LOWER COLUMBIA RIVER AQUATIC NONINDIGENOUS SPECIES SURVEY

Mark Sytsma, Portland State University
John Chapman, Oregon State University
Jeff Cordell, University of Washington

DRAFT

Literature Review and Sampling Plan
June 2002

Prepared by:

Robyn Draheim, Portland State University

Table of Contents

Lower Columbia River Aquatic Nonindigenous Species Survey

1. SUMMARY

1.1 Introduction

Introductions of aquatic nonindigenous species (ANS) into the United States are increasing, along with their social, economic and ecological impacts. Following a substantial amplification in the speed and volume of global trade over the past century, the discharge of ballast water into marine and aquatic systems world-wide has become a significant pathway for ANS introductions. In spite of the considerable volume of shipping received by the five major freshwater and brackish ports on the lower Columbia River, previous studies of ANS and ballast water release on the West Coast of North America have focused on ports in estuaries and bays such as San Francisco Bay and Coos Bay, with little consideration given to freshwater ports. This oversight was noted in 1996 when the National Invasive Species Act identified the need to conduct an ecological and ballast water discharge survey of the Columbia River System (Appendix A). In the fall of 2001 the Lower Columbia River Aquatic Nonindigenous Species Survey (LCRANS) began.

The objective of LCRANS is to characterize ANS in the lower Columbia River (146 river miles from Bonneville Dam to the Pacific Ocean, and the tidal portions of the major tributaries) (Figure 1). This two-year investigation will serve as a baseline for evaluating the rate of species introductions to the river, aid the US Coast Guard in evaluating the efficacy of ballast water guidelines, and contribute important new information to ongoing regional ANS studies.

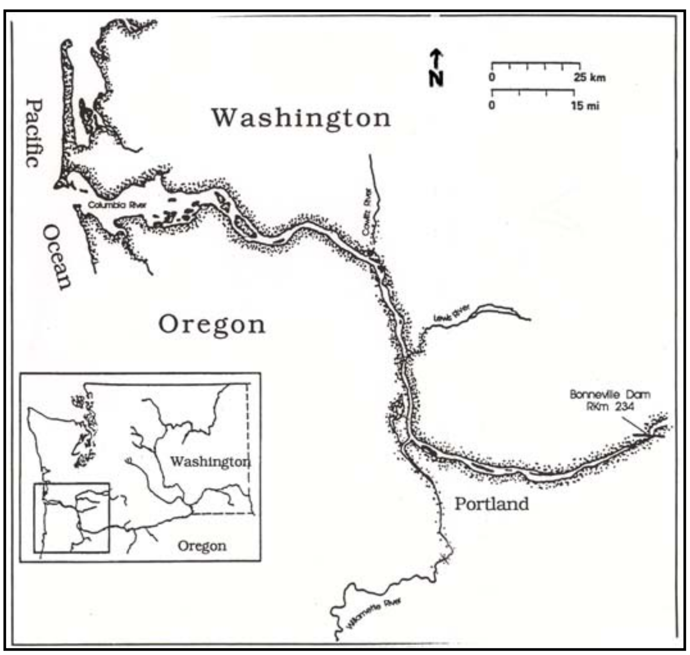

Figure 1. Map of the lower Columbia River (Modified from Hinton and Emmett 1994).

The survey design, progress and results of this research are being produced in consultation with the LCRANS Technical Advisory Committee (TAC). The TAC consists of local, regional and national experts on biological invasions of aquatic systems, taxonomy, and regional resource management (see Appendix B).

The project has three primary components:

- Aquatic Nonindigenous Species Literature Review and Sampling Plan Development
- Taxonomic Field Surveys 2002 – 2003
- Final Report

This report describes results of the first stage of the project, the literature review and sampling plan.. Existing literature on the lower Columbia River was surveyed with the intent of compiling a preliminary list of non-native species reported in the study area as well as identifying gaps in the taxa and/or habitats evaluated and sites that have a reliable historical record facilitating evaluation of invasion rates. The information collected during the literature review has been used in the development of the first year sampling plan to ensure that the survey will fill important data gaps and effectively build on the existing knowledge to better discern the invasion history and biological condition of the lower Columbia River.

The second stage of the project, the 2002 and 2003 field surveys, will be guided by sampling plans developed for each year. Both plans will identify sampling locations, protocols, and taxonomic expertise required for identification of organisms. The 2002 survey will focus on taxa and habitats that are poorly represented in the literature, as well as sites that that have been proposed as part of a long-term monitoring program. The 2003 survey will build upon data collected the previous year, re-sampling long-term stations and selecting new stations in an adaptive sampling strategy. Where appropriate, members of the TAC are asked to lend their specific expertise to the project for the evaluation of taxonomic lists, advice on targeted sampling efforts, species identification, etc. The existing timeline allows for sampling over two years, 2002-2003, potentially encompassing year-to-year and seasonal variation in populations.

The final report, due in September 2003, will include an analysis of current species composition, areas of origin, and mechanisms of ANS introduction into the lower Columbia River; recommendations for continued monitoring; and the baseline historical data needed to assess the value of ballast water management programs. For each ANS, the report will characterize the timeframe, source, vector, distribution and impacts of invasion.

During the years 2002-2003, we plan to present aspects of the Lower Columbia River Aquatic Nonindigenous Species Survey at several scientific meetings, as well as at workshops and public talks including:

- Pacific Estuarine Research Society, Portland, OR, May 2002
- 12th International Aquatic Invasive Species Conference, TBA, 2003
- Conference of the Estuarine Research Federation, Seattle, WA, September 2003
- Third Marine Bioinvasions Conference, TBA, 2003

1.2 Literature Survey

The literature survey of the lower Columbia River began in October 2001. Publications, reports, gray literature and collection records referring to projects conducted on the lower Columbia River were reviewed with the intent of compiling a list of reported non-native species present in the study area as well as identifying gaps in the taxa and/or habitats evaluated (please see Appendix C for complete list of references).

There is a dearth of historical information available on the flora and fauna of the Columbia River, for both ANS and native species alike. Faunal collection records for the lower Columbia River and tributaries, are hampered by lack of taxonomic resolution for many groups as well as by limited geographic scope. "Unpopular" or "difficult" taxonomic groups such as polychaetes, oligochaetes, chironomids, etc. even now continue to be overlooked by research in the lower Columbia River. Additionally records of taxa such as polychaetes are confounded by less than adequate regional identification keys (Leslie Harris personal communication). The three most significant research investigations of the flora and fauna of the lower Columbia River are the Columbia River Estuary Data Development Project (CREDDP) authorized by the US Congress in 1978, the Bi-State Water Quality Program (Bi-State) conducted in the early 1990's, and the Environmental Monitoring and Assessment Columbia River Program (EMAP – Columbia River) which concluded its two-year sampling plan in 2000. Combined, these three research projects provide the most comprehensive understanding of the flora and fauna of the lower Columbia River system.

The following list summarizes the numbers of aquatic nonindigenous and cryptogenic species in major taxonomic groups recorded as present in the lower Columbia River compiled from the literature survey. A complete list is available in Appendix D.

Nonindigenous Species

- Plants – 16 species
- Mammals – 1 species
- Amphibians – 1 species
- Fishes – 37 species*
- Annelida – 2 species
- Amphipoda – 3 species
- Cirripedia – 1species
- Copepoda – 3 species
- Cumacea – 1 species
- Decapoda – 4 species*
- Isopoda – 1 species
- Bivalvia – 2 species
- Gastropoda – 1 species

* Indicates species counts which include introductions that failed or are thought to have failed to become established, for example: *Homerus americanus*, American lobster, has been introduced intentionally with no known surviving populations

Cryptogenic Species

- Annelida – 29 species**
- Amphipoda – 3 species
- Copepoda – 1 species
- Isopoda – 1 species
- Nemertea – 1 species
- Plants – 2 species***

** May include native species that have been mis-identified
*** Both invasive species populations (Phragmites and reed canary grass) may be the result of non-cultivars/genotypes but not enough information is currently available to make this determination

The above list of ANS species consists of both intentionally and unintentionally introduced species. The non-native fishes on this list are dominated by intentionally introduced species, many released in order to bolster native populations for harvest and sport purposes (Smith 1896, Lampman 1946). Contrary to this, the invertebrates on this list are thought to be primarily the result of unintentional introductions. The cryptogenic species list is divided between species which are believed to be non-native, but for which current knowledge is limited and, in the case of numerous polychaetes, native species which may have been misidentified as cryptogenic species.

While the non-native fishes of the lower Columbia River and its tributaries have been documented by many people (Hutchinson and Aney 1964, Reimers and Bond 1967, McConnell et al. 1973, Bottom et al. 1984, Ward and Nigro 1992, North et al. 2002) there are many invertebrate taxa present in the lower Columbia River that are poorly studied yet known to successfully invade other locations. These taxa include marine species present only at the mouth of the river, mysids, barnacles, other large and small crustaceans, plankton (both benthic and holoplankton) polychaetes, oligochaetes, freshwater bivalves, gastropods, and aquatic insects.

From the literature review it can be concluded that there are numerous areas and habitats within the lower Columbia River that are poorly studied. Large areas of seemingly patchy habitat exist in the estuary that are not well characterized. Many ANS have been reported from the two relatively high salinity bays at the mouth of the Columbia, Trestle Bay and Baker Bay (Furota and Emmett 1993, Hinton and Emmett 2000, WEMAP unpublished data), but there have been no investigations in either of these areas focusing on the ANS and their impacts. While common along the main stem (although greatly reduced in size and number) tidal freshwater sloughs and swamps are also poorly characterized. Such areas may provide protection from strong flushing events and could be a haven for non-native aquatic macrophytes, insects and epibenthic invertebrates, and many exist adjacent to major deep-water ports, both features that make them of special interest to this survey. Other sites of interest have high concentrations of taxa that have been poorly characterized, i.e. oligochaetes.

While little or no long-term habitat monitoring data exist for many locations in the lower Columbia River, there are several areas we believe will make ideal long term study habitats for which previous survey information exits. This information comes primarily from the three major lower Columbia River surveys mentioned above (CREDDP, Bi-State, and WEMAP – Columbia River) but also from smaller, geographically limited research.

1.3 Field Surveys

The second stage of the project, the 2002 and 2003 field surveys, will be guided by sampling plans developed for each year. The literature review is integral to the development of a stratified and adaptive sampling plan. Limited resources and a vast study area require that we identify areas of interest i.e. potential hot-spots (locations closely associated with ballast water release, habitats associated with previously reported ANS and cryptogenic species, etc.), and areas that have been understudied previously. It is equally important that we avoid duplication of efforts with new and ongoing projects, working instead toward cooperative goals. Both plans will identify sampling locations, protocols, and taxonomic expertise required for identification of organisms.

The 2002 survey will focus on taxa and habitats that are poorly represented in the literature, as well as sites that can be re-sampled at regular intervals in a long-term monitoring program, and/or sites that have a reliable historical record that will permit evaluation of invasion rates. In 2003 we will evaluate the data collected in 2002, identify and resample those stations that will serve as long-term monitoring stations, as well as identify any new stations to be sampled during the final year of the project. At that point in time we anticipate that we will also have access to the 2000 WEMAP data from the main stem of the lower Columbia River and will be able to utilize the additional data. When appropriate, members of the TAC will be asked to advise the targeted sampling efforts, species identifications, etc.

The taxonomic scope of the LCRANS project is limited to free-living macrophytes and animals, except in unmistakable cases of disease causing organisms and parasites which will be noted when appropriate, i.e. whirling disease.[1] Taxa that have not been well studied by previous investigators will be the primary focus of these surveys. Surveys of taxonomic groups such as the fishes, which are the most well-studied fauna of the lower Columbia River, will not be actively undertaken, because they are already adequately covered in the literature.

Geographic Scope
The following are areas that have been chosen for reconnaissance surveying in April 2002. Reconnaissance surveys will result in the selection of specific stations at each location for rapid assessment teams of taxonomic teams to visit in Summer of 2002.

[1] A collaborative study has been proposed by Jerri Bartholomew of Oregon State University to conduct surveys of ANS for pathogens of commercially important species of fish in the lower Columbia River, and to develop methods to detect and assess survival of these pathogens in ballast water. The study will focus on specific parasitic, bacterial and viral pathogens of salmonid and non-salmonid fish that are economically important and for which we have molecular detection tools and considerable data on their distribution. The study will directly survey parasites and pathogens of ANS that could serve as vectors, and to develop a baseline for presence and diversity of these pathogens in the lower Columbia River. Examples of parasites include the Myxozoa, which are a large parasite taxon that is especially amenable to introduction because of the durable spores that they form. The Myxozoa have a complex life cycle, typically requiring an annelid alternate host. Annelids are one of the most common taxa detected in ballast water from ships at West Coast ports, and have been targeted because of the lack of existing data.

