*Ptychocheilus oregonensis*), and largescale sucker (*Catostomus macrocheilus*). Starry flounder (*Platichthy stellatus*), an estuarine species, are extremely tolerant of low salinities and were also found in Segment 2. Other, less abundant species occurring in Segments 3 and 4 included carp (*Cyprinus carpio*), coast-range sculpin (*Cottus aleuticus*), longnose sucker (*Catostomus*), and speckled dace (*Rhinichthys osculus*).

4.4.2.2 Epibenthic Invertebrates. Data characterizing the epibenthic communities of River Segments 2, 3, and 4 were not available. Several epibenthic species were abundant in the riverine sand and mud habitats of River Segment 1 (i.e., copepods, cladocerans, and ostracods). Because of similarities in habitat, these species are also expected to occur in these upriver, freshwater reaches.

4.4.2.3 Benthic Invertebrates. Riverine sand and mud habitats occur in River Segments 2, 3, and 4. In addition, riverine gravel habitats occur only in Segment 4. Data describing the invertebrate communities in these riverine habitats were limited, and no data were available for the riverine mud habitats in River Segment 4. In general, the biological communities identified in each of the three river segments were similar. Based on data collected as part of a river rock groin construction project (McCabe et al. 1990) and a dredging project study (McCabe and Hinton 1990), dominant benthic invertebrates identified in River Segment 2 are presented in Table 6. Abundant benthic taxa in River Segments 3 and 4 were identified as part of a white sturgeon habitat study (Nigro 1990) and are also presented in Table 6.

Riverine Sand Habitats—Dominant taxa identified in the riverine sand habitats of River Segments 2, 3, and 4 included Arthropoda (crustaceans and insects), Mollusca (bivalves), and Annelida (oligochaetes). *Corophium salmonis*, which was also abundant in the estuarine and riverine habitats of River Segment 1, was abundant throughout the riverine sand habitats in all three river segments. Biting midge larvae (Ceratopogonidae), Asiatic clam (*Corbicula manilensis*), and oligochaetes and were also widely distributed throughout the sand substrates of the upriver segments. In addition, flatworms and midge larvae (Chironomidae) were common in the sandy substrates of River Segments 3 and 4. These species were not found in River Segment 2, but are likely present in this reach of the river as well.

Riverine Mud Habitats—The dominant species of benthic invertebrates in the riverine mud habitats in River Segments 2 and 3 were the same as those found in the riverine sand habitats, except for the oligochaetes. This taxa was found only in the riverine muds of River Segment 2. Flatworms and midge larvae were also not found in the riverine mud habitats of the three river segments, but it is likely that these species are present throughout the muddy substrates of these river segments.

Riverine Gravel Habitats—Riverine gravel habitats only occur in the upper reaches of River Segment 4. Dominant taxa identified in the riverine gravel habitats of River Segment 4, were similar to those abundant in the riverine sand habitats in segments 2, 3, and 4. *Corophium salmonis* was the only species that was not also found in the riverine gravel habitats.

Table 6. Characteristic taxa of the benthic habitat types occurring in River Segments 2, 3, and 4 of the lower Columbia River.

Taxa	Habitat Type: Riverine gravel	Riverine sands	Riverine muds
Phylum ARTHROPODA			
Class CRUSTACEA			
Amphipoda			
Corophium salmonis		2,3,4	2,3,4[a]
Ostracoda		4	4[a]
Class INSECTA			
Diptera (larvae)			
Ceratopogonidae	4	2,3,4	2,3,4[a]
Chironomidae		3,4	
Phylum MOLLUSCA			
Class BIVALVIA			
Corbicula manilensis	4	2,3,4	2,3,4[a]
Phylum ANNELIDA			
Class OLIGOCHAETA	4	2,3,4	2,4[a]
Phylum PLATYHELMINTHES			
Class TURBELLARIA		3,4	

[a] Mud habitat data not available, but species presence likely

4.4.2.4 ***Macroalgae.*** Data were not available identifying macroalgae in River Segments 2, 3, or 4.

4.4.2.5 ***Aquatic Vascular Plants.*** Data are limited regarding the distribution and diversity of aquatic vascular plants specific to River Segments 2, 3 and 4. The major sources of data for these river segments were Tabor (1976) and analysis of National Wetland Inventory maps (USFWS 1986) Tabor surveyed riparian habitats in the Columbia River from its mouth to RM 292. Riparian habitats were identified by dominant vegetative communities (overstory, understory, and herbaceous). Although only limited locations were sampled within River Segments 2 through 4, it is assumed that the observed patterns are prevalent over this entire region

The characteristic zonation, moving from elevations below mean high tide to higher elevations above mean high tide, for riparian habitats in this region was: 1) hardstem bulrush; 2) river bulrush; 3) hardstem bulrush with smartweed and/or arrowhead; 4) hardstem bulrush with aster, water hemlock, rushes, grasses, horsetail, and others; 5) cattail; 6) willow with sedge understory, and 7) cottonwood, willow, and spruce with a dense understory of shrubs, herbs, and grasses. This vertical profile of vegetation was translated into a matrix of emergent, scrub-shrub, and forested wetlands. In general, wetlands in Segment 2 were wider and more interspersed, while wetlands in Segments 3 and 4 were more narrow and linear in juxta-position.

For the purposes of this survey, wetland vegetation was simplified in terms of herbaceous or woody vegetation, rather than by frequency of inundation as detailed for River Segment 1. Table 7 lists dominant or common herbaceous or woody plant species present in River Segments 2 through 4.

Based on total acreage, Segment 2 was dominated by emergent marsh, shrub Pacific willow, and mature willow/cottonwood wetlands. Dominant wetland communities changed in Segments 3 and 4. Forested wetlands, principally mature black cottonwood, Columbia River willow, Pacific willow, and Oregon ash overstories and stinging nettle/blackberry understories, became the dominant riparian communities. The available data does not indicate significant differences in dominant vascular plant communities or species among Segments 2 through 4.

Table 7. Characteristic aquatic vascular plants of the riverine habitats in River Segments 2, 3, and 4 of the lower Columbia River.