- Trestle Bay (OR)
- Baker Bay (WA)
- Tansy Point (OR)
- Chinook / Chinook Point (WA)
- Youngs Bay (OR)
- Tongue Point (OR)
- Cathlamet Bay/Lewis and Clark National Wildlife Refuge (OR)
- Coal Creek Slough/Fisher Island Slough (WA)
- Longview/Kelso (WA)
- Cottonwood Island/Carrolls Channel (WA)
- Woodland Peninsula (WA)
- Multnomah Channel / Sauvie Island (OR)
- Vancouver Lake River (WA)
- Columbia Slough (OR)

2. LOWER COLUMBIA RIVER

2.1 Introduction

The Columbia River is the largest river in the Pacific Northwest and the second largest in the United States (in terms of volume discharged). The Columbia River drainage basin covers 259,000 square miles (671,000 km^2) with territory in seven states and one Canadian province. The tidal influence of the Pacific Ocean is evident 146 miles (234 km) upriver to Bonneville Dam, the last of many impoundments encountered by the seaward flowing river. The lower Columbia – that portion below the Bonneville extending to the mouth – drains approximately 18,000 square miles. Representing only seven percent of the entire Columbia basin, it is the most developed and urbanized portion of the river.

For thousands of years the Columbia River has been central to the existence and cultures of numerous Native American tribes. Lewis and Clark's exploration of the Columbia River in the early 1800's ushered in two decades of transformation. In 1825 the British Hudson's Bay Company established a post at Fort Vancouver. With the arrival of the first European American settlers in the 1840's, immigrants who reached the lower Columbia and Willamette river valleys via the Oregon Trail, the shape and character of Columbia River began to change. Like many other bays and estuaries up and down the West Coast, the lower Columbia River became a busy conduit for commerce, with ships arriving daily bearing supplies and immigrants, and leaving laden with timber and fish. Since then, the region has continued to grow, and with it its demands on the river.

According to the Lower Columbia River Estuary Project (LCREP) "historical evidence indicates that since 1870, more than half of estuarine wetlands have been lost as a result of diking, draining, filling, dredging, and flow regulation." (LCREP 1999). In 1932 construction began on the first of more than 10 major main-stem dams that altered the flow regime of the Columbia. In 1938 Bonneville Dam, was completed and, at 146 miles upstream from the mouth, marked the new upper boundary of tidal influence along the river. By the mid 1970's, more than ten major dams had been erected on the main stem of the Columbia. Today the river is the site of numerous commercial and recreational activities including fishing, hydroelectric power generation, irrigation, shipping and boating.

The lower Columbia River delineates much of the north/south boundary between the states of Oregon and Washington. There are three major tributaries entering the Columbia River downstream of Bonneville Dam; the Willamette River on the Oregon side, and the Lewis and Cowlitz rivers from Washington. There are 5 major ports along the lower Columbia River; Astoria, Longview/Kelso, Kalama, Vancouver and Portland. In 1998, the US Department of Commerce reported that these five deep-water ports support a shipping industry responsible for transporting 30 million tons of foreign trade worth $13 billion each year. (LCREPP 1999)

Maximum flows on the river occur in May, June and July due to melting of the winter snowpack in the headwater regions while minimum flows last from September to March with periodic high flows occurring on the lower Columbia during these months due to heavy winter rains falling on the coastal regions (Holton 1984). The flow of the Columbia River is heavily influenced by the combined effects of water storage and irrigation diversion in the middle and upper basins. It has been estimated that, since impoundment, the volume of flow during May-June has been reduced by more than 50% (Ebel et al. 1989).

For the purpose of this study we have subdivided the lower Columbia River basin into three regions (Figure 2).

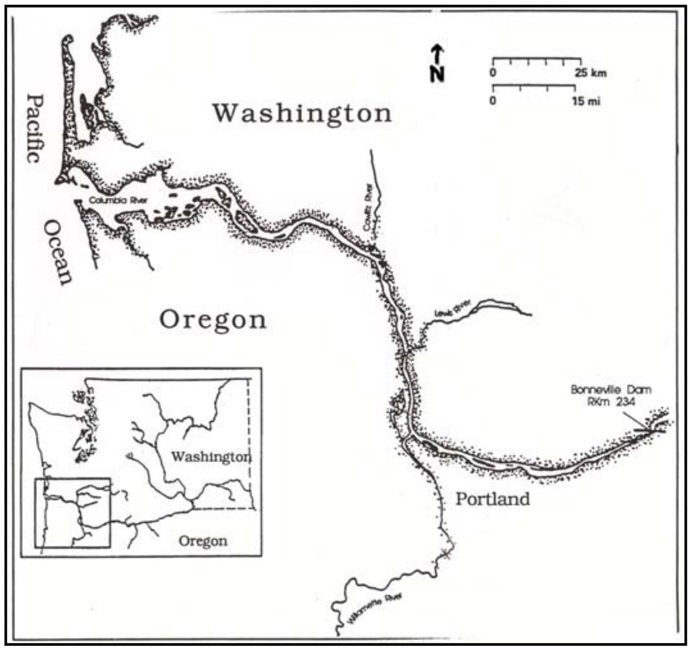

Figure 2. (Modified from Hinton and Emmett 1994)

From the mouth to Skamokawa, WA (~ river mile 35) it is a coastal plain estuary[2]. Sand deposition in the middle reach of the estuary has formed vast areas of sand flats and shoals and additional dredge disposal has built up some of these areas into more distinct islands. There are four large shallow embayments surrounding the estuary (Grays, Baker, Youngs and Cathlamet) that drain the surrounding land (Holton 1984). Upstream of Skamokawa, from Puget Island to Longview, WA and the confluence of the Cowlitz River, the Columbia consists primarily of a single channel bordered by steep valley wall (Holton 1984). Further upstream, from Longview to the start of the Columbia River Gorge near Bonneville Dam, the river valley widens into a low-elevation flood plain.

2.2 The Changing Nature of Invasions

[2] This delineation of the estuary is an oversimplification. The boundaries of the Columbia River estuary can be viewed as fluctuating daily, seasonally, and/or annually. Further complicating any generalization is the presence of an artificially maintained navigation channel via which saline waters travel up the river but in a highly confined space. Please see Simenstad et al. (1990) for a more detailed discussion of the physical and chemical characteristics of the Columbia River estuary.

Human beings, unlike other species, often bring their favorite food, sport and ornamental species, with them when they colonize new locations (Minns and Cooley 1999). This pattern held true for the new arrivals to the Columbia River Basin. Perhaps more than anything else, the wild Pacific salmon is the best-known icon of the Pacific Northwest. As we face the rapid decline of native salmon stocks in the Pacific Northwest it is ironic to note that, while the early settlers rapidly took advantage of the abundance of salmon in the region making it the basis of a multi-mullion dollar industry, they soon "tired" of its pink flesh and yearned for the game fishes of their childhoods (Lampman 1946).

> "They could catch a salmon whenever they wanted it. They measured their cutthroat trout, *Salmo clarkii*, by the bushel.. [but], by Godfrey, what they really wanted was a big mess of catfish." (Lampman 1946)

In the late 1800's the United States Fish Commission (the precursor to the US Fish and Wildlife Service) became actively involved in the transport and stocking of Atlantic/Eastern fish species on the West Coast to "increase the quality and variety of food and game fishes" and supplement the "worthless and unpalatable [ ] fish" (Smith 1896). Today, more than 20 species of non-native yet popular game fish have been introduced to the lower Willamette and Columbia rivers.

One early fish introduced into the lower Columbia River Basin was the carp, *Cyprinus carpio* (Smith 1896, Lampman 1946). Lauded as a European delicacy while being as easy to raise as "pigs in your back yard" – the first shipments of carp arrived in the Willamette Valley in 1879 and 1880. A great number of the carp thrived and reproduced in the pond of one Captain John Harlow and, with the arrival of a vigorous spring freshet swelling the waters of the Sandy River, the newly freed fish of Captain Harlow made their way into the lower Columbia River system in May 1881 (Lampman 1946). The US Fisheries Commission supplied additional shipments of carp to the Pacific Northwest from stock raised in California (Smith 1896) and by 1892 the populations of carp had grown so vast and become such a nuisance that "The Oregonian" newspaper reported that fishermen were "offering to supply farmers with any desired quantity [for use as fertilizer] at $5 a ton" (Lampman 1946).

American shad (*Alosa sapidissima)*, first released in California in 1871, rapidly expanded along the Pacific Coast and were caught in the Columbia River as early as 1876 (Smith 1896), ten years prior to the intentional stocking of shad fry in the Columbia Basin. Recently, measures have been enacted by NMFS to reduce American shad populations in the Columbia River because they are believed to both prey on and compete with juvenile salmon (R. Sharma personal communication 2002, NMFS 1995). Unlike salmon, American shad appears to have been bolstered by the dams and impoundments that threaten many native fish (Weitkamp 1994).

In 1914 the Oregon Fish and Game Commission granted permission to a private individual to introduce bullfrogs (*Rana catesbeiana)* into the mid-Columbia River basin below John Day (Lampman 1946). In 1924 or 1925 it is reported that bullfrogs resulting from the above planting were shipped to Portland for further distribution (Lampman 1946). Adults bullfrogs are responsible for significant levels of predation on native aquatic species, particularly the Western pond turtle and the spotted frog (Crayon 2002).

While the earliest non-native species introduced to the lower Columbia River were the result of intentional plantings, more recent arrivals appear to be the result of unintentional introductions.

It has been hypothesized that the extreme changes to the lower Columbia River resulting from numerous upstream dams and the continued manipulation of river flow have played a role in the successful establishment of these recent ANS arrivals (Weitkamp 1994, Cordell et al 1992).

Historically the free-flowing Columbia River may have supported an "average to rich bottom fauna in which caddis fly and chironomid larvae, mayfly nymphs and mollusks predominated" (Roebeck et al. 1954 in Ebel et al 1989). However, aside from catch data of commercially important species, few biological records exist for the lower Columbia Basin that predate the construction of the dams (Weitkamp 1994). Today the main stem of the lower Columbia River is considered depauperate, supports a low diversity of species, and the biological integrity of the river is further impeded by loss of wetlands, pollution and other impacts related to industrialization, navigational improvement and urbanization. While many adjustments to impounding a river happen very quickly (Petts 1984) geophysical changes may require more than 100 years to adjust to major alterations of flow (Sherwood and Creager 1990). The strong linkage between biological communities and their surrounding physical characteristics may mean that the lower Columbia River is still in the process of adjusting to changes and it is this adjustment period that some believe may have benefited ANS (Weitkamp 1994).

The latest three ANS known to have become established in the lower Columbia River, the New Zealand mudsnail (*Potamopyrgus antipodarum*), a Siberian freshwater prawn (*Exopalaemon modestus*) and an Asian calanoid copepod (*Pseudodiaptomus inopinus*), appear to differ greatly from the above early invaders. None are fishes and none have value as game species. As such, none of these species are believed to have been intentionally introduced but there exists no clear documentation of the dates and vectors of introduction. The researchers who first identified *P. inopinus* believe that introduction took place between 1980 and 1990 via ballast water released from ships arriving from Asia (Cordell et al. 1992). First captured in 1995 by NMFS researchers, *E. modestus* was immediately recognized as an invasive species, there being no true freshwater shrimp native to the Columbia River (Emmett et al. in press). It is believed that this species may have arrived entrained in ballast water given the number vessels arriving from it's native range (Emmett et al. in press). The arrival *P. antipodarum,* as recorded in the benthic sampling reports of the Clatsop Economic Development Council's salmon net pen operation in Youngs Bay, may initially have been mis-identified as the native gastropod *Fluminicola virens* and it was not until its abundance grew significantly that it was correctly identified as an invasive species (R. Litton personal communication). It is not known how this snail arrived in the lower Columbia River, however, this population has the same genetic fingerprint as the snails in Snake River (personal communication Mark Dybdahl).

These three species serve to demonstrate that the nature of invasions in the lower Columbia River may be changing from a history of intentional introductions to bolster game or food fish populations, often with negative results, to one characterized by unintentional introductions (perhaps via ballast water) of species which may have a unknown or negative impact on the river.

3. LITERATURE REVIEW

3.1 Purpose:

The literature review of the lower Columbia River was begun in October 2001. Publications, reports and collection records from projects conducted on the lower Columbia River were surveyed in order to characterize the state of knowledge regarding non-native species present in the lower Columbia River. The goals of the literature review are threefold: 1.) to compile a list of non-native species already reported from the Columbia River, 2.) to identify taxa that have been poorly studied, or represented in previous studies, 3.) to identify areas of interest, i.e. potential ANS hot-spots i.e. habitats associated with previously reported ANS and cryptogenic species, as well as habitats that have been under studied.

3.2 Summary of Findings:

No systematic survey of ANS exists for the lower Columbia River. In addition, no comprehensive checklist or inventory of species exists for this region. Parts of the lower Columbia Rive received far more attention than others (e.g. the estuary compared to the freshwater main stem).

Relative to other aquatic systems along the West Coast, the flora and fauna of the lower Columbia River has been poorly studied. There are several theories that may explain this lack of comprehensive research. As a political boundary between the states of Oregon and Washington, neither state has taken the lead and characterized the whole system. With no major research universities along its banks, the lower Columbia River has not benefited from scores of graduate student researchers whose basic research projects contribute to a large knowledge base. As a massively impounded, altered and dredged system (LCREP 1999), little of the natural river remains below the Bonneville Dam and the main stem of the lower Columbia is often written off by researchers and agencies as "depauperate." While the Columbia River estuary has been the subject of both a comprehensive survey and numerous site-specific studies the tidally influenced portion which extends upriver to the Bonneville Dam is less well-studied. Tidal-freshwater areas are often disregarded by researchers world wide as neither the purview of the estuarine scientists, nor of interest to researchers studying rivers (Yozzo and Diaz 1999). Lastly, for more than the past two decades, much of the scientific effort in the region has been dominated by salmon, leaving little funding for other studies.