Species	Scientific Name	Vegetation Type	
		Woody	Herbaceous
Vine maple	*Acer circinatum*	X	
Big-leaf maple	*Acer macrophyllum*	X	
Northern maidenhair	*Adiantum pedatum*		X
Creeping bentgrass	*Agrostis alba*		X
Red alder	*Alnus rubra*	X	
Red three-awn	*Aristida longiseta*		X
Lady-fern	*Athyrium filix-femina*		X
American wintercress	*Barbarea orthocera*		X
Sloughgrass	*Beckmannia syzigachne*		X
Dull Oregongrape	*Berberis nervosa*	X	
Cheatgrass	*Bromus* spp.		X
Shepherd's purse	*Capsella bursa-pastoris*		X
Sedge	*Carex* spp.		X
Creek dogwood	*Cornus stolnifera*	X	
Hazelnut	*Corylus cornuta*	X	
Black hawthorn	*Crataegus douglasii*	X	
Cyperus	*Cyperus erythrorhizos*		X
Teasel	*Dipsacus syvestris*		X
Spikerush	*Eleocharis* spp.		X
Canada waterweed	*Elodea canadensis*		X
Fireweed	*Epilobium augustifolium*		X
Fiddlegrass	*Epilobium hirsutum*		X
Horsetail	*Equisetum* spp.		X
Mosses	*Fissidens* spp.		X
Oregon ash	*Fraxinus latifolia*	X	
Bedstraw	*Galium* spp.		X
Cleavers	*Galium aparine*		X
Salal	*Gaultheria shallon*	X	
Creeping charlie	*Glecoma hederacea*		X
Bractless hedge-hyssop	*Gratiola ebracteata*		X
Creambush oceanspray	*Holodiscus discolor*	X	
Orange balsam	*Impatiens capensis*		X
Rush	*Juncus* spp.		X
Northern bugleweed	*Lycopus uniflorus*		X
Moneywort	*Lysimachia nummularia*		X
Skunk cabbage	*Lystichitum americanum*		X
Yellow monkey-flower	*Mimulus guttatus*		X
Miner's lettuce	*Montia perfoliata*		X

Table 7 (Continued).

Species	Scientific Name	Vegetation Type	
		Woody	Herbaceous
Candy flower	*Montia sibirica*		X
Small-flowered forget-me-not	*Myosotis laxa*		X
Pacific water-parsley	*Oemanthe sarmentosa*		X
Reed canarygrass	*Phalaris arundinacea*		X
Sitka spruce	*Picea sitchensis*	X	
Smartweed	*Polygonum coccineum*		X
Sword fern	*Polystichum munitum*		X
Black cottonwood	*Populus trichocarpa*	X	
Silverweed	*Potentilla* spp.		X
Buttercup	*Ranunculus* spp.		X
Poison oak	*Rhus diversiloba*	X	
Coast black gooseberry	*Ribes divaricatum*	X	
Yellowcress	*Rorippa* spp.		X
Wild wood rose	*Rosa gymnocarpa*	X	
Blackberry	*Rubus* spp.	X	
Dock	*Rumex* spp.		X
Columbia River willow	*Salix fluviatilis*	X	
Hooker's willow	*Salix hookeriana*	X	
Pacific willow	*Salix lasiandra*	X	
Bulrush	*Scirpus* spp.		X
Arrowhead groundsel	*Senecio triangularis*		X
Snowberry	*Symphoricarpus albus*	X	
Western red cedar	*Thuja plicata*	X	
Western starflower	*Trientalis latifolia*		X
Western hemlock	*Tsuga heterophylla*	X	
Broad-leaved cattail	*Typha latifolia*		X
Stinging nettle	*Urtica dioica*		X
Common mullein	*Verbascum thapsus*		X
Vetch	*Vicia* spp.		X

5.0 BIOLOGICAL INDICATORS

5.1 OVERVIEW

"In order to be able to choose indicators we must first determine the question of what is to be indicated" (Hellawell 1986). This task is often difficult and complex. An indicator quantifies the magnitude of stress, degree of exposure to the stressor, or degree of ecological response to the exposure (Hunsaker and Carpenter 1990). This broad definition includes the use of biological, habitat, and chemical indicators for assessing environmental quality. This report focuses only on the use of biological indicators for assessing water and sediment quality and associated biological impacts that are appropriate for the Columbia River project.

In the lower Columbia River there are many different sources and types of contaminants as shown in Table 8. The information in this table was compiled from the Task 2 Report and is based on limited historical data. While not all-inclusive due to data gaps, it clearly demonstrates the variety of the potential pollutants of concern in the lower Columbia River. Although this list of potential pollutants is extensive, these pollutants can be categorized and matched with appropriate biological indicators for meaningful environmental monitoring.

There are two types of biological indicators: exposure indicators and response indicators. Exposure indicators establish that organisms were subjected to a potentially deleterious stressor and quantify the extent of that exposure. However, exposure indicators cannot be used to detect deleterious effects. In contrast, response indicators demonstrate that deleterious effects. are occurring, but are usually limited in their ability to identify the cause of the effect. Thus, in most instances, both response and exposure indicators are needed to establish that effects are occurring and to identify the cause of those effects.

A list of biological endpoints and their applicability by contaminant class are presented in Table 9. Specific indicators may respond to few or many factors. The indicators listed in Table 9 are intended to provide approaches for as many of the potential water-quality problems as possible.

There are two basic approaches applicable to biological monitoring of water quality in the lower Columbia River. The first is the use of measurements of organisms inhabiting the river as biological indicators. *In situ* measurements provide a direct assessment of environmental

Table 8. Summary of the pollutants of concern for the lower Columbia River.

<u>Point Source</u>

Municipal Wastewater
- Chlorine
- nutrients
- pathogens
- metals
- organics

Pulp/Paper Mills
- copper
- lead
- nickel
- chlorinated organics
- halogenated organics
- biocides
- pathogens

Aluminum Industry
- aluminum
- benzo(a)pyrene
- fluoride
- antimony
- nickel
- chromium

Wood Industry
- oil & grease
- phenols
- creosote
- copper
- cadmium
- chromium
- zinc

Seafood Processing
- oil & grease
- nutrients

Power Generating
- Temperature
- sodium
- sulfate
- aluminum
- boron
- oil & grease
- copper
- iron

Chemical Industry
- oil & grease
- toxic organic coumpounds
- cyanide
- copper
- nickel
- zinc
- magnesium
- cobalt
- arsenic
- chromium
- lead
- cadmium
- tin
- nutrients

Miscellaneous Industry
- heat
- oil & grease
- phenol
- chromium
- sulfide

Agricultural Facilities
- settleable solids
- chemicals from fish rearing ponds

Table 8. (Continued)

Non-Point Source

Forests - Growing, Harvesting, Processing Timber
- logging activities
- clearcutting practices
- road building & maintenance
- reforestation
- slash burning
- fertilizers
- herbicides/pesticides

Agriculture Practices
- animal wastes
- access to streams by livestock
- poor pasture practices
- excessive chemical applications

Urban Activities
- automotive products
- household & garden chemicals
- pet wastes
- septic system products
- new construction
  - -sediments
  - -nutrients
  - -pathogens
  - -heavy metals
  - -petroleum products
  - -pesticides
  - -insecticides
  - -fertilizers

Other Sources/Activities

Marinas & moored boats
- detergents & paints
- solvents
- chemicals
- gasoline
- diesel fuel
- raw sewage
- petroleum products