The Columbia is unique among West Coast estuaries. As it is a system dominated by freshwater, it is not readily comparable to other coastal areas that have well documented ANS populations. As an estuarine/river system it is equally difficult to compare it to well-studied freshwater systems such as the Great Lakes. Much of the work on the West Coast prior to the mid-1990's is the product of a few dedicated researchers. Unlike coastal bays and estuaries up and down the coast, the lower Columbia River does not appear to have been invaded (yet) by two of the more "prominent" West Coast ANS (i.e. species that have received media attention and funding in the past), the green crab (*Carcinus maenus)* and smooth cord grass (*Spartina* spp.*)*. The perceived lack of impacts, or threat of impacts, has resulted in understudy and poor characterization of ANS in the Columbia River.

In addition to the lack of research adequately characterizing both the lower Columbia River system and the presence of ANS, there is limited information available for many of the invertebrate taxa, such as oligochaetes and epibenthic meiofauna. Further complications are due to the possibility that previous collection records may be rife with mis-identifications (personal communication John Chapman, Leslie Harris).

There have been three major projects that studied/characterized the lower Columbia River. In 1984 the results of the Columbia River Estuary Data Development Program (CREDDP) were published to augment the Atlas of Physical and Biological Characteristics of the Columbia River Estuary. In the early 1990's the Bi-State Water Quality Program published its findings on the state of the lower Columbia River. Lastly, in 2000 the Environmental Protection Agency began a two-year sampling effort in the lower Columbia River as part of its Environmental Monitoring and Assessment Program West Coast Project (WEMAP). However, at the time of this report the WEMAP data are not yet available in their entirety. From these three projects, bolstered by many smaller site-specific collection records, we have been able to piece together a inventory of the flora and fauna of the lower Columbia River (although there are still knowledge gaps associated with many taxa) and have preliminarily identified the non-native and cryptogenic species in this inventory(Appendix D).

3.2 Review

The first extensive survey of fauna in the Columbia River estuary was completed by Haertel and Osterberg (1967). Previous ecological investigations of the estuary were limited to surveys of economically important species conducted by the Fish Commission of Oregon (Haertel and Osterberg 1967). Zooplankton, benthic invertebrates and fishes were sampled at seven stations along the main stem between the mouth of the river and Harrington Point (river mile 20) over a 21 month period from 1963 - 1965. The study focused on main stem habitats and was limited to those taxa that could be collected in trawls and plankton nets. Two non-native species were collected by Haertel and Osterberg (1967) an Asian clam, *Corbicula fluminea,*[3] and the American shad, *Alosa sapidissima,*[4] and one cryptogenic species *Saduria entomon,* an isopod. No mention was made by Haertel and Osterberg (1967) that the above species were not, or may not be native to the Columbia River estuary.

In 1973, the National Marine Fisheries Service (NMFS), in cooperation with the Army Corps of Engineers (COE), conducted a brief survey of stations in the lower Columbia River (including one station on the lower Willamette River) (McConnell et al. 1973). From this NMFS developed a "checklist" of aquatic organisms (finfish, shellfish, benthic and epibenthic invertebrates, and zooplankton) for the region (Durkin 1973, Durkin and McConnell 1973, McConnell et al. 1973, Misitano 1973, Sanborn 1973.) While this was only a cursory survey, it appears to be the first

[3] First reported from the Columbia River in 1938, thought to be purposely introduced as a food item (Britton and Morton 1977).

[4] First captured in the Columbia River in 1876 - the result of the range expansion of a population previously introduced in California, later stocked directly into the Columbia River by the US Fish Commission in 1885 (Smith 1896).

attempt to develop an inventory of species for the entire lower Columbia River and it provided useful distribution data for several species. According to Holton (1984), this was the first documentation of *Corophium salmonis* (a native estuarine amphipod known to have a high freshwater tolerance) as far upstream as Portland (McConnell et al. 1973), a species later reported by NMFS as being distributed even further up the Columbia River, well above the Bonneville Dam (Muir and Emmett 1988). Similar to Haertel and Osterberg (1967), no note or discussion of the presence of non-native species was included.

Subsequent studies of benthic invertebrates located in the lower Columbia River have resulted in site-specific inventories of species (Holton 1984). Many of these studies were conducted by NMFS and focused on monitoring community level changes resulting from engineering projects such as dredging, dredge disposal, revetment construction, etc. (e.g. Durkin 1975, Sanborn 1975a, Sanborn 1975b, Higley et al. 1976) and are of limited geographic scope with varying taxonomic resolution. Other research projects focused on single taxa, such as amphipods (e.g. Holton and Higley 1976, Davis and Holton 1976). The presence of, if any, ANS was not noted in any of these reports.

More extensive baseline information exists for the brackish water fauna in Youngs Bay, in the lower Columbia River estuary. Between 1973 and 1975, a baseline study of the biological characteristics of Youngs Bay was conducted by Oregon State University (CREDDP 1980a, b). This comprehensive study developed abundance data for benthic infauna, ichthyoplankton, and fishes, sampling 42 stations in Youngs Bay and its freshwater tributaries (Higley and Holton 1975). Additional research by NMFS (Durkin et al. 1977) provided similar information for Alder Cover on the west side of Youngs Bay, as did a report by Montagne and Associates (1977 in CREDDP 1980a). Further research of the lower estuary by Oregon State University (Higley et al. 1976 , Higley and Holton 1978) reported that the euryhaline species assemblage in Youngs Bay (Higley and Holton 1975) shifted to one dominated by more marine fauna with a higher variety of polychaetes and amphipods nearer to the mouth of the river (CREDDP 1980a).

<u>The Columbia River Estuary Data Development Program</u>

The Columbia River Estuary Study Taskforce (CREST), located near the mouth of the Columbia River in Astoria, Oregon, was founded in 1974 to gather scientific background material on the estuary and to produce a management plan based on this data. Initial data gathering resulted in the publication of the "Columbia River Estuary Inventory of Physical, Biological, and Cultural Characteristics" (Seaman 1977). With the limited information available, the Inventory developed generalized distribution charts for several dominant estuarine species and taxonomic groups (Good 1977a, Good 1977b).

Based on data needs identified during the development of the Inventory, the US Congress authorized and funded the Columbia River Estuary Data Development Program (CREDDP), which provided the first and most comprehensive study of the Columbia River estuary[5] to date. The purpose of CREDDP was to enhance understanding of the ecology of the Columbia River estuary and to provide information useful to land and water use decisions (Holton 1984). The

[5] CREDDP defines the estuary as covering the area from the bar at the mouth of the river to the eastern tip of Puget Island (river mile 45) (CREDDP 1980).

goal of CREDDP was to build upon a foundation of historic work. The data collected by the CREDDP researchers remain, even today, an important source of information relied upon by local governments as well as state and federal agencies (http://www.oregonvos.net/~crest/). The comprehensive CREDDP undertaking covered salmonid and non-salmonid fishes (Bottom et al. 1984), mammals (Howerton 1984), benthic infauna (Holton 1984), epibenthic organisms (Simenstad 1984), tidal marsh plants (MacDonald and Winfield 1984), and benthic and water column primary production (MacIntire 1984, Small and Frey 1984).

The first publication by the newly formed CREDDP team was a two volume "Literature Survey of the Columbia River Estuary" (CREDDP 1980) summarizing the previous research by major taxonomic group and providing an annotated bibliography for each. This literature survey remains the definitive summary of research on the Columbia River estuary prior to 1980. We have summarized above the main research projects that provided collection information useful to this study but have not attempted recreate the scope of this project.

As part of the CREDDP report on benthic infauna of the Columbia River estuary, Holton (1984) chose to study eight "key" species benthic invertebrate species (see Table 1.). These eight species were chosen for their "perceived importance", i.e. based on their previously reported abundance in the estuary and their occurrence in gut content analyses of fishes (Holton 1984). It is interesting to note that, of these eight species, only four are native to the Columbia River. The non-native species are, however, widely distributed in the major estuaries along the West Coast (Cohen and Carlton 1995, Cohen et al. 1998, Ruiz et al. 2000, Cohen et al. 2001), and *Capitella capitata* complex has been collected from the smaller bays and coastal waters of the region (WEMAP unpublished data). Holton (1984) did note briefly that *Hobsonia florida* was an invasive species from the Atlantic coast but no other mention of non-native species was made in the report in spite of their "perceived importance" in the system.

Table 1. Key benthic invertebrate species in the Columbia River Estuary identified by the Columbia River Estuary Data Development Project (Holton1984)

	Species	**Status**
Polychaeta	*Capitella capitata [complex]*	cryptogenic
	Hobsonia florida	nonindigenous
	Hediste [Neanthes] limnicola	native
	Pseudopolydora kempi	nonindigenous
Bivalvia	*Corbicula fluminea*	nonindigenous
	Macoma balthica	native
Amphipoda	*Corophium salmonis*	native
	Eohaustorius estuarius	native

The MacDonald and Winfield (1984) survey of tidal marsh plants in the Columbia River estuary included three species of aquatic nonindigenous plants. The most prevalent of these was *Typha angustifolia* (cattail) found in Youngs Bay (17% cover), Cathlamet Bay (1% cover) and Puget Island (11% cover). Also noted were *Cotula coronopifolia* (brass buttons) present near the survey site at Ilwaco (in Baker Bay) and *Iris psuedocornus* (yellow iris) in Grays Bay and covering less than 1% of the Puget Island survey site. MacDonald and Winfield (1984) also noted that *Phalaris arundinacea*[6] (reed canary grass) was widely distributed at freshwater low marshes.

The CREDDP survey of fishes was performed by NMFS in 1980-1981 and analyzed by Oregon Department of Fish and Wildlife (ODFW) (Bottom et al. 1984). 75 species were caught at 49 stations, primarily located in the main stem of the estuary, using bottom trawls, beach seines and purse seines. Of the 75 species captured, 12 of them were non-native species, most are species thought to have been intentionally introduced "game fish" planted to enhance recreational fishing (Smith 1896, Hutchinson and Aney 1964). However no mention of these fish and their status as non-native was made in this report. This trend holds true for almost every ANS collected during the CREDDP survey. Only the invertebrates *Hobsonia florida* and *Corbicula fluminea* have individual mentions of being introduced into the Columbia River (Fox et al. 1984, Holton et al. 1984).

Upstream of the Columbia River estuary, limited biological sampling was being done in the 1970's and early 1980's by Portland General Electric at the Trojan Nuclear Power Plant located near Prescott, OR (PGE 1979, personal communication Lolita Carter). Fish, zooplankton, phytoplankton, periphyton and benthic invertebrate collections were made annually in the adjacent waters of the Columbia River as well as in Recreation Lake and Near Creek on the Trojan Power Plant property (PGE 1979). Fish and most plankton specimen were identified to species (PGE 1979, Geiger unpublished data) while benthic invertebrate data was reported only for general taxonomic categories (e.g. oligochaeta, amphipoda, chironomidae) (PGE 1979).

Samples of drift macroinvertebrates were collected in 1984 in the Columbia River by Muir (1990) as part of a study of white sturgeon, *Ascipenser transmontanus,* eggs and larval abundance downstream of McNary Dam conducted by NMFS (Muir and Emmett. 1988) and the Washington Department of Fish and Wildlife (WDFW) (Nigro 1988). Muir (1990) went on to identify the prey items available to fishes in the lower Columbia River below the Bonneville Dam, and reported that macroinvertebrate drift below the dam was both sparse and of low species diversity. The most commonly captured aquatic insects were net spinning caddis flies (*Cheumatopsyche* spp.), genus known to benefit from impoundments (Petts 1984).

The 1984 study of *Ascipenser transmontanus* was followed by a study of the feeding ecology of these fish in the lower Columbia River by McCabe et al. (1993) who collected juvenile sturgeon from the tidal freshwater main stem as well as the estuary. Benthic samples were analyzed at two stations in the main stem and the NMFS researchers noted that the invasive freshwater clam *Corbicula fluminea* were a temporally important prey item for juvenile sturgeon. Recognizing the necessity for rectifying the limited benthic invertebrate information upstream of the estuary in the lower Columbia River, McCabe et al. (1997) analyzed all of the benthic invertebrate samples taken (but not reported on) by the previous investigation. They described the abundance of benthic invertebrate populations in main channel habitats along the lower Columbia River

[6] Reed canary grass is considered by this study to be cryptogenic as current research may not be sufficient to determine if native populations have been replaced by an invasive introduced genotype (personal communication Rosemary Laird).

from the Bonneville Dam to the Kalama River. The benthic samples were collected from depth greater than 13 ft (4 m), and may not reflect the invertebrate communities at all aquatic habitats along the river, however, this study expanded understanding of the biological community of the main stem of the Columbia River below the Bonneville Dam.

Research continued in the Columbia River estuary during and after the CREDDP inventory. These site-specific collections continued to add to the characterization of the estuary, one taxa and/or one location at a time (Durkin et al 1981, McCabe 1981, Higley et al. 1983). Benthic invertebrate and substrate sampling was conducted in Cathlamet Bay by NMFS for the USFWS (Emmett et al. 1986, Durkin et al. 1982).