Leaking Storage Tanks
- flammables, combustibles, toxics

Highways & Railroads
- petroleum products
- gasoline
- diesel fuel

Urban, Stormwater & CSO Runoff

no data available

Loading from Tributaries
- pesticides
- priority organics
- ammonia
- nutrients
- siltation
- organic enrichment/dissolved O_2
- thermal modifications
- flow alteration
- pathogens
- suspended solids
- noxious aquatic plants
- filling & draining

Atmospheric Deposition

no data available

Table 8. (Continued)

In-Place Pollutants

Hazardous Waste Sites

Ostrander Rock Disposal Site
- naphthalene
- pentachlorophenol
- 1,1,2 trichloroethane
- manganese
- isopropanol
- trifluoroethane

Radakovich landfill
- arsenic
- cadmium
- mercury

Reynolds Metals Company
- fluoride
- cyanide

Weyerhauser Company
- mercury

Longview Fibre
- lead
- chromium
- barium
- arsenic

ALCOA
- cyanide
- fluoride

Columbia Marine Lines
- benzene
- ethylbenzene
- toluene
- naphthalene
- 1,1,1,-trichloroethane
- 1,1-dichloroethane
- cyanide

Burlingtron Northern Railyard
- lead
- acetone
- 2-methyl naphthalene
- PCB
- pesticides
- chromium
- cadmium
- cyclohexane
- fluroanthene
- pyrene
- chrysene
- acetone
- toluene
- naphthalene
- phenanthrene
- fluorene
- diesel

Columbia Steel
- pentachlorophenol
- creosote
- diesel

Port of Vancouver
- lead
- arsenic
- cadmium
- copper

Malarkey Roofing
- pcb
- cyanide
- toluene
- lead compounds
- arsenic compounds
- mercury
- zinc
- semivolatiles
- cadmium
- chromium
- pyrene

Allied Plating
- chromium
- copper
- nickel
- zinc
- iron
- arsenic
- barium
- cadmium
- lead
- mercury
- beryllium
- cyanide
- sulfates
- chlorides
- phenols
- radioactivity
- methylene chloride

Table 8. (Continued)

Frontier Hard Chromium
- chromium

Custom Care Cleaners
- acetone
- chlorobenzene
- ethylbenzene
- toluene
- xylene

Tidewater Barge Lines
- oil & grease
- heavy metals

Nu Way Oil
- 1,1,1-trichloroethane
- bromomethane
- chloromethane
- dichloroethane
- dichloroethene
- methyl ethyl ketone
- 1,1,2-trichloroethene
- o-xylene
- ethyl benzene
- methyl isobutyl ketone
- toluene
- tetrachloroethene
- 2-methylnaphthalene
- phenanthrene
- naphthalene
- phenol
- arochlor 1260
- arochlor 1242
- pentachlorophenol
- o-cresol
- 2,4-dimethylphenol
- p-resol
- bis(2-chloroethyl)ether
- antimony
- arsenic
- cadmium
- chromium
- copper
- lead
- nickel
- selenium
- thalium
- zinc
- cyanide
- silver
- mercury
- beryllium
- methylene chloride
- 1,1-dichloroethane
- 1,1-dichloroethene
- trans-1,2-dichloroethane
- chloroform
- carbon tetrachloride
- trichloroethene
- 4-methyl-2-pentanone
- xylenes
- 4-methylphenol
- bis(2-ethylhexyl)phthalate

East Multnomah County
- tetrachloroethylene
- trichloroethylene

Landfills

Astoria Landfill
- iron
- manganese

Coal Creek Landfill
- chromium

Cowlitz County Municipal
- iron
- manganese

Santosh Landfill
- iron
- chlorine
- sulfate
- ammonia

St. Johns Municipal
- iron
- manganese
- total phosphorus
- total nitrogen
- un-ionized ammonia
- copper
- cadmium
- zinc
- lead

Hamilton Island
- cadmium
- copper
- chromium
- lead
- zinc
- benzoic acid
- toluene

Table 9. Biological endpoints used to assess various contaminant effects.

	Metals	TBT	Volatile Organics	Phenols	PAH	Phthalate Esters	Chlorinated Hydrocarbons	Chlorinated Pesticides	PCBs	Dioxin/ Furan	Fluoride	Nutrients	Temperature
EXPOSURE INDICATORS													
BIOCHEMICAL													
Bioaccumulation	X	X		X	X	X	X	X	X	X	X		
Enzyme Production (MFO)	X						X	X					
Protein Production (metallothioneins)	X												
RESPONSE INDICATORS													
INDIVIDUAL													
Reproductive Effects	X	X		X		X	X	X	X			X	X
Genetic Aberrations	X											X	
Growth/Development	X	X	X	X	X	X	X	X	X	X	X	X	X
Lesions and Neoplasms					X		X		X				
Morphological Abnormalities		X											
Survival	X	X	X	X	X	X	X	X	X	X	X	X	X
Abundance	X	X						X				X	
Age Structure	X	X						X				X	
Growth Rates	X							X				X	
COMMUNITY													
Diversity	X					X	X	X				X	X
Community Composition	X					X	X	X				X	X
Total Abundance	X							X				X	X
Colonization Rates	X							X				X	X

conditions. This approach is limited, however, because suitable species to support a given test cannot always be found in the system, or because natural variability in the test species substantially reduces the power of the indicator to demonstrate an exposure or effect. A second approach uses surrogate organisms in *in situ* or laboratory tests to provide indirect assessments of exposure and response. Use of *in situ* or laboratory bioassays provide the advantage of experimental control. Selected endpoints can be monitored more easily. In addition, some indicators can only be used under controlled conditions. However, the controlled test results may not directly relate to responses in the natural system.

The decision to use one approach or the other depends upon the contaminant in question and the potential indicator organism. Field studies may provide the realism often absent in laboratory studies. However, interpretation of results is often compromised because of a lack of control of experimental conditions. Under these circumstances, a laboratory or *in situ* bioassay may be preferred. In many cases, the endpoints measured under controlled experimental conditions are similar to those measured in wild organisms and include both mortality and sublethal effects such as alterations in growth, development, reproduction, biochemistry, physiology, and behavior. *In situ* bioassays may be preferred because they combine the benefits of both field studies and laboratory studies.

5.2 EXPOSURE INDICATORS

The occurrence and magnitude of exposure to a physical, chemical, or biological stress can be measured by several biochemical endpoints. Bioaccumulation in various organisms is the only biological indicator that is consistently categorized as an exposure indicator. Other biochemical measures, including enzyme and protein production, can technically fall into either category of indicator. Exposure indicators are diagnostic when used in conjunction with response indicators.

5.2.1 Bioaccumulation

Bioaccumulation is an exposure indicator; it is a phenomenon, not an effect. Many freshwater and marine organisms have the potential to accumulate contaminants directly from the water and sediments or from consumption of food containing the contaminants. The degree of accumulation depends on the availability and persistence of the compound in the environment. Bioaccumulation can only occur if the rate of uptake exceeds its rate of elimination.

5.2.2 Biomarkers

Biomarkers are defined as "...measurements that indicate, in biochemical or cellular terms, exposure of an organism to a chemical" (Hunsaker et al. 1990). Few biomarkers have been consistently applied in environmental monitoring because many protocols are currently being developed and refined. However, they are considered one of the most promising categories of indicators and therefore should remain candidate indicators for the lower Columbia River.

Biomarkers include a diverse array of physiological components including DNA, blood chemistry assays, metabolites of xenobiotics, the cytochrome P-450 monooxygenases systems (MFO), and metallothioneins (Hunsaker et al. 1990; McCarthy and Shugart 1990).

While there are numerous biomarkers to choose from, two of the most commonly used and accepted biomarkers are metallothioneins and MFOs. Metallothionein, a protein found in fish, has been used to indicate exposure to various metals, including cadmium, copper, mercury, silver and zinc. The discovery of proteins similar to metallothionein in invertebrates such as oysters, mussels, clams, and crabs indicates that marine invertebrates possess mechanisms similar to those of vertebrates with respect to the intracellular binding of metals (Roesijadi 1980).

Enzyme production has been used as an indicator of exposure to organic compounds (McCarthy and Shugart 1990). Hepatic mixed function oxygenase (MFO) enzyme activity can increase in response to petroleum hydrocarbons, PCBs and other chlorinated organic compounds.

5.3 RESPONSE INDICATORS

Response indicators are used to demonstrate that effects have occurred as a result of exposure to environmental stresses. Indicators based on all levels of ecological organization, from the individual to the community, can be used to measure response. There are numerous types of response indicators depending on the contaminant in question, the purpose of the indicator and system of interest. Commonly measured endpoints in individual organisms include alterations in reproduction, development, growth, histology, morphology and survival. Population or community parameters that can be measured and used as biological indicators include abundance, age structure, growth rates, composition, and process rates.

5.3.1 Individual Response Indicators

The success of a population depends upon the ability of individuals within the population to successfully reproduce. Organisms that are in gametogenic production are often considered to be highly sensitive to environmental changes. Egg production, percent fertilization, brood size, and hatching success are just a few of the reproductive variables used as endpoints in biological monitoring (McKim 1985; U S. EPA 1988a).

Growth represents a graded response to environmental conditions that can be quantified through repetitive, non-destructive measurements. Reduced growth is a response often observed after exposure to adverse environmental conditions. Reduced growth has been measured in numerous organisms and has been associated with exposure to sublethal concentrations of various contaminants (Black 1973; Anderson 1977; Appeldoorn 1981; Fritz and Lutz 1986; Ropes 1987; Stromgren 1987).

Changes in cellular or tissue structure that are used as response indicators include presence of lesions, neoplasms, skeletal abnormalities, and developmental abnormalities. Many organic and inorganic environmental contaminants, including insecticides, petroleum compounds, PCBs, and tributyltin, have been found to cause cellular and tissue changes in both fish and invertebrates (Meyers and Hendricks 1985) Hepatic neoplasms and other diseases have been associated with elevated concentrations of aromatic hydrocarbons, PCBs and chlorinated butadienes (Malins et al. 1988). There is a large array of contaminants from industrial, agricultural and municipal sources that can induce skeletal abnormalities, such as vertebral lesions in fish (Mehrle and Mayer 1985). For example, vertebral damage and lesions were induced by exposure to organophosphate pesticides (McCann and Jasper 1972), metals such as zinc, cadmium, and lead (Bengtsson 1975), and crude oil (Linden 1976). Developmental abnormalities can also occur in juvenile fish and invertebrates. Bivalve larvae abnormalities have been commonly used in regulatory applications throughout the United States (APHA 1985; Tetra Tech 1986).

Reduction in survival is a biological response that integrates exposure to environmental concentrations of contaminants. It is one of the least sensitive endpoints because mortality is an all-or-nothing response. This endpoint has the most practical applications in laboratory and *in situ* tests. However, important information can be gained from monitoring survival of selected organisms, especially where toxicity responses are well documented.

5.3.2 Population Response Indicators

A biological population is defined as a group of individuals of a single species that reside in a distinct geographic area. Populations are not commonly used in environmental monitoring due to insufficient information on the population dynamics or degree of natural variability of most plant and animal species. However, some populations are useful for environmental monitoring by assessing abundance, age structure, growth rates, and sex ratios (Hellawell 1986).

5.3.3 Community Response Indicators

A biological community is an assemblage of plants and animals that reside in a particular place. Within environmental monitoring programs, a subset of the community is often used, (e.g., invertebrates). Decreases in the number of taxa present, shifts in the makeup of the community membership, increases in the number of opportunistic taxa, changes in abundance, and alterations in recruitment have all been documented community responses to environmental stresses. Accordingly, community response indicators that are commonly measured include diversity, composition, abundance, and colonization rates (U.S. EPA 1988b). While communities naturally exhibit a high degree of variability, sampling of background or control areas can allow toxic or other effects to be identified. Community response indicators have been widely used in pollution impact studies and long-term monitoring programs in aquatic environments.

6.0 BIOLOGICAL INDICATORS FOR THE LOWER COLUMBIA RIVER

The lower Columbia River is a highly complex system ranging from riverine freshwater to marine environments with a diverse array of stressors that can elicit a wide variety of responses in the biological components of the system. No one indicator will adequately address all needs in all areas of concern. Selection of biological indicators is based on contaminants of concern, habitat types, characteristic biological communities, established endpoints, and goals of the program.

Characteristic biological communities in the lower Columbia River include pelagic and demersal fishes, benthic and epibenthic macroinvertebrates, and algae and vascular aquatic plants. Major taxonomic groups that may provide indications of exposure and response are presented in Table 10.

6.1 CRITERIA AND SELECTION OF TARGET ORGANISMS

There are many important considerations when selecting appropriate organisms to be used in biological monitoring programs. Hellawell (1986) suggests that ideal characteristics of target organisms include:

- cosmopolitan distribution,
- well documented taxonomic classification,
- economic importance,
- documented capacity to bioaccumulate or respond to contaminants,
- suitable for laboratory use,
- readily available or easily collected.

Fish are widely used in biological monitoring programs for a variety of environmental contaminants. Many species of fish have broad distributions and occupy a variety of habitats. Protocols for many species are well developed for use as both exposure and response indicators. Exposure to metals and chlorinated organic compounds can be quantified with bioaccumulation and enzyme production measurements in individual fish. Histological and morphological changes are most useful in demersal fishes. Responses in these organisms can be more closely correlated with magnitude of sediment contamination if they are in direct contact with bottom substrates. Population variables for both pelagic and demersal fish provide a general assessment of water quality conditions but cannot delineate contaminant-specific effects.