For 12 months in1980-1981 Furota and Emmett (1993) sampled macrobenthic invertebrates along a 1800 ft (550 m) transect covering 11 sites along a tidal gradient in Baker Bay, southwest of Ilwaco. The macroinvertebrate community of this fine-sand tide flat region was dominated by estuarine invertebrates abundant throughout the year, marine species abundance increased toward the subtidal end of the transect and marine species abundance declined after a spring freshette on the Columbia (Furota and Emmett 1993). Present in the collection records are four non-native species (two polychaetes *Hobsonia florida* and *Pseudopolydora kempi*, the marine bivalve *Mya arenaria*, and the eelgrass *Zostera japonica*) and five cryptogenic species (the polychaetes *Polydora cornuta*, *Pygospio elegans*, *Manayunkia aestuarina* and *Glycinde polygnatha*, and the isopod *Saduria entomon*.

In 1990 a more detailed analysis of the CREDDP data was published as a special volume of “Progress In Oceanography” on the Columbia River Estuary (Simenstad et al. 1990). Prior to this other analyses of the CREDDP data had also been published in peer review journals (e.g. Simenstad and Cordell 1985).

<u>The Bi-State Water Quality Program</u>

In the late 1980’s the states of Washington and Oregon, concerned about the integrity and water quality of the Columbia River system, initiated the Bi-State Water Quality Program (Bi-State Program) (Ellis and DeGasperi 1994). The program focused on the Lower Columbia River from the Bonneville Dam to the mouth, the most highly industrialized stretch of the river. Physical and chemical water quality parameters were the primary focus of the study however, as part of the 6-year Bi-State Program, benthic invertebrates were sampled at 54 locations along the main stem of the lower Columbia River from the mouth to the Bonneville Dam (Ellis and DeGasperi 1994).

While the Bi-State Program had a broader geographic scope than previous CREDDP studies, the limited biological data collected does not provide as detailed an overview of the habitat and faunal assemblages of the tidal freshwater stretch of the lower Columbia River as the CREDDP data does for the lower estuary. The Bi-State data is unique in that, although taxa such as the oligochaetes remain unresolved, the survey did identify much of the insect larvae collected to greater taxonomic resolution than previous studies (Tetra Tech 1993) although still limited to practical levels of identification. As the focus of this study was on chemical and toxicological water quality, no discussion of the distribution of ANS was included. Benthic invertebrates were sampled primarily to determine if community composition could be correlated to the water quality “health” of a site, something the study was unable to do (Ellis and DeGasperi 1994). The

Bi-State Program did succeed in identifying a number of problems related to water quality, habitat, toxins and contaminants, as well as fish and wildlife health, and based on these findings, the Lower Columbia River Estuary became a part of the National Estuary Program (LCREP 1999).

In 1995 the US Army Corp of Engineers (USACE) oversaw the modification of a portion of the south jetty to restore fish access in Trestle Bay (Hinton and Emmett 2000). Monitoring of fishes as well as benthic and epibenthic invertebrates before and after the breach of the jetty was conducted by NMFS. Prior to the breach water had been exchanged through the jetty but habitat within the Bay could not be utilized by larger fishes. The non-native and cryptogenic species discovered in the species collection by Hinton and Emmett (2000) are nearly identical to those reported by Furota and Emmett (1993) in Baker Bay in 1981 with the addition of one cryptogenic polychaete *Scolelepsis squamata*, and one non-native cumacean *Nippoleucon hinnumensis*, and no reports of *Glycinde polygnatha* (Furota and Emmett 1993, Hinton and Emmett 2000). In spite of the unusually large number of non-native and cryptogenic species (greater than ten) no discussion of ANS was made in either report.

Further upstream geographically limited investigations were made by NMFS into the benthic invertebrate communities present at the Westport Ferry Channel (OR) as well as at Cottonwood Island (WA). Between 1989 and 1994 the effects of dredging on benthic invertebrates were measured in the navigation channel of the Westport Ferry before and after dredging was conduced by USACE (McCabe et al. 1998, McCabe and Hinton 1990). Benthic invertebrate species collections were similar to those reported further upstream in main channel habitats by McCabe et al. (1997) with *Corbicula fluminea* and *Hyalella azteca* the only non-native and cryptogenic species appearing on the species lists. Cottonwood Island, the site of another USACE project, was surveyed in 1987 and 1988, before and after the construction of a rock-groin (McCabe et al. 1990). Unlike the above benthic invertebrate communities, these shallower locations were characterized by a greater diversity of aquatic insect larvae, identified only to the lowest practical taxa.

In 1991, a brief article summarized the capture of *Anguilla* spp. eels along the West Coast of North America and on the Aleutian and Hawaiian Islands (Williamson and Tabeta 1991). Three eels were captured in the vicinity of Portland, OR. The authors reported that numerous attempts were made in the past to stock the West Coast with *Anguilla rostrata.* All of the eels in the survey, Williamson and Tabeta (1991) concluded, were either intentional live seafood releases or escapees and would be unable to reproduce as the eastern Pacific Ocean lacks the necessary physical conditions for this catadromous species.

In the first publication since 1944 to report the establishment of a nonindigenous species in the lower Columbia River, Cordell et al. (1992) described *Pseudodiaptomus inopinus*, a planktonic Asian calanoid copepod present in the estuary. The team of researchers reporting the finding of this ANS in samples collected in 1990 made similar surveys of zooplankton in 1979 and 1980 with out finding this species, thus narrowing the window of time when the copepod might have arrived. Cordell et al. (1992) reported that the transport and introduction of *P. inopinus* was likely through ballast water and hypothesized that its establishment may have been enhanced by the anthropogenic manipulation in river flow below the Bonneville Dam.

The 1990s saw a resurgence in studies of fishes (likely due to improvements in water quality) in the lower Willamette, which has been overlooked by researchers in much the way as the main stem of the lower Columbia River. Work by Ward and Nigro (1992) and Farr and Ward (1993) complemented an earlier report by Hutchinson and Aney (1964) to the Oregon State Water Resources Board describing the general distribution of fish species present in the lower Willamette Basin and noting whether or species were introduced into the system (primarily as games fish). Three introduced species identified in this early report but not labeled as game fish were the common carp, goldfish and tench (Hutchinson and Aney 1964). Farr and Ward (1993) surveyed the fishes of the Lower Willamette River, reporting the presence of 19 non-native species including *Piaractus brachypomus*, a traumatogenic species from the Amazon.[7] In 2000 the City of Portland began a four year project to study both the resident and anadromous fishes of the lower Willamette (North et al. 2002) and will continue to report the presence of non-native fishes.

In 1994, a review of the impacts of dams on the estuarine environment of the Columbia River was published by NMFS and the Bonneville Power Administration (Weitkamp 1994). This report was unique in that it included a review of ANS in the lower Columbia River, discussed the potential impacts of ANS on salmonids and the ecology of the estuary and put forth the idea that impounding the river may have benefited non-native species.

In 1995 NMFS researchers sampling at river mile 74 (river km 120) discovered a new ANS in the Columbia River, a freshwater Siberian prawn, *Exopalaemon modestus,* (Emmett et al. in press). Subsequent studies captured additional prawns further and further upstream and into the Columbia River Slough in Portland, OR (C. Smith personal communication, S. Johnson personal communication, Emmett et al. in press).

The Clatsop Economic Development Council runs several net pen salmon raising facilities in and around Astoria, OR. As part of their NPDES permitting, the CEDC is required to take benthic invertebrate samples on annual basis (R. Litton personal communication). The CEDC benthic sampling surveys show a dramatic increase in *Fluminicola virens* at their pens in Youngs Bay in 1995, and 1996 (Litton unpublished data) later attributed to the establishment of (and subsequent mis-identification of) the ANS *Potamopyrgus antipodarum*, the New Zealand mudsnail (R. Litton personal communication). Since then the CEDC has found the invasive snail near their net pens in Cathlamet Bay, and a population of *P. antipodarum* has also been reported from Hammond, OR (M. Dybdahl personal communication, CEDC 2000). The population in Hammond, OR has been found to have the same genotype as the population of mudsnails in the Snake River (Dybdahl in press) indicating the Hammond population originated upstream. It is not known how this range expansion occurred.

<u>The Environmental Monitoring and Assessment Program</u>

The Environmental Monitoring and Assessment Program (EMAP) is a research program housed by the US Environmental Protection Agency that seeks to “develop the tools necessary to

[7] It is unlikely that this species could have survived its introduction into the Willamette and has not been found in subsequent surveys (D. Ward personal communication).

monitor and assess the status and trends of national ecological resources" (http://www.epa.gov/emap/). This program began sampling coastal bays and estuaries along the East Coast in 1990 and, in 1999 initiated sampling projects along the West Coast (EMAP Western Pilot). Sampling of the lower Columbia River was conducted over a two-year span 1999-2000 with samples collected by the Washington Department of Ecology and the Oregon Department of Environmental Quality.

There are eight 1999 Washington sample locations in Grays Bay, the Cowlitz River, Carrolls Channel, and Martin Slough. The seventeen 1999 Oregon sampling locations are located in the small bays and sloughs adjacent to the main stem of the lower Columbia River Estuary. These include Youngs Bay, Cathlamet Bay, and many smaller sloughs and tributaries. In 2000, EMAP samples were collected from 50 locations in the main channel of lower Columbia River estuary. The sampled area included the entire length of the tidally-influenced portion of the river, extending upstream to the Bonneville Dam.

Lastly, in 2000 the Environmental Protection Agency began a two-year sampling effort in the lower Columbia River as part of its Environmental Monitoring and Assessment Program (EMAP). In 1999 25 locations were selected and sampled in the bays and sloughs of the lower Columbia River, while 50 stations located along the main channel were sampled in 2000.

3.3 Conclusion:

Many of the previous studies performed in the lower Columbia River have several things in common: a lack of taxonomic resolution with individuals identified only to the lowest practical levels, a logical protocol for a variety of projects but one that leaves many taxa poorly studied; lack of geographic scope making some areas well-studied and others virtually un-sampled; and little to no discussion of non-native species even when those species are found to dominate biomass and/or play a role in the feeding ecology of commercially important species. With the growing awareness of ANS as well as their potential economic and ecological impacts it is likely that an increase ANS reporting and discussion of their ecological role in future studies of the lower Columbia River will occur.

The lower Columbia River is often divided into two areas, the estuary and the freshwater main stem, the estuary has been studied more thoroughly than the main stem portion of Columbia River. The main stem of the lower Columbia River has been characterized as depauperate, industrialized and impacted by anthropogenic manipulations of the river. Few studies have characterized the biota of the main channel habitat and fewer have ventured into the adjacent sloughs and backwaters of the main stem.

Given the above conclusions a sampling plan for characterizing the ANS present in the Columbia River that optimizes effort and resources was developed. Biological data generated by the sampling plan will assist in the evaluation of rates and vectors of invasion and will allow establishment of long-term ANS monitoring stations.

While attempts were made to obtain all information available in the published literature, reports from local, state and federal agencies, consulting firm surveys and other records, it is likely that this review is not complete – additional small reports, papers and collections made by local agencies, consulting groups, etc. continue to surface, however, they are not likely to provide additional information needed for the development of the species list/year one sampling plan being of limited taxonomic scope (and quality). Additional reports, however, are not likely to provide information of value in the development of the species list and first year sampling plan because of the typically limited taxonomic scope of these reports. Additional reports may help ascertain the distribution and impacts of non-native species. New reports will continue to be collected, reviewed, and added to the project.

4. SURVEY PLAN

The intent of the Lower Columbia River Aquatic Nonindigenous Species Survey (LCRANS) is to provide a broad and comprehensive search for ANS in the lower Columbia River (from Bonneville Dam to the Pacific Ocean including the tidally influenced portions of major tributaries where possible). Since most of the previous biological research and species collections in the lower Columbia River have not focused on ANS, we hope to provide qualitative baseline information on the presence and distribution of ANS in this portion of the river. The baseline information may be used to evaluate new species discoveries in the river and help evaluate the efficacy of ballast water management and other activities implemented to reduce ANS introductions.

4.1 2002 Survey: Approach

To detect both recent introductions and previously established populations of ANS in the lower Columbia River in 2002 we will use the following methods:

Rapid Assessment Surveys

Marine, estuarine and freshwater invertebrates and aquatic macrophytes will be extensively sampled in three general locations: the Columbia River estuary, the Longview/Kelso corridor, and the Willamette river valley flood plain. We will utilize experienced ecologists, biologists and taxonomists to survey major habitats and communities and catalog each species collected, native and non-native species alike. Some identifications will be made in the field, others in the laboratory during the survey, still others may require highly specialized investigations that will be undertaken by taxonomists in the own labs. The goals of the rapid assessment survey are two-fold: to create an inventory of species in the lower Columbia River basin and to generate data for distributional maps. Rapid assessment surveys will be conducted in the freshwater portion of the study area from June 24th - June 28th. In the estuary sampling will take place from July 8th – July 12th.

Focused Surveys

In addition to the above rapid assessment surveys we will also focus our sampling efforts on taxa-specific field collections at appropriate locations. The objective of this strategy is to utilize taxonomic experts to sample and analyze key taxonomic groups that are difficult to identify, resulting in their being under-studied on the lower Columbia River. Wherever feasible, we will encourage taxonomic experts to sample the sites using their own specialized methods, equipment and knowledge. Some focused surveys will be performed by individuals or smaller teams throughout the full sampling season to enhance distribution data, species collection, etc.

Re-examination of archived samples

In the fall and winter of 2002 –2003 we plan to evaluate the possibility of re-examining samples collected from previous studies. We will be especially interested in ANS collected only once by researchers as well as by species collected previously that were not collected during our sampling. Such re-evaluation by taxonomic experts will allow us to determine whether species were previously misidentified or represent ANS that failed to become established.