Benthic invertebrates are very important in biological monitoring because they can show cumulative effects of both past and present exposures, and responses are indicative of site-specific conditions. Benthic invertebrates are found in all habitats in the Columbia River and a few species have cosmopolitan distributions. Protocols for field, *in situ* and laboratory tests are well developed and have been widely applied in environmental monitoring. Reproductive impairment, growth, and survival in surrogate invertebrate taxa have successfully been used in both in-situ field and laboratory bioassays to provide indirect measures of environmental conditions. Polychaetes, crustaceans, and bivalves have been used to assess the effects of many contaminants, including metals, PCBs, pesticides and other chlorinated organic compounds. Indicators such as diversity, composition, and abundance of pollution-sensitive taxa are most useful as direct measures of benthic and epibenthic community responses to contaminant exposure. Bioaccumulation in selected species has also been extensively used as a monitoring tool. Individual taxa such as mussels and crabs have been commonly used as indicators of exposure to both metals and organic compounds.

Algae, commonly used in eutrophication studies, have limited use in monitoring the presence or effects of chemical contaminants. Reproductive impairment and growth are potential response endpoints measured in the laboratory. Aquatic macrophytes are typically used in eutrophication assessments or metals contamination studies. They provide a qualitative assessments of population or community effects but have not had broad application in environmental monitoring.

Generally, bacterial populations are the most insensitive organisms to contaminants. There are very few reported cases of chemical toxicity to microorganisms at a concentration below that which adversely affects higher animals (Pritchard and Bourquin 1985). Bacterial tests, commonly used as indicators of public health problems, have been restricted to that phase of the project.

6.2 CANDIDATE BIOLOGICAL INDICATORS

Historically, biological pollution monitoring has focused on the use of a single species to quantify water quality problems. A more recent approach incorporates multiple measures of both exposure and response. Because of the combination of varying habitat and associated biological communities in the lower Columbia River, and the fact that contaminants may vary substantially in form and location, no single indicator or approach may work in all areas. Therefore, a suite of species or approaches provides a more thorough evaluation of environmental conditions and is recommended for monitoring the biological health of the lower Columbia River Within the lower Columbia River, fish and benthic invertebrates have the broadest distribution and are therefore recommended as target organisms a long-term monitoring program. It is not possible at this stage of Task 4 to state which organisms will be most appropriate for the lower Columbia River. In addition, water quality conditions can be described on either a site-specific or system-wide basis depending on the particular taxa selected

Fish populations can be used in large scale determinations of contaminant effects in the lower Columbia River system. A number of fish species have a wide distribution and are tolerant to the range of salinities encountered in the lower river. Species recommended as target organisms include both demersal (starry flounder, sturgeon, and cottids) and pelagic (salmonids, perch, carp, and peamouth) taxa. These taxa can be used to measure both exposure and response endpoints. While all recommended taxa likely feed on benthic invertebrates, only demersal fish are in direct contact with bottom sediments and may be more indicative of exposure to site-specific contaminants. Because of their ability to metabolize some organic compounds (e.g., PAHs), fish are better suited as indicators of metal, chlorinated hydrocarbon (e.g., PCBs and pesticides) and radionuclide accumulation. Measures of enzyme production (e g., MFO) in fish can indicate exposure to other classes of organic compounds. Metallothionein production in fish can indicate exposure to selected metals (e.g., cadmium, copper, gold, mercury, silver and zinc).

Salmonid bioassays would be most useful for measuring site-specific, point-source effects in the lower Columbia River. Protocols are well developed for using juvenile salmonids to measure acute toxicity both metals and organics under laboratory conditions. Salmonids can also be used for *in situ* measures of acute contaminant effects. Demersal fish species such as starry flounder are frequently used as indicators of sublethal responses to contaminants (Spies et al. 1990).

Benthic invertebrates are recommended as indicators of both exposure and response. Community structure, abundance and distribution of sensitive and tolerant taxa can provide information on effects of chronic exposure to contaminants in the river. These endpoints should be included in any long-term monitoring program. To refine these community level measurements, endpoints using individual taxa are recommended.

Polychaete and bivalve taxa can be used as exposure indicators by measuring contaminant concentrations in whole body tissues. Because of the sessile nature of these taxa, they can provide site-specific information about exposure not possible with more motile organisms. Use of bivalves in bioaccumulation studies has had broad application throughout the United States. *In situ* measurements of exposure using mussels and clams are highly recommended. In addition, laboratory tests of growth and reproductive impairment in mysid and polychaete species can be used to assess the overall water quality in the lower Columbia River.

These are only preliminary recommendations for biological indicators. Additional data on the concentrations and spatial distribution of contaminants in sediments and water, concentrations of contaminants in fish and invertebrate, and benthic invertebrate community data will be collected during the field survey as part of Task 6 of the Bi-State Program. Selection of biological indicators will be refined and this information will be incorporated in the final monitoring program recommendations.

7.0 SUMMARY

The lower Columbia River can be characterized as a highly dynamic system consisting of a freshwater riverine reach and an estuarine/marine reach. The biological communities present in the river are diverse in response to the wide variety of environmental conditions Biological communities in the lower river can be characterized according to sediment type, flow characteristics and salinity. Representative biological communities include pelagic and demersal fishes, benthic and epibenthic macroinvertebrates, and algae and vascular aquatic plants. The greatest number of species and habitat types occur in the estuary, or the first river segment.

There is a myriad of pollution sources affecting the lower Columbia River. These include urban and stormwater runoff, landfills and hazardous waste sites, marinas, and industries such as wastewater treatment facilities, agricultural establishments, wood processing operations, power plants, and pulp and paper mills. The pollutants that may occur in the river include trace elements, petroleum products, pesticides, and volatile organics.

It is necessary to use an integrated approach to monitor the biological health of the lower Columbia River because of the complexity of the river itself and the diversity of potential contaminants. This approach should combine both biological and chemical measurements for a thorough appraisal of environmental conditions. Biological assessment of water quality can be accomplished through the use of biological indicators. As no one biological indicator will adequately address all needs in all areas of concern, the use of several species and their associated endpoints for both exposure and response indicators is preferred. Using a suite of species provides a more thorough evaluation of environmental conditions and is recommended for monitoring the biological health of the lower Columbia River.

Within the lower Columbia River, fish and benthic invertebrates have the broadest distribution. These organisms are primary candidates for use in a long-term biological monitoring program. Assessments performed at the individual, population or community level will provide both site-specific and systemwide information. Valuable information will be gained through the use of field, *in situ*, and laboratory bioassays. By using this approach, water quality problems in the lower Columbia River can be identified to allow effective management of all Columbia River resources and beneficial uses.

8.0 REFERENCES

Anderson, J W. 1977 Effects of petroleum hydrocarbons on the growth of marine organisms. Rapp. P -v. Reun. Cons. Int. Explor. Mer. 157-165.

APHA. 1985. Standard methods for the examination of water and wastewater 16th Edition. 1268 pp.

Appeldoorn, R. S. 1981. Response of soft shell clam Mya arenaria growth to onset and abatement of pollution. J. Shellfish Res. 1(1):41-50.

Bengtsson, B E. 1975. Vertebral damage in fish induced by pollutants. In: J. H. Koeman and J. J. T. W. A. Strick (Eds.), Sublethal Effects of Toxic Chemical on Aquatic Animals, Elsevier, New York, pp. 23-30.

Black, R. 1973. Growth rates of intertidal molluscs as indicators of effects of unexpected incidents of pollution. J. Fish. Res. Board Can. 30:1385-1388.

Bottom, D.L. and K.K. Jones. 1990. Species composition, distribution, and invertebrate prey of fish assemblages in the Columbia River Estuary. Prog. Oceanog. 25:243-270.

Bottom, D.L., K.K. Jones and M.J. Herring. 1984. Fishes of the Columbia River. Final report on the fish work unit of the Columbia River Estuary Data Development Program. Oregon Department of Fish and Wildlife, Portland, OR. 113 pp. + appendices.

Fox, D.S., S. Bell, W. Nehlsen and J. Damron. 1984. The Columbia River Estuary atlas of physical and biological characteristics. Columbia River Estuary Study Taskforce, Astoria, OR. 87 pp. + appendices.

Fritz, L. W. and R. A. Lutz. 1986. Environmental perturbations reflected in internal shell growth patterns of *Corbicula fluminea*. Veliger 28(4):401-417.

Hellawell, J.M. 1986. Biological indicators of freshwater pollution and environmental management. Elsevier Applied Science Publishers. New York. 546 pp.

Holton, R.L. 1984. Benthic infauna of the Columbia River Estuary. Final report on the benthic infauna work unit of the Columbia River Estuary Data Development Program. College of Oceanography, Oregon State University, Corvallis, OR. 179 pp. + appendices.

Hunsaker, C.T. and D.E. Carpenter, eds. 1990. Ecological Indicators for the Environmental Monitoring and Assessment Program. EPA 600/3-90/060. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC.

Jay, D.A., B.S. Giese and C.R. Sherwood. 1990. Energetics and sedimentary processes in the Columbia River Estuary. Prog. Oceanog. 25:157-174.

Jones, K.K., C.A. Simenstad, D.L. Higley, and D.L. Bottom. 1990. Community structure, distribution and standing stock of benthos, epibenthos and plankton in the Columbia River Estuary. Prog. Oceanog. 25:211-242.

Linden, O. 1976. The influence of crude oil and mixtures of crude oil dispersants on the ontogenic development of Baltic herring, *Clupea harengus membras* L. Ambio 5:136-140.

McCabe, G.T., S.A. Hinton, R.L. Emmett, and R.J. McConnell. 1990. Benthic invertebrates, sediment characteristics, and demersal fishes off Cottonwood Island, Columbia River, before and after rock-groin construction, 1987-1988 Final Report. 16 pp. + appendices.

McCabe, G.T and S.A. Hinton. 1990. Benthic infauna and sediment characteristics in the Columbia River near Westport, Oregon, August 1989 Final Report. 14 pp.

McCann, J. A and R. L. Jasper. 1972 Vertebral damage to blue-gills exposed to acute levels of pesticides Trans. Am. Fish. Soc. 101:317-322.

McCarthy, J. and L. R. Shugart. 1990. Indicator fact sheets for biomarkers. In: C. T. Hunsaker and D. E. Carpenter (Eds.), Environmental Monitoring and Assessment Program - Ecological Indicators. United States Environmental Protection Agency, Office of Research and Development. EPA/600/3-90/060. pp. G7-G30.

McKim, J. M. 1985. Chapter 3: Early life stage toxicity tests. In: G. M. Rand and S. R. Petrocelli (Eds.), Fundamentals of Aquatic Toxicology. Hemisphere Publishing Corporation, Washington, pp. 58-95.

Mehrle, P. M. and F. L. Mayer. 1985. Chapter 10: Biochemistry/Physiology. In: G. M. Rand and S. R. Petrocelli (Eds.), Fundamentals of Aquatic Toxicology. Hemisphere Publishing Corporation, Washington, pp. 264-282.

Meyers, T. R. and J. D. Hendricks. 1985. Chapter 11: Histopathology. In: G. M. Rand and S. R. Petrocelli (Eds.), Fundamentals of Aquatic Toxicology. Hemisphere Publishing Corporation, Washington, pp. 283-334.

Nigro, A.A. (ed.). 1990. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam. Annual progress report, April 1989 -March 1990. Oregon Department of Fish and Wildlife, Portland, OR.

Pennak, R.W. 1978. Fresh-Water Invertebrates of the United States. 2nd edition. New York, NY: John Wiley & Sons. 803 pp.

Pritchard, P. H. and A. W. Bourquin. 1985. Chapter 8: Microbial toxicity studies. In: G. M. Rand and S. R. Petrocelli (Eds.), Fundamentals of Aquatic Toxicology. Hemisphere Publishing Corporation, Washington, pp. 177-217.

Roesijadi, G. 1980. The significance of low molecular weight, metallothionein-like proteins in marine invertebrates: Current status. Mar. Environ. Res. 4:167-179.

Ropes, J. 1987. Age and growth, reproductive cycle and histochemical tests for heavy metals in hard clams *Mercenaria mercenaria* from Raritan Bay, USA, 1974-1975. U. S. Natl. Mar. Fish. Serv. Fish. Bull 85(3):653-662.

Simenstad, C., D. Jay, C.D. McIntire, W. Nehlsen, C. Sherwood and L. Small. 1984. The dynamics of the Columbia River Estuary, Vol. II. Columbia River Estuary Study Taskforce, Astoria, OR. pp. 341-695.

Simenstad, C.A., L.F. Small, and C.D. McIntire. 1990. Consumption processes and food web structure in the Columbia River Estuary. Prog. Oceanog. 25:271-297

Snyder, G.R. and R.J. McConnell. 1970. Subsurface water temperature of the Columbia River at Prescott, Oregon (River Mile 72), 1968-69: Technical advisory committee Columbia River thermal effects study. Bureau of Commercial Fisheries, Seattle, WA. 8 pp.

Stromgren, T. 1987. Effect of oil and dispersants on the growth of mussels. Mar. Environ. Res. 21:239-246.

Tabor, J.E. 1976. Inventory of riparian habitats and associated wildlife along the Columbia River, Vol 2A Oregon Cooperative Wildlife Research Unit, Oregon State University, Corvallis, OR. 861 pp

Tetra Tech. 1986. Recommended protocols for conducting laboratory bioassays on Puget Sound sediments Final Report TC-3991-04.