Emergence Traps

The lack of information available on aquatic insects in the lower Columbia River, combined with the growing records of invasive aquatic insects (such as mosquitoes) has led us to consider the practicality of using emergence traps to collect adult aquatic insects for identification. We will use both submerged and suspended emergence traps to gather a full spectrum of aquatic insects. Further consultation with aquatic entomologists will allow us to strategically sample the basin.[8]

Cooperative Projects

In addition to the above sampling plans we are very conscious of the need to work cooperatively with new and on-going research in the lower Columbia River. Not only with this allow us to expand our coverage of the study area, it will also allow us to stretch our research budget while increasing regional awareness of ANS issues and the need to identify and report new species.

- We will be working with the Washington Department of Ecology to expand their qualitative non-native aquatic plant surveys along the Washington side of the lower Columbia River to a greater number of locations, including along the Oregon side of the river basin.

- We are investigating collaboration with the City of Portland, which as part of their Endangered Species Act Program, will begin annual sampling of benthic invertebrates in the autumn of 2002 along the lower Willamette River as part of a four-year project (North et al. 2002).

- We are coordinating our ANS survey with efforts by Portland State University to monitor and detect Chinese mitten crabs and zebra mussels in the lower Columbia River and will continue to share information between the two projects.

- Through our Technical Advisory Committee we have developed close ties to a variety of regional programs as well as agencies that conduct research with in our sampling area. Through close communication with these committee members we will stay up-to-date with sampling efforts taking place along the lower Columbia River and will have the opportunity to develop cooperative ties to these specific projects.

[8] There is also a growing interest in introduced mosquitoes because they may be vectors for human and animal diseases. However, the majority of introduced mosquitoes are “container” species (i.e. breeding and transportation is associated with manmade structures such as tires) and are less likely to be found in our study areas (J. Townzen personal communication). County vector control offices in the region sample routinely for mosquitoes and we will be in contact with them to stay up-to-date about any newly introduced species and have them identify any mosquitoes we find in our surveys.

Our sampling strategy utilizing the above array of methods will serve to maximize spatial, temporal, taxonomic, and habitat coverage, while focusing our resources on areas thought to be at high risk of invasion as well as locations and taxa with little or no available information. As ANS, especially previously undocumented species, may be distributed patchily throughout the study area, we hope to overcome this stochastic element and increase our ability to detect ANS in the lower Columbia River by employing a variety of sampling strategies at different times and locations throughout the spring and summer. The field surveys will provide broad coverage of the lower Columbia River, additionally targeting locations which we anticipate will serve as long-term monitoring stations. Without meticulous identification to species by expert taxonomists, ANS may be confused with similar native species or may belong in taxonomic groups which are rarely or never resolved to the species level. Utilizing taxonomic experts whenever possible (by bringing them to the study site or contracting work from them) will provide definitive identifications as well as allowing for thorough evaluation of the status of each species collected.

4.2 2002 Survey: Sampling Locations

Sampling sites and locations were selected using the following criteria. Many of these locations encompass patches of varying habitat with numerous sites which have the following characteristics:

- areas likely to be associated with ballast water discharge
- ports and sites of sustained disturbance by human activities
- habitats with previously reported ANS and cryptogenic species;
- marinas, floats, buoys, and pilings with accessible fouling communities;
- poorly studies locations in the estuary and along the tidal freshwater main-stem
- locations reported to or believed to support poorly studied taxa
- locations with historical data allowing for the calculation of invasion rates and the establishment of long-term monitoring stations

The locations listed below have been selected for sampling in the 2002 sampling season. Many of these sites are ideal permanent sampling locations and are noted as such. Sampling will take place at numerous stations at each location as determined by the taxonomic experts and sampling teams upon arrival at each location and as allowed by gear, tide height, etc. Before being accepted most sites were visited by a reconnaissance survey team.

- Trestle Bay (OR)
- Baker Bay (WA)
- Tansy Point (OR)
- Chinook / Chinook Point (WA)
- Youngs Bay (OR)
- Tongue Point (OR)
- Cathlamet Bay/Lewis and Clark National Wildlife Refuge (OR)
- Coal Creek Slough/Fisher Island Slough (WA)

- Longview/Kelso (WA)
- Cottonwood Island/Carrolls Channel (WA)
- Woodland Peninsula (WA)
- Multnomah Channel / Sauvie Island (OR)
- Vancouver Lake River (WA)
- Columbia Slough (OR)

4.2.1 Columbia River Estuary

ADD LABELED MAP

Trestle Bay and Baker Bay

These two bays, one on either side of the river, were chosen because they are high salinity (polyhaline) areas that have high primary productivity, extensive tidal flats and high numbers of ANS and cryptogenic species. Trestle Bay is a physically protected site and was extensively sampled by NMFS before and after the breaching of its riprap jetty (Hinton and Emmett 2000). It is also protected from development as a part of Fort Stevens State Park. Previous sampling efforts indicate that Trestle Bay may be the site of more than ten non-native and cryptogenic species. Baker Bay is partially protected by tidal sand flats and sand islands, although there is a channel that extends to Ilwaco Harbor along the west side of the bay. Ilwaco is not a deep water port but the harbor has berths for recreational and small commercial fishing vessels. Previous sampling efforts in Baker Bay identified a shift in the benthic community when freshwater flow is at its lowest in mid-summer (Furota and Emmett 1993). In addition, both sites are downstream of the Astoria anchorage, a site where ballast water is released by ships waiting to dock or to continue upstream. A small boat will be used to reach areas and taxa in both bays that cannot be sampled from the shoreline or from existing over-water structures. Boats can be launched at Ilwaco and in Hammond, OR upstream of Trestle Bay. We also intend to obtain permission to sample the Coast Guard dock at Cape Disappointment just outside of Baker Bay at the mouth of the Columbia. This will represent the highest salinity station in our survey.

Tansy Point and Chinook Point

The downstream edge of Youngs Bay is Tansy Point, a location thought to demarcate the shift from hard to soft biofouling communities (A. Baptista personal communication) and the generalized delineation of the polyhaline and mesohaline portions of the estuary. Chinook Point, on the Washington side of the river at the east end of Baker Bay appears to be the most closely corresponding site to Tansy Point. Chinook and Tansy Points represent the ends of physical gradients that may be ideal for spotting poorly distributed non-native species. Both sites are also closely associated with the above-mentioned Astoria anchorage and associated ballast water discharge. Habitat at both sites consists of mudflats, riprap and a narrow band of brackish-water vegetation. Sites are readily accessible by boat and automobile.

Youngs Bay

Located in the mesohaline portion of the Lower Columbia River estuary, Youngs Bay was chosen for its unique brackish tidal mud flats (both exposed and sheltered). With over 20 years of sampling history (conducted by NMFS, OSU and CREDDP), Youngs Bay is a well-studied area. This large, shallow embayment supports moderate densities of benthic infauna (Fox et al. 1984) and a composite species list for this area reports the presence of ten nonindigenous species: two non-native fishes, two plants and six invertebrates, and three cryptogenic invertebrates. As such it appears to be an ideal location for long-term monitoring of ANS. The proximity of the Port of Astoria and the Astoria anchorage suggest that Youngs Bay may be the site of frequent ballast water inoculations. Youngs Bay has a mixture of urbanized shoreline, riprap and diked mudflats. The varied habitats in Youngs Bay will be accessed by boat, automobile and foot via the western dike access roads.

At the north end of the bay at the mouth of Youngs River there are salmon net pens run by the Clatsop Economic Development Council (CEDC). The CEDC net pens have associated benthic invertebrate data collected over the past ten years. It was here that New Zealand mudsnails (*P. antipodarum)* were first identified in the lower Columbia River (Litton unpublished data).

<u>Tongue Point</u>

This narrow spit of land is located at the eastern edge of Astoria, OR and delineates the general boundary between the mesohaline and the oligohaline and tidal freshwater portions of the Columbia River. The Columbia River runs along the western side of Tongue Point while the eastern side borders Cathlamet Bay. There are several large docks built by the Department of Defense that will serve as ideal sampling locations. More recently the CEDC has expanded it net pen operation to Tongue Point and benthic invertebrate samples have been taken at this location as well.

<u>Cathlamet Bay</u>

This large tidal freshwater bay is dominated by tidal mud flats, emergent marsh and sand flats. The marsh islands that make up the Lewis and Clark National Wildlife Refuge in Cathlamet Bay are vast and have received limited study, however, previous studies have documented more than five non-native species distributed through out the islands. Located upstream of the Astoria anchorage, strong tides may occasionally deliver ballast water to the area. A small, light-weigh, flat-bottomed boat will be needed to sample the bay and associated flats.

4.2.2 Longview/Kelso Corridor

ADD LABELED MAP

The array of stations making up the Longview/Kalama corridor, from the Woodland peninsula downstream past Kalama, Cottonwood Island, Longview/Kelso, to Coal Creek Slough, can be compared to view possible effects of ballast water on the middle stem of the Lower Columbia River. Moving downstream, the Port of Kalama (an active grain terminal) lies between Woodland and Cottonwood Island. Cottonwood Island is upstream of the mouth of the Cowlitz River as well as the Port of Longview. Downstream of the Port of Longview and its adjacent anchorage is a system of sloughs and drainages we will refer to as Coal Creek Slough. Along the main-stem of this corridor are several deeper water, channel sites previously sampled for benthic invertebrates by NMFS (McCabe et al. 1997). Re-sampling at any of these locations will allow us to develop an invasion time-line should new ANS be found there.

Coal Creek Slough

Downstream of both the Ports of Kalama and Longview and the Longview/Kelso anchorage, the Coal Creek Slough area includes a vast area of interconnected, tidally influenced drainage ditches as well as an extensive slough protected by the Willow Grove peninsula. Sampling of the slough will be done from a small boat, while the drainage ditches are accessible by foot. Preliminary sampling in an adjacent drainage ditch found thickets of *Iris pseudocorus* (yellow flag), mats of *Myriophyllum aquaticum* (parrot feather), and a large snail tentatively identified as a Chinese mystery snail never officially reported from the lower Columbia River.

Port of Longview

The Port of Longview is one of five deep-water ports on the lower Columbia River and boasts an expansive system of berths exporting timber, agricultural and mining products. The Port of Longview is bordered on the south side by the Cowlitz River and is a heavily industrialized area. The port is more exposed to scouring and high flows than Coal Creek Slough and will likely support a depauperate benthic community. As an areas of sustained disturbance and one closely associated with ballast water discharge it is important to investigate the biological community. The team will sample the port from a larger boat, possibly also obtaining other access to the port to facilitate sampling of pilings and other infrastructure.

Cottonwood Island

Cottonwood Island is located on the Washington side of the river between the Port of Kalama and the Port of Longview. The river side of the Island was surveyed in 1987-1988 by NMFS (McCabe et al. 1990) during the construction of a rock groin. The benthic invertebrate community was similar to that of the main-channel habitats but with a more diverse aquatic insect community (McCabe et al. 1997, McCabe et al. 1990). The bank side of the island, Carrolls Channel, was the location of a benthic invertebrate survey by the Bi-State program in 1990 and an unusually high number of polychaetes and oligochaetes was reported from this site (Tetra-Tech 1993).

Woodland Peninsula

Located downstream of the confluence of the Lewis and Columbia Rivers, the Woodland Peninsula is characterized by low-lying depositional islands, sandy beaches and sloughs. Upstream of the two deep-water ports along this corridor of the lower Columbia River this location should provide a contrast to the heavily urbanized, ballast-discharge associated areas mentioned above. There are numerous sites along the peninsula accessible by either car or boat that will available for sampling by the team.

4.2.3 Willamette River Confluence

ADD LABELED MAP

Both the Ports of Vancouver and Portland lie within the vast flood plain created by the confluence of the Willamette and Columbia Rivers. Bordered by these ports and their cities, this the most heavily industrialized stretch of the river.

Vancouver Lake/River and Sauvie Island/Multnomah Channel

Two sites, Vancouver Lake River and Multnomah Channel were chosen for comparison. Both locations appear to mirror each other on opposite sides of the river. Both enter the Columbia at approximately the same location and run upstream for several miles. However Multnomah Channel is fed by Willamette River, while the Vancouver Lake River feeds from the newly restored Vancouver Lake, and may be inoculated by ballast water released in the Willamette. In addition, Multnomah Channel has been the site of two unverified mitten crab sightings. Recently, beach seines by Oregon State University in Big McNary Lake, a shallow, turbid lake on Sauvie Island, have reported *Exopalaemon modestus* (Emmett et al. in press).

Columbia Slough

The Columbia Slough, including Smith and Bybee Lakes, is a wildlife area surrounded by urban corridors. The eighteen-mile slough parallels the Columbia River, flowing west to where it empties into the Willamette River in Portland. Historically, the slough served to absorb flood waters from the Columbia River, but industrialization and other changes to adjacent lands have altered its function and it is now a slow-moving "drainage ditch." The City of Portland Endangered Species Act Program has been seining the slough and reports capturing the Siberian prawn, *Exopalaemon modestus,* by the hundreds in the north slough (C. Smith personal communication).

Smith and Bybee Lakes are currently only open to one-way flow through flood gates but will be opened to two-way flow in fall of 2002. All seven species of the fish now in the lakes are introduced non- fish, and the lakes also support nutria and bullfrogs.