US EPA. 1988a. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to marine and estuarine organisms. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory, EPA/600/4-87/028.

US EPA. 1988b. Review of ecological risk assessment methods. United States Environmental Protection Agency, Office of Policy, Planning and Evaluation, EPA/230-10-88-041.

USFWS. 1986. Miscellaneous National Wetlands Inventory maps. 7.5 minute series.

APPENDIX A

APPENDIX A

GLOSSARY OF TERMS

Acute - Occurring over a short period of time; used to describe brief exposures and effects which appear after exposure. Does not refer to severity.

Alga (plural, algae) - simple plant form having no true roots, stems, or leaves. Algae range in size from microscopic single-celled plants to large seaweeds.

Anadromous - pertaining to fish which hatch in fresh water, migrate to ocean waters where they mature, and return to fresh water to spawn.

Benthic - relating to or occurring at the bottom of a body of water; bottom dwelling.

Bioaccumulation - general term describing a process by which chemicals are taken up by organisms from water directly or through consumption of food containing the chemicals.

Bioassay - a test used to evaluate the relative potency of a chemical by comparing its effect on a living organism with the effect of a standard preparation on the same type of organism.

Bioconcentration - The accumulation of a chemical in tissues of an organism to concentrations that are greater than the concentrations in the medium in which the organism resides.

Biological Indicator - A characteristic of the environment that, when measured, quantifies the magnitude of stress, habitat characteristics, degree of exposure to a stressor, or degree of ecological response to the exposure.

Biomarker - Measurements that indicate, by biochemical or cellular changes, exposure of an organism to a chemical.

Biomonitoring - use of living organisms as "sensors" in water quality surveillance to detect changes and to indicate whether aquatic life may be endangered.

Channel - the deeper part of a river, harbor, or strait.

Chronic - Occurring over a long period of time, either continuously or intermittently; used to describe ongoing exposures and effects that develop only after a long exposure.

Classification - A hierarchical partitioning of ecological resource categories based on increasing similarity of specifically defined attributes.

Community - an association of plants and animals in a given area or region in which the various species are more or less interdependent upon each other.

Demersal - pertaining to an organism, such as a fish, living close to or on the bottom of a body of water; pertaining to the habitat close to or on the bottom.

Ecosystem - A local complex of interacting plants, animals, and their physical surroundings which is generally isolated from adjacent systems by some boundary, across which energy and matter more; examples include a watershed, an ecoregion, or a biome.

Emergent wetland – characterized by erect, rooted, herbaceous hydrophytes, excluding mosses and lichens. Wetland usually dominated by perennial plants.

Epibenthic – pertaining to the habitat that includes the sediment surface and the overlying one meter of water, or to the organisms that live in this habitat

Estuary – the region, usually in a river, where fresh river water mixes with saline ocean water

Eutrophic – a body of water, generally shallow, that is rich in dissolved nutrients but deficient in oxygen.

Exposure Indicator – A characteristic of the environment measured to provide evidence of the occurrence or magnitude of a response indicator's contact with a physical, chemical, or biological stress.

Fluvial – pertaining to a river; of riverine origin; pertaining to the riverine, or freshwater, portion of an estuary

Food web – the combination of all of the food chains in a community.

Food chain – a series of organisms depending upon one another for food; begins with plants and ends with carnivores.

Forested wetland – characterized by woody vegetation that is 6 m tall or taller.

Gametogenesis – The and development of mature gametes, or sex cells.

Habitat – the natural home or specific environment in which an organism lives.

Habitat type – the specific environment in which a community of organisms live; a grouping or classification of similar habitats

Index (Indices) – Mathematical aggregation(s) of indicators or metrics; one example is the Index of Biotic Integrity (IBI), which combines several metrics describing fish community structure, incidence of pathology, population sizes, and other characteristics.

Intertidal – the area exposed at low tides and inundated at high tides; defined as the area between Extreme Low Tide and Extreme High Tide.

Invertebrate – an animal that does not have a backbone.

Larva (plural, larvae) – an immature form of an animal which is unlike the adult form and which requires fundamental changes before reaching the basic adult form.

Lethal – Causing death by direct action.

Macroalgae – benthic multicelled algae (>0.5 mm in length) typically found on the sediments of tidal mudflats.

Macrophytes – a macroscopic plant normally associated with wetlands.

Metallothioneins – A protein found in fish that has been used to indicate exposure to various metals, including cadmium, copper, mercury, silver, and zinc. Similar proteins have been measured in invertebrates.

MFO – Mixed function oxygenase (MFO) systems are enzyme systems of biota that oxidize organic compounds. In fish and some invertebrates MFO activity can increase in response to exposure to petroleum hydrocarbons, PCBs and other chlorinated organic compounds.

Microalgae – single-celled algae (<0.5 mm in length) found within the water column or attached to submerged substrates.

Neap tides – tides having ranges less than the mean tidal range.

Parts per thousand (ppt) – a unit of measurement used in describing salinity. Water with a salinity of one ppt contains one unit of salt for every thousand units of water by weight.

Pelagic – residing in the water column.

Population – all the individuals belonging to a single species or several species which are closely associated and occupy a particular area or space.

Response Indicator – A characteristic of the environment measured to provide evidence of the biological condition of a resource at the organism, population, community, or ecosystem process level of organization.

Riparian Habitat – pertaining to the bank or shore of a river, lake, or stream.

River Mile (RM) – mileage measurements along the main navigation channel of the Columbia River. River Mile 0 is at the river mouth.

Saline – pertaining to waters containing dissolved salts.

Salinity – saltiness, especially of water, usually measured in parts salt per thousand parts water.

Sediments – the organic and inorganic particulate materials, including gravel, sand, silt and clay, that cover the bottom of the river

Shoal – a general term referring to a shallow area such as a sandbar.

Slough – a narrow channel cutting through an intertidal area and receiving tidal flow.

sp. – species (singular); used to refer to one species in a genus when the actual species name is not known.

spp. – species (plural); used to refer to more than one species in a genus when the actual species name is not known.

Stressor – Measurements used to provide information on human activities or externalities that can cause stress in ecological entities; three types of stressor indicators are considered in EMAP; hazard indicators, management indicators, and natural process indicators. Examples are the incidence of fertilizer application, which can increase concentrations in lakes; incidence of dredging/filling, which can diminish availability of wetland habitat; and climatic fluctuations, which can promote damage by pathogens.

Tidal mudflat – an unvegetated intertidal area composed of fine sediments, such as silt.

Tidal marsh – an intertidal area covered with non-woody flowering plants.

Tidal flat – a tidal sandflat or mudflat.

Tidal channel – a channel through which water drains and fills intertidal areas.

Tidal – pertaining to tides or an area periodically flooded and exposed by the tides.

Tides – the periodic rise and fall of sea level produced by the gravitational forces of the moon and sun acting upon the rotating earth.