4.3 2002 Survey: Focal Taxonomic Collections

Focused surveys are necessary not only to ensure accurate identification species within key taxa with known invaders but also to identify species within taxa that are difficult to identify, overlooked or poorly studied by previous studies. Temperature and salinity will be measured at each collection site. All specimens will be identified to lowest possible taxonomic category. Voucher specimens will be deposited with the Los Angeles County Museum, the California Academy of Sciences and the Smithsonian National Museum of Natural History where appropriate. The precise locality records (lat/long coordinates), notes for each collection site and species distribution maps will be available in the final report.

4.3.1 Aquatic Macrophytes

Aquatic plants and macroalgae will be sampled both as part of the rapid assessments in June and July and as the subject of their own focal survey in mid-August. Freshwater and brackish areas will be surveyed by teams of aquatic plant experts following transects, raking at intervals along each transect, identifying plants (collecting if laboratory identification necessary), and moving on when all expected species and no additional new species have been found. Voucher specimen will be collected, pressed, and archived at Portland State University. The emphasis in the aquatic macrophytes surveys will be on submersed species, a group that are not well described in most wetland studies.

4.3.2 Polychaetes

Polychaete sampling will be focused on but not limited to the estuary, especially those sites where large numbers of possibly mis-identified species wave been reported, such as Trestle Bay, Baker Bay and Youngs Bay. Sampling in soft bottom habitats will be done using benthic grab samplers and box cores. Box cores and dredges are better for sampling mixed soft/hard bottoms. Dredges and sleds will be necessary for hard/rocky bottoms. Long handled scrapers will be used for sampling intertidal rocks, pilings, etc.

The soft sediments will be gently washed with low pressure water flow for screening, to avoid damaging soft-bodied animals. Algal or rocky substrate material will also be screened gently and residue on the screens will be saved to retain any organisms clinging to it. A 0.5-mm mesh screen will be used. Polychaetes will be relaxed with 7% magnesium chloride before fixation in 5-10% formalin. After several days in formalin the samples will be gently rinsed with fresh water to remove the formalin, then preserved in 70-80% ethyl alcohol. Live specimens to be preserved for DNA analysis will go directly into 95% ethyl alcohol.

4.3.3 Oligochaetes

Oligochaete collections will be made via benthic grab samples, cores or dredges. Samples will be washed on a 0.5-mm sieve, picked and all collected organisms fixed in 10% formalin. Intertidal and subtidal mud, silt and silt/sand substrates, especially those with high organic content will be the focus of oligochaete collections. Sampling will take place in all three study areas; the estuary, Longview/Kelso corridor and the Willamette confluence. Oligochaetes will be sent to taxonomic experts for identification.

Oligochaete samples may also be investigated for the presence of pathogens of commercially important species of fish by Jerri Bartholemew of Oregon State University.

4.3.4 Peracarid crustaceans

Survey samples will be collected by hand, scrapings, cores, or dredge as necessary to remove biological communities or substratum from floats, intertidal pilings rocks and intertidal or shallow subtidal mudflats accessible at each collection site. These samples will be washed on an

0.5-mm mesh sieve directly or decanted onto an 0.5-mm mesh sieve and washed following vigorous sloshing in buckets of river water, to suspend organisms from the removed substratum.

Harbor float, rock and piling substratums will be emphasized in all three survey areas but other available habitats will sampled as available. Organisms will be picked directly from substratums during sample collection or from the sieves after washing or from voucher samples of substratums and examined under a stereomicroscope. All collected organisms will be fixed in 10% formalin before transfer to 70% ETOH for long-term preservation. All specimens will be identified to lowest possible taxonomic category. Precise locality records and notes for each collection site will be available from the author.

4.3.5 Copepod Crustaceans

Copepods will be identified from three types of samples. The first method will consist of sweeps made through algal and fouling assemblages on the underside of docks, using a small hand-held net consisting of 130-µm mesh material attached to a stainless steel hoop of approximately 15-cm diameter. An effort will be made to disturb algal and bivalve holdfasts in order to capture copepods from those microhabitats. The second type of samples will be vertical water column plankton hauls made with a 0.25-m diameter 250-µm mesh plankton net off of docks and other over-water structures, river banks and/or from a small boat. The net will be lowered to the bottom, and after waiting approximately one minute for disturbance to dissipate, the net will be slowly pulled to the surface. The third type of samples will be taken in sweeps made through submerged and emergent macrophytes, using a small hand-held net consisting of 130-µm mesh material attached to a stainless steel hoop of approximately 15-cm diameter.

In the laboratory, each sample will be examined under a dissecting microscope, and several representatives of each species of copepod will be removed. Each species will then be further examined under a compound microscope. Identification will be made as far as possible without dissection of individuals (with the exception of occasional removal of the abdomen to facilitate viewing the fifth leg).

4.3.6 Decapod Crustaceans

Focused surveys will be undertaken to capture and map the distribution of non-native freshwater decapod crustaceans, especially the Siberian prawn *Exopalaemon modestus* (adding to preliminary distribution maps by Emmett et al in press.) and the mitten crab *Eriocheir spp.* which has been sighted but never verified from a variety of locations in the lower Columbia River. *Eriocheir spp.* trapping efforts will be undertaken in collaboration with surveying being conducted by Toni Pennington, Portland State University, Portland, OR. A variety of gear will be utilized to capture freshwater decapods. *E. modestus* have been caught previously in dredges, grab samplers, plankton tows, seines, etc. *Eriocheir spp.* are more difficult to capture due to their avoidance of traditional crab and crayfish traps (T. Veldhuizen personal communication). Baited lines, traps, dredges and crab condos will be deployed in areas with sightings. Outreach to and collaboration with local crayfishermen will expand the number of people actively looking for these crabs. Captured *Eriocheir* specimen will be sent to experts at the University of Washington and the California Academy of Sciences for identification within the genus.

4.3.7 Mollusks

Marine, brackish, and freshwater bivalves and gastropods will be collected by hand, via scrappers, dredges and benthic grab samples. Many endemic freshwater taxa are restricted to cold, clear, flowing water (Frest and Johannes 1995), other taxa can be found in slow moving, warmer sloughs, etc. Coarse substrates may support rich fauna, although some are restricted to soft substrate. Habitats characterized by, nutrient loading and/or other organic and inorganic water pollution generally have low diversity faunas dominated by widespread species as do areas with abundant macrophytes and/or abundant epiphytic algae (Frest and Johannes 1995). Collection methods will vary according to substrate type and degree of aquatic macrophyte cover. Notes on collection conditions, substrate, habitat, and associated flora and fauna will be made at each site.

To ensure successful identification we will follow the preservation methods outlined in Frest and Johannes (1995): For samples expected or known to contain difficult to identify species, relaxation, fixation, and preservation using a succession of menthol, dilute formalin, and either isopropyl or ethyl alcohol will be undertaken. After careful sorting, samples will be cleaned prior to relaxation to remove as much extraneous organic matter as possible. lf larger mollusks are present, they will be removed and relaxed separately. Sieved mollusks should be spread in a shallow layer in as many flat-based containers as necessary and covered with habitat water to a depth of several inches. A small amount of menthol and/or propylene phenoxytol will be added to each container which will be left undisturbed over night. After 12 hours, the water will be replaced with 4% formalin. In 1-2 days, this will be replaced by 70 % isopropyl or ethyl alcohol. For long-term preservation, the specimens will be placed in 70% ethyl alcohol-15% glycerin, buffered to pH 7.

4.3.8 Aquatic Insects

Sampling protocols for aquatic insects will be determined by the habitat being sampled (guidelines taken from Merritt et al. 1996). In large river areas grab samplers will be used to collect insects located in benthic sediments, plankton samplers will be used to collect drift and neuston specimen, and, where feasible, emergence traps will be placed to capture adults. In shallow vegetated standing and slow water habitats grab samplers and scrappers will be used to collect specimen in sediments, scrappers and manual removal will be used to sample in the vegetation itself, dip nets and plankton tows will be used to sample neuston, floating and submerged emergence traps will also be deployed. Sediments will be gently rinsed on 0.5-mm mesh sieves, picked and sorted as best as possible in the field. Vegetation samples will be agitated in buckets of water and picked.

Collected specimen will be fixed with 95% ethanol and specimen will be stored in 80% ethanol for preservation. Further sorting may occur before specimen are shipped to their respective taxonomic experts for identification.

4.4 2003 Survey

The analysis of the baseline biological data collected in 2002 will shape the 2003 sampling plan. In addition we will continue to work cooperatively with ongoing and new research projects in the lower Columbia River. A unique aspect of the 2003 sampling year will be the implementation of fouling plate community surveys.

Fouling Plate Surveys

Working cooperatively with the Smithsonian Environmental Research Center (SERC) we will be developing any array of fouling plates that will be deployed throughout the lower Columbia River. These survey plates will also be part of a larger nation-wide fouling plate survey conducted by SERC. The objective will be to provide a replicable standard sampling method for assaying ANS. Cooperation with the Coast Guard Auxiliary will be essential for the placement and collection of fouling plates. As the timeline for the development and implementation of this sampling strategy is lengthy, deployment of fouling plates has been scheduled for the spring of 2003.

Fouling plate arrays will be deployed at a variety of locations to be determined in consultation with SERC. At each site several arrays will be suspended at depths of either 1 meter or 3 meters below mean low water level. Each array will consist of settling plates attached to a frame made of two crossed pieces of PVC pipe, suspended in a horizontal position by a line attached to a dock or float and weighted by a concrete block. Settling plates made of thick PVC or plywood will be attached to each of the ends of the PVC pipe in a horizontal position. The horizontal orientation will assure that sediment will not accumulate on the underside, providing a clean surface in addition to several irregular surfaces of the frame and top surfaces for settlement. To maximize the chance of detecting possible ANS at each site, the arrays will be dispersed as widely as possible to sample the range of microhabitats present. We plan to deployed the plates during the spring of 2003 and retrieved them in fall, providing a “soak time” of about 4 months.

5.0 REFERENCES

Bottom, D.L. K.K. Jones, and M. J. Herring. 1984. Fishes of the Columbia River Estuary. CREDDP, Astoria, Oregon. 113pp.

Britton, J.C. and B. Morton. 1979. *Corbicula* in North America: the evidence reviewed and evaluated. Pages 249-287 in: Britton, J.C. (ed.), Proc. 1st Int'l *Corbicula* Symposium. Texas Christian Univ. Fort Worth TX, Oct 13-15, 1977.

Cohen, A.N. and J.T. Carlton. 1995. Nonindigenous Aquatic Species in a United States Estuary: A Case Study of the Biological Invasions of the San Francisco Bay and Delta. United States Fish and Wildlife Service. 246pp.

Cohen, A.N, C.E. Mills, H. Berry, M.J. Wonham, B. Bingham, B. Bookheim, J.T. Carlton, J.W. Chapman, J.R. Cordell, L.H. Harris, T. Klinger, A. Kohn, C.C. Lambert, G. Lambert, K. Li, D. Secord and J. Toft. 1998. Report of the Puget Sound Expedition, September 8-16, 1998; A rapid assessment survey of non-indigenous species in the shallow waters of Puget Sound. For the Washington State Department of Natural Resources, Olympia, WA and the United States Fish and Wildlife Service, Lacey, WA. 37.pp.

Cohen, A.N. H. Berry, C.E. Mills, D. Milne, K. Britton-Simmons, M.J. Wonham, D.L. Secord, J.A. Barkas, Brian Bingham, Betty E. Bookheim, J.E. Byers, J.W. Chapman, J.R. Cordell, B. Dumbauld, Allan Fukuyama, L.H. Harris, A.J. Kohn, K. Li, T.F. Mumford Jr., V. Radashevsky, A.T. Sewell and K. Welch. 2001. Washington State Exotics Expedition 2000: A rapid survey of exotic species in the shallow waters of Elliot Bay, Totten and Eld Inlets, and Willapa Bay. For the Washington State Department of Natural Resources, Olympia, WA. 47pp.

Columbia River Estuary Data Development Program (CREDDP). 1980a. A Literature Survey Of The Columbia River Estuary; Volume 1 Summary. Pacific Northwest River Basins Commission, Vancouver, WA. 63pp.

Columbia River Estuary Data Development Program (CREDDP). 1980b. A Literature Survey Of The Columbia River Estuary; Volume 2 Annotated Bibliography. Pacific Northwest River Basins Commission, Vancouver, WA.

Cordell, J.R., C.A. Morgan and C.A. Simenstad. 1992. Occurrence of the Asian calanoid copepod *Pseudodiaptomus inopinus* in the zooplankton of the Columbia River Estuary. Journal of Crustacean Biology. 12(2)260-269.

Davis, J.S. and R.L. Holton. 1976. Diel activity of two amphipods in the Columbia River estuary. Proceedings of the 5th Technical Conference: Estuaries of the Pacific Northwest, April 1976. Oregon State University, Engineering Experiment Station Circular.

Durkin, J.T. 1973. A list of crustacean shellfish of the lower Columbia River between the mouth and river mile 108 July to October 1973. Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA. 4pp.

Durkin, J.T. and R.J. McConnell. 1973. A list of fishes of the lower Columbia and Willamette rivers. Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA. 13pp.

Durkin, J.T. 1975. An investigation of fish and decapod shellfish found at four dredge material disposal sites and two dredge sites adjacent to the mouth of the Columbia River. For the United States Army Corps of Engineers and National Marine Fisheries Service.

Durkin, J.T., S.J. Lipovksy, G.R. Snyder and M.E. Tuttle. 1977. Environmental studies of three Columbia River Estuarine Beaches. Final Report to Columbia River Program Office. Environmental Conservation Division NOAA-NMFS. 78pp.

Durkin, J.T., S.J. Lipovsky and R.J. McConnell. 1979. Biological impact of a flowlane disposal project near Pillar Rock in the Columbia River estuary. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 92pp.

Durkin, J.T., T.C. Coley, K. Verner and R.L. Emmett. 1981. An aquatic species evaluation at four self scouring sites in the Columbia River estuary. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 46pp.

Durkin, J.T., R.L Emmett, K. Verner, T.C. Coley, W. Muir, G.T. McCabe, Jr. and R.J. McConell. 1982. Benthic macroinvertebrates and substrate of Cathlamet Bay, Oregon. Final Rep. to US Fish and Wildlife Service by the US National Marine Fisheries Service, Seattle, WA. 87pp.

Dybdahl in press

Ebel, W.J. C.D. Becker, J.W. Mullan and H.L. Raymond. 1989. The Columbia River - toward a holistic understanding. p. 205-219. In D.P. Dodge [ed.] Proceedings of the International Large River Symposium. Can. Spec. Publ. Fish. Aquat. Sci. 106.

Ellis, S.G. and C.L. DeGasperi. 1994. The Lower Columbia River Bi-State Program 1991 reconnaissance survey. Lake and Reservoir Management.

Emmett, R.L., G.T. McCabe, Jr., T.C. Coley, R.J. McConnell, and W.D. Muir. 1986. Benthic sampling in Cathlamet Bay, Oregon, 1984. Final Report to U.S. Army Corps of Engineers by U.S. National Marine Fisheries Service, Seattle, Washington. 11pp plus appendices.

Emmett, R.L., S.A. Hinton, D.J. Logan, and G.T. McCabe Jr. In press. Introduction of the Siberian Prawn, *Exopalaemon modestus* (Heller, 1862), into the Lower Columbia River. Biological Invasions.

Fox, D.S., S. Bell, W. Nehlsen and J. Damron. 1984 The Columbia River Estuary: Atlas of Physical and Biological Characteristics. Columbia River Estuary Data Development Program, Astoria, OR.

Frest, T.J. and E.J. Johannes. 1995. Interior Columbia Basin Mollusk Species of Special Concern. Report prepared for Interior Columbia Basin Ecosystem Management Project, Walla Walla, WA.

Furota, T. and R.L. Emmett. 1993. Seasonal changes in the intertidal and subtidal macrobenthic invertebrate community structure in Baker Bay, lower Columbia River estuary. U.S. Dept. Commerce NOAA Tech. Memo. NMFS-NWFSC-5. 68pp.

Geiger, S. Unpublished phytoplankton data archived at Portland State University, Portland, OR.

Good, J.W. 1977a. Plankton. In M.H. Seaman (ed.) Columbia River Estuary Inventory of Physical, Biological and Cultural Characteristics. CREST, Astoria OR. 304.1-304.11.

Good, J.W. 1977b. Benthic Invertebrates. In M.H. Seaman (ed.) Columbia River Estuary Inventory of Physical, Biological and Cultural Characteristics. CREST, Astoria OR. 305.1-305.16.

Haertel, L. and C. Osterberg. 1967. Ecology of zooplankton, benthos and fishes in the lower Columbia River Estuary. Ecology. 48:459-472.

Higley, D.L. and R.L Holton. 1975. Biological baseline data Youngs Bay, Oregon, 1974. School of Oceanography, Oregon State University. 91pp.

Higley, D.L., R.L. Holton, and P.D. Komar.1976. Analysis of benthic infauna communities and sedimentation patters of a proposed fill site and nearby regions on the Columbia River estuary. Final Report to Port of Astoria, Astoria, Oregon.

Hines, A.H. and G.M. Ruiz. 2000. Fouling community surveys. In A.H. Hines and G.M. Ruiz. Biological Invasions Of Cold-Water Coastal Ecosystems: Ballast-Mediated Introductions In Port Valdez / Prince William Sound, Alaska Final Project Report, 15 March 2000.

Hinton S.A. and R.L. Emmett. 2000. Biological surveys of the Trestle Bay enhancement project 1994, 1996-1997. U.S. Dept. Commerce NOAA Tech. Memo. NMFS-NWFSC-39. 72pp.

Holton, R.L. and D.L. Higley. 1976. Gammaridean amphipods in the Columbia River Estuary. Proceedings of the 5th Technical Conference: Estuaries of the Pacific Northwest, April 1976. Oregon State University, Engineering Experiment Station Circular. p 9-12.

Holton, R.L. 1984. Benthic Infauna of the Columbia River Estuary. CREDDP, Astoria, Oregon. 179pp.

Hutchinson, J.M. and W.W. Aney. 1964. The fish and wildlife resources of the lower Willamette basin, Oregon, and their water use requirements. A report with recommendations to the Oregon State Water Resources Board. Federal Aid to Fish Restoration Progress Report. Fisheries Stream Flow Requirements Project F-69-R-1, Job Number 2, Portland, OR, June 1964.

Lampman, B.H. 1946. The Coming of the Pond Fishes; an Account of the Introduction of Certain Spiny-Rated Fishes, and Other Exotic Species, into the Waters of the Lower Columbia River Region and the Pacific Coast States. Binfords and Mort, Portland, Oregon. 177pp.

Litton, R.K. Unpublished data from the Clatsop Economic Development Council Fisheries Project, Astoria, OR.

Litton, R.K. 2000. Youngs Bay Benthic Invertebrate Studies. Report by Clatsop Economic Development Council Fisheries Project, Astoria, OR for Oregon Department of Environmental Quality. 20 pp.

Lower Columbia River Estuary Program (LCREP). 1999. Lower Columbia River Estuary Plan: Comprehensive Conservation and Management Plan, Vol. 1., June 1999. The Lower Columbia River Estuary Program, Portland, Oregon. 222pp.

MacDonald, K.B. and Winfield. 1984. Tidal Marsh Plant Production in the Columbia River Estuary. CREDDP, Astoria, Oregon. 108pp.

McCabe G.T. Jr., 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. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 17pp.

McCabe G.T. Jr., R.L. Emmett and S.A. Hinton. 1993. Feeding ecology of juvenile white sturgeon (*Acipenser transmontanus*) in the lower Columbia River. Northwest Science. 67(3)170-180.

McCabe G.T. Jr., S.A. Hinton, R.L. Emmett, and B.P. Sanford. 1997. Benthic invertebrates and sediment characteristics in main channel habitats in the lower Columbia River. Northwest Science. 71(1)45-55.

McCabe G.T. Jr., S.A. Hinton and R.L. Emmett. 1998. Benthic invertebrates and sediment characteristics in a shallow navigation channel of the lower Columbia River, before and after dredging. Northwest Science. 72(2)116-126.

McConnell, R.J., J.T. Durkin, D. A. Misitano and H.R. Sanborn.1973. Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA. 5pp.

Merritt, R.W., V.H. Resh and K.W. Cummins. 1996 Design of aquatic insect studies: collecting sampling and rearing processes. p. 12-28. In Merritt, R.W and K.W. Cummings (ed.) Introduction to the aquatic insects of North America. 3rd Edition. Kendall Hunt Publishing Company, Dubuqe, IO. 862 pp.

Misitano, D.A. 1973. A checklist of zooplankton in the lower Columbia and Willamette rivers. July to October 1973. Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA.

Montagne and Associates. 1976. Natural resource base and physical characteristics of the proposed offshore oil platform fabrication site. For Pacific Fabricators Inc., Warrenton, OR. 91pp. As cited in Columbia River Estuary Data Development Program (CREDDP). 1980a. A Literature Survey Of The Columbia River Estuary; Volume 1 Summary. Pacific Northwest River Basins Commission, Vancouver, WA. 63pp.

Muir, W.D. and R.L Emmett. 1988. Food habits of migrating salmon smolts passing Bonneville Dam in the Columbia River, 1984. Regulated Rivers: Research and Management. 2:1-10.

Muir, W.D. 1990 .Macroinvertebrate drift abundance below Bonneville Dam and its relation to juvenile salmonid food habits. Masters Thesis, Portland State University, Portland, Oregon. 40.

National Marine Fisheries Service (NMFS). 1995. Proposed Recovery Plan for Snake River Salmon. NOAA, NMFS, Northwest Region, 7600 Sand Point Way N.E. BIN C15700, Building 1, Seattle, Washington. March 1995.

Neal, V.T. 1972. Physical aspects pf the Columbia River and its estuary. p 14-40 In: A.T. Pruter and D.L. Alberson (eds.), The Columbia River Estuary and Adjacent Ocean Waters, Bioenvironmental Studies. University of Washington Press. Seattle, WA.

Nigro, A.A. 1988. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam. Annual Progress Report, July 1987 – March 1988. For Bonneville Power Administration, Division of Fisha nd Wildlife, Project Number 86-50, Portland, OR.

North, J.A. L.C. Burner, B. S. Cunningham, R. A. Farr, T.A. Friesen, J. C. Harrington, H. K. Takata and D. L. Ward. 2002. Relationships between bank treatment, nearshore development and anadromous and resident fish in the lower Willamette River, Annual Report May 2000-June 2001. Report to the City of Portland-Bureau of Environmental Services Endangered Species Act Program. 130pp.

Petts, G.E. 1984. Impounded Rivers: Perspectives for Ecological Management. John Wiley and Sons, New York, NY. 326pp.

Reimers, P.E. and C.E. Bond. 1967. Distribution of fishes in tributaries of the Lower Columbia River. Copeia. 3:541-550.

Robeck, G.C. C. Henderson and R.C. Palange. 1954. Water Quality Studies on the Columbia River. US Department of Health, Education and Welfare.

Ruiz, G.M. P.W. Fofonoff, J.T. Carlton, M.J. Wonham, and A.H. Hines. 2000. Invasion of coastal marine communities in North America: apparent patterns, processes and biases. Annual Review of Ecology and Systematics. 31:481-531.

Sanborn, H.R. 1973. A list of benthic animals in the lower Willamette and Columbia Rivers August to October 1973. Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA. 6pp.

Sanborn, H.R. 1975a. An investigation of the benthic infauna at two dredge and four dredge disposal sites adjacent to the mouth of the Columbia River. Environmental Conservation Division NMFS-NWFSC. 19pp.

Sanborn, H.R. 1975b. Benthic infauna observed at five sites in the Columbia River from August 1973 to July 1974. Environmental Conservation Division NMFS-NWFSC. 19pp.

Sherwood C.R. and J.S. Creager. 1990. Sedimentary geology of the Columbia River Estuary. Progress In Oceanography. 25: 15-80.

Simenstad, C.A. L.F. Small, C.D. McIntire, D.A. Jay and C. Sherwood. 1990a. Columbia River Estuary studies: an introduction to the estuary, a brief history, and prior studies. Progress In Oceanography. 25:1-13.

Smith, H.M. 1896. A review of the history and results of the attempts to acclimatize fish and other water animals in the Pacific States. Bulletin of the United States Fish Commission. 15: 379-472.

Tetra Tech. 1993. Lower Columbia River Bi-State Program Task 6: Reconnaissance Report. May 1993. Vol. 1. The Lower Columbia River Bi-State Water Quality Program.

Ward, D.L. and A.A. Nigro. 1992. Differences in fish assemblages among habitats found in the lower Willamette River, Oregon: application of and problems with multivariate analysis. Fisheries Research. 13:119-132.

Weitkamp, L. 1994. A review of the effects of dams on the Columbia River estuarine environment, with special reference to salmonids. Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration.

WEMAP Unpublished data collected in 1999

Williamson, G.R. and O. Tabeta. 1991. Search for *Anguilla* eels on the West Coast of North America and on the Aleutian and Hawaiian Islands. Japanese Journal of Ichthyology. 33(3)315-317.

Yozzo, D.J. and R.J. Diaz. 1999. Tidal freshwater wetlands: invertebrate diversity, ecology, and functional significance. P.889-918. In: D.P. Batzer, R.B. Rader and S.A. Wissinger (eds.), Invertebrates in Freshwater Wetlands of North America: Ecology and management. John Wile1y & Sons, New York.

6.0 APPENDICES

6.1 APPENDIX A: National Invasive Species Act of 1996, P.L. 104-332

The National Invasive Species Act of 1996 (P.L. 104-332) reauthorized and amended the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (P.L. 101-646).

...

'(1) ECOLOGICAL SURVEYS.—

H. R.4283—10

''(A) IN GENERAL.—The Task Force, in cooperation with the Secretary, shall conduct ecological surveys of the Chesapeake Bay, San Francisco Bay, and Honolulu Harbor and, as necessary, of other estuaries of national significance and other waters that the Task Force determines—

''(i) to be highly susceptible to invasion by aquatic nuisance species resulting from ballast water operations and other operations of vessels; and

''(ii) to require further study.

''(B) REQUIREMENTS FOR SURVEYS.—In conducting the surveys under this paragraph, the Task Force shall, with respect to each such survey—

''(i) examine the attributes and patterns of invasions of aquatic nuisance species; and

''(ii) provide an estimate of the effectiveness of ballast water management and other vessel management guidelines issued and regulations promulgated under this subtitle in abating invasions of aquatic nuisance species in the waters that are the subject of the survey.