Vascular plants – a plant characterized by the possession of vessels conducting a fluid such as ferns and flowering plants.

Water column – the water or its vertical extent

Wetland – land or areas where the soil has a high moisture content, such as tidal flats or swamps.

Woody vegetation – trees and shrubs

APPENDIX B

EVS ENVIRONMENT, 2517 Eastlake Ave. East, Suite 200, Seattle, WA 98102 (206) 328-4188	
LOWER COLUMBIA RIVER BI-STATE WATER QUALITY PROGRAM	Project Number: 2/271-07
Interviewer. Dr Mark D. Munn	Date: September 12, 1991
Person Interviewed: Dr Dave C McIntyre	Affiliation: Department of Botany and Plant Pathology, Oregon State University
Address: Oregon State University, Corvallis, OR 97331	Phone: (503) 737-5289
RE: Lower Columbia River Biology and Environmental Indicators	

Dr McIntyre was one of the biologist that worked on CREST/CREDDP. His speciality is aquatic botany and primary productivity. Dr. McIntyre stated that the aquatic plant communities in the lower Columbia River were relatively limited in diversity or area. There are some eel grass communities in the estuary and a some marsh habitat on the margins of the estuary. Baker Bay has a community of Scirpus americana that is relatively dense in the summer, but dies out fast by late August.

Due to the lack of abundance and information, Dave does not think that aquatic macrophytes would be very good indicators in the lower Columbia River system.

In regards to benthic algae, there is presently very little known about the species that occur in the lower river and even if more was known, the communities would be extremely variable due to the physical instability of the system. Due to these factors, Dr. McIntyre does not think that benthic algae would be useful as an indicator of contaminant problems in the lower river.

Based upon his experience, he stated that he thought that animals would be more useful that plants in an environmental monitoring program.

EVS ENVIRONMENT, 2517 Eastlake Ave East, Suite 200, Seattle, WA 98102 (206) 328-4188	
LOWER COLUMBIA RIVER BI-STATE WATER QUALITY PROGRAM	Project Number: 2/271-07
Interviewer: Dr. Mark D Munn	Date: September 16, 1991
Person Interviewed: Robert Hughes	Affiliation: NSI Technology Services
Address: 200 Southwest 35th Street, Corvalis, OR 97333	Phone: (503) 757-4516
RE: Biological Indicators	

Mr. Hughes is a contractor at the US EPA lab in Corvalis and is heavily involved in the EMAP program. He is one of the authors of Indicator Strategy for Inland Surface Waters, which is a chapter in the US EPA publication Environmental Monitoring and Assessment Program: Ecological Indicators (EPA/600/3-90/060).

Mr. Hughes comments centered around the approach one takes in selecting an indicator. He said that while it is the ecosystem level that is of primary concern, the biological indicators that are most useful are ones that deal at the community and lower levels of organization He recommended that we consider multiple indicators for each site of concern since no one biological indicator is useful for all questions.

Of the biological monitoring tools available, he recommends macroinvertebrates and benthic fish, both of which address the sediment quality issues. He was not sure if using aquatic plants (macrophytes or algae) would be useful in the lower Columbia River, but felt that based upon other studies that plants would probably not be useful

Mr. Hughes stated that while contaminants are an issue in the lower Columbia River, he thought that flow alterations from the dams and sediment input may be equal or greater threats to the system.

EVS ENVIRONMENT, 2517 Eastlake Ave East, Suite 200, Seattle, WA 98102 (206) 328-4188	
LOWER COLUMBIA RIVER BI-STATE WATER QUALITY PROGRAM	Project Number: 2/271-07
Interviewer: Dr Mark D Munn	Date: September 17, 1991
Person Interviewed: Andy Schaedel	Affiliation Oregon Department of Environmental Quality
Address: 811 SW 6th Avenue, Portland, OR 97204	Phone. (503) 229-6121
RE: Biological monitoring and lower Columbia River	

The majority of our discussion focussed on the use of chlorophyll for assesing water quality. Mr. Schaedel said that the main rational for using chlorophyll for water quality monitoring is related to its use as an indicator of potential eutrophication problems Oregon DEQ periodically determines chlorophyll at various stations and if the value falls above a certain level then further assessments would be made.

For additional information on the Columbia River biota he recommended that I talk with Gene Foster or Rick Haffle of Oregon DEQ.

EVS ENVIRONMENT, 2517 Eastlake Ave East, Suite 200, Seattle, WA 98102 (206) 328-4188	
LOWER COLUMBIA RIVER BI-STATE WATER QUALITY PROGRAM	Project Number: 2/271-07
Interviewer Dr Mark D Munn	Date: September 16, 1991
Person Interviewed. Larry Small	Affiliation. Department of Oceanography, Oregon State University
Address. Department of Oceanography, Oregon State Unversity, Corvalis, OR	Phone. (503) 737-5195
RE: Lower Columbia River	

Dr. Small was involved in the Columbia River estuary CREDDA study and has worked extensively with Dave McIntyre and Charles Simenstad. Dr. Small stated that based upon his experience in the estuary portion of the river, that using sediment, flow patterns, and salinity for delineating habitats and biological communities is very realistic given the nature of the river

He also stated that given the types of biological communities, that using fish and benthic invertebrates may be better for monitoring than other taxonomic groups.

EVS ENVIRONMENT, 2517 Eastlake Ave. East, Suite 200, Seattle, WA 98102 (206) 328-4188	
LOWER COLUMBIA RIVER BI-STATE WATER QUALITY PROGRAM	Project Number: 2/271-07
Interviewer: Dr. Mark D Munn	Date:
Person Interviewed: Robert Wisseman	Affiliation: September 17, 1991
Address: 3490 Northwest Deer Run Rd., Corvalis, OR 97330	Phone: (503) 752-1568
RE: Biology of lower Columbia River	

Mr. Wisseman is an invertebrate taxonomist that has his own business He is the individual that will be identifying the freshwater invertebrates from this study. Based upon his experience, he stated that the benthic invertebrate community would probably consist of chironomids and oligochaetes He said he would be suprised if we found a very high diversity given the sustable substrate.

EVS ENVIRONMENT, 2517 Eastlake Ave. East, Suite 200, Seattle, WA 98102 (206) 328-4188	
LOWER COLUMBIA RIVER BI-STATE WATER QUALITY PROGRAM	Project Number: 2/271-07
Interviewer Dr Mark D Munn	Date September 20, 1991
Person Interviewed: Stu McKenzie	Affiliation USGS
Address: Water Resources Division, 10615 SE Cherry Blossom Drive, Portland, OR 97216	Phone (503) 231-2016
RE: Biology of lower Columbia River	

The USGS has extensive experience in water quality but have not done much in biological assessment on the lower Columbia River. He recommended that we contact Robert McConnel for additional information. He does not think we will find much biological information on the riverine section of the lower Columbia River.