''(2) BALLAST WATER DISCHARGE SURVEYS.—

''(A) IN GENERAL.—The Secretary, in cooperation with the Task Force, shall conduct surveys of ballast water discharge rates and practices in the waters referred to in paragraph (1)(A) on the basis of the criteria under clauses (i) and (ii) of such paragraph.

''(B) REQUIREMENTS FOR SURVEYS.—In conducting the surveys under this paragraph, the Secretary shall—

''(i) examine the rate of, and trends in, ballast water discharge in the waters that are the subject of the survey; and

''(ii) assess the effectiveness of voluntary guidelines issued, and regulations promulgated, under this subtitle in altering ballast water discharge practices to reduce the probability of accidental introductions of

aquatic nuisance species.
(3) COLUMBIA RIVER.—The Secretary, in cooperation with the Task Force and academic institutions in each of the States affected, shall conduct an ecological and ballast water discharge survey of the Columbia River system consistent with the requirements of paragraphs (1) and (2).'';

6.2 APPENDIX B: Technical Advisory Committee

Name:	Affiliation
Jim Athern	US Army Corps of Engineers
Jerri Bartholomew	Oregon State University
Jim Carlton	Williams College
Lolita Carter	Portland General Electric
Sebastian Degens	Port of Portland
Mark Dybdahl	Washington State University
Rich Everett	United States Coast Guard
Terrence Frest	Deixis Consultants
Jon Graves	Oregon Graduate Institute
Kathy Hamel	Washington Department of Ecology
Leslie Harris	Los Angeles County Museum of Natural History
Paul Heimowitz	Oregon Sea Grant
R. Deedee Kathman	Aquatic Resources Center
Denny Lassuy	US Fish and Wildlife Service
Henry Lee II	USEPA Coastal Ecology
Claudia Mills	University of Washington
Annette Olson	University of Washington
Blaine Parker	Columbia River Inter-Tribal Fish Commission
Jennifer Parsons	Washington Department of Ecology
Greg Ruiz	Smithsonian Environmental Research Center
Scott Smith	Washington Department of Fish and Wildlife
David Strayer	Institute of Ecosystem Studies
Bruce Sutherland	Lower Columbia River Estuary Program
Jim Townley	Columbia River Steamship Operators Assoc.
Matthew VanEss	Columbia River Estuary Studies Taskforce
Gary Wade	Lower Columbia Fish Recovery Board
David Ward	Oregon Department of Fish and Wildlife
Bob Wisseman	Aquatic Biology Associates
Richard Zack	Washington State University

6.3 Appendix C: Lower Columbia River References

Altman, B., C.M. Henson and I.R. Waite. 1995. Summary of Information on Aquatic Biota and Their Habitats in the Willamette Basin, Oregon, through 1995. United States Geological Survey, Water-Resources Investigations Report 97–4023. 188pp.

Blahm, T.H., R.J. McConnell and L.G. Davis. 1977. Effect of agitation dredging on benthic communities, water quality and turbidity at Chinook Channel. Report to United States Army Corps of Engineers, North Pacific Division. Portland, OR.

Blahm, T.H., R.J. McConnell and J.M. Shelton. 1978. Impact of flow-lane disposal at Dobelbower Bar. Report to United States Army Corps of Engineers, North Pacific Division. Portland, OR. September 1978.

Blahm, T.H., J.T. Durkin, R.J. McConnell, L.G. Davis and T.C. Coley. 1979. Portland Harbor Pre-dredge and Disposal Study. Final Report to Army Corps of Engineers and National Marine Fisheries Service. 24pp plus appendices.

Bottom, D.L., K.K. Jones, and M. J. Herring. 1984. Fishes of the Columbia River Estuary. Columbia River Estuary Data Development Program, Astoria, Oregon. 113pp.

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

Britton, J.C., and B. Morton. 1979. *Corbicula* in North America: the evidence reviewed and evaluated. Pages 249-287 in: Britton, J.C. (ed.), Proc. 1st Int'l Corbicula Sym., Texas Christian Univ., Fort Worth TX, Oct 13-15, 1977.

Brock, R., J.H. Bailey-Brock, and J. Goody. 1999. A case study of efficacy of freshwater immersion in controlling introduction of alien marine fouling communities: the USS Missouri. Pacific Science. 53(3)223-231.

Burch, J.B.1989. North American Freshwater Snails. Malacological Publications, Hamburg Michigan. 365pp.

Carlton, J.T., and J. Hodder. 1995. Biogeography and dispersal of coastal marine organisms: experimental studies on a replica of a 16th-century sailing vessel. Marine Biology. 121:721-730.

Clarain, E.J. et al. 1978. Habitat development field investigations, Miller Sands marsh and uplands habitat development site Columbia River, OR. Summary Report. D-77-38 Vicksburg, MI, United States Army Corps of Engineers Waterways Experiment Station, Dredged Material Research Program.

Columbia River Estuary Data Development Program (CREDDP). 1980a. A Literature Survey Of The Columbia River Estuary; Volume 1 Summary. Pacific Northwest River Basins Commission, Vancouver, WA. 63pp.

Columbia River Estuary Data Development Program (CREDDP). 1980b. A Literature Survey Of The Columbia River Estuary; Volume 2 Annotated Bibliography. Pacific Northwest River Basins Commission, Vancouver, WA.

Cordell, J.R., C.A. Morgan and C.A. Simenstad. 1992. Occurrence of the Asian calanoid copepod *Pseudodiaptomus inopinus* in the zooplankton of the Columbia River Estuary. Journal of Crustacean Biology. 12(2)260-269.

Cordell, J.R., and S.M. Morrison. 1996. The invasive Asian copepod *Pseudodiaptomus inopinus* in Oregon, Washington, and British Columbia estuaries. Estuaries. 19(3)629-638.

Craddock, D.R. T.H. Blahm and W.D. Parente. 1976. Occurrence and utilization of zooplankton by juvenile chinook salmon in the lower Columbia River. Trans. Am. Fish. Soc. 105:72-76.

Daly, K.L., and D.M. Damkaer. 1986. Population dynamics and distribution of *Neomysis mercedis* and *Alienacanthomysis macropsis* (Crustacea: Mysidacea) in relation to the parasitic copepod *Hansenulus trebax* in the Columbia River Estuary. Journal of Crustacean Biology. 6(4)840-857.

Davis, J.S., and R.L. Holton. 1976. Diel activity of two amphipods in the Columbia River estuary. Proceedings of the 5th Technical Conference: Estuaries of the Pacific Northwest, April 1976. Oregon State University, Engineering Experiment Station. Circular

Durkin, J.T. 1973. A list of crustacean shellfish of the lower Columbia River between the mouth and river mile 108 July to October 1973. Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA. 4pp.

Durkin, J.T. and R.J. McConnell. 1973. A list of fishes of the lower Columbia and Willamette rivers. Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA. 13pp.

Durkin, J.T. 1975. An investigation of fish and decapod shellfish found at four dredge material disposal sites and two dredge sites adjacent to the mouth of the Columbia River. For the United States Army Corps of Engineers and National Marine Fisheries Service.

Durkin, J.T., S.J. Lipovksy, G.R. Snyder and J.M. Shelton. 1976. Section I: Changes in epibenthic estuarine fish and invertebrates from propeller agitation dredging. In: National Marine Fisheries Service. Impact of agitation dredging at Chinook Channel. Report to United States Army Corps of Engineers North Pacific Division, Portland, OR.

Durkin, J.T., S.J. Lipovksy, G.R. Snyder and M.E. Tuttle. 1977. Environmental studies of three Columbia River Estuarine Beaches. Final Report to Columbia River Program Office. Environmental Conservation Division NOAA-NMFS. 78pp.

Durkin, J.T., S.J. Lipovsky and R.J. McConnell. 1979. Biological impact of a flowlane disposal project near Pillar Rock in the Columbia River estuary. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 92pp.

Durkin, J.T. and R.L. Emmett. 1980. Benthic invertebrates, water quality and substrate texture in Baker Bay, Youngs Bay, and adjacent areas of the Columbia River Estuary. Final Rep. to U.S. Fish and Wildlife Service by U.S. National Marine Fisheries Service, Seattle, WA. 44p. plus appendices.

Durkin, J.T., T.C. Coley, K. Verner and R.L. Emmett. 1981. An aquatic species evaluation at four self scouring sites in the Columbia River estuary. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 46pp.

Durkin, J.T., R.L Emmett, K. Verner, T.C. Coley, W. Muir, G.T. McCabe, Jr. and R.J. McConnell. 1982. Benthic macroinvertebrates and substrate of Cathlamet Bay, Oregon. Final Rep. to US Fish and Wildlife Service by the US National Marine Fisheries Service, Seattle, WA. 87pp.

Dybdahl in press

Ebel, W.J., C.D. Becker, J.W. Mullan and H.L. Raymond. 1989. The Columbia River - toward a holistic understanding. p. 205-219. In D.P. Dodge [ed.] Proceedings of the International Large River Symposium. Can. Spec. Publ. Fish. Aquat. Sci. 106.

Ellis, S.G., and C.L. DeGasperi. 1994. The Lower Columbia River Bi-State Program 1991 reconnaissance survey. Lake and Reservoir Management.

Emmett, R.L., G.T. McCabe, Jr., T.C. Coley, R.J. McConnell, and W.D. Muir. 1986. Benthic sampling in Cathlamet Bay, Oregon, 1984. Final Report to U.S. Army Corps of Engineers by U.S. National Marine Fisheries Service, Seattle, Washington. 11pp plus appendices.

Emmett, R.L.1997. Estuarine survival of salmonids: the importance of interspecific and intraspecific predation and competition. 147-158. In Emmett, R.L. and M.H. Schwele (eds). Estuarine and Ocean Survival of Northeast Pacific Salmonids: Proceedings of the Workshop. U.S. Dept. Commerce., NOAA Tech. Memo. NMFS-NWFSC-29. 313p.

Emmett, R.L., S.A. Hinton, D.J. Logan, and G.T. McCabe Jr. In press. Introduction of the Siberian Prawn, *Exopalaemon modestus* (Heller, 1862), into the Lower Columbia River. Biological Invasions.

Farr, R.A., and D.L. Ward. 1993. Fishes of the lower Willamette River, near Portland, Oregon. Northwest Science. 67:16-22.

Fishman Environmental Services. 1996. Studies of Dredged Material Rehandling Sites: Channel Deepening Feasibility Study. Port of Portland, Portland OR.

Fox, D.S., S. Bell, W. Nehlsen and J. Damron. 1984 The Columbia River Estuary: Atlas of Physical and Biological Characteristics. Columbia River Estuary Data Development Program, Astoria, OR.

Frest, T.J., and E.J. Johannes. 1995. Interior Columbia Basin Mollusk Species of Special Concern. Report prepared for Interior Columbia Basin Ecosystem Management Project, Walla Walla, WA.

Furota, T., and R.L. Emmett. 1993. Seasonal changes in the intertidal and subtidal macrobenthic invertebrate community structure in Baker Bay, lower Columbia River estuary. U.S. Dept. Commerce NOAA Tech. Memo. NMFS-NWFSC-5. 68pp.

Gadomski, D.M., and C.A. Barfoot. 1998. Diel and distributional abundance patterns of fish embryos and larvae in the lower Columbia and Deschutes rivers. Environmental Biology of Fishes. 51:353-368.

Giese, B.S., and D.A. Jay. 1989. Modelling tidal energetics of the Columbia River Estuary. Estuarine, Coastal and Shelf Science. 29:549-571.

Good, J.W.1977a. Plankton. In M.H. Seaman (ed.) Columbia River Estuary Inventory of Physical, Biological and Cultural Characteristics. Columbia River Estuary Studies Taskforce, Astoria OR. 304.1-304.11.

Good, J.W. 1977b. Benthic Invertebrates. In M.H. Seaman (ed.) Columbia River Estuary Inventory of Physical, Biological and Cultural Characteristics. Columbia River Estuary Studies Taskforce, Astoria OR. 305.1-305.16.

Gustafson, R.G., T.C. Wainwright, G.A. Winans, F. W. Waknitz, L.T. Parker and R.S. Waples. 1997. Status Review of Sockeye Salmon from Washington and Oregon. NOAA Technical Memorandum, National Marine Fisheries Service, Seattle, Washington. NMFS-NWFSC-33.

Haertel, L. 1965. Biological studies in the Columbia River estuary. pp 3-38. In C.L. Osterberg (ed.) Progress Report: Ecological Studies of Radioactivity in the Columbia River Estuary and Adjacent Pacific Ocean, 1964-1965. Department of Oceanography, Oregon State University. 255pp.

Haertel, L., and C. Osterberg. 1967. Ecology of zooplankton, benthos and fishes in the lower Columbia River Estuary. Ecology. 48:459-472.

Haertel, L., C. Osterberg, H. Curl Jr., and P. Kilho Park. 1969. Nutrient and plankton ecology of the Columbia River Estuary. Ecology. 50:962-978.

Haertel, L.S. 1970. Plankton and Nutrient Ecology of the Columbia River Estuary. Ph.D. Thesis, Oregon State University. 71pp.

Hamilton, P. 1990. Modeling salinity and circulation for the Columbia River estuary. Progress in Oceanography. 25:113-156.

Hanson, E., and M. Sytsma. 2001. Oregon State Aquatic Nuisance Species Management Plan. Center for Lakes and Reservoirs, Portland State University. 91pp.

Heron, G.A., and D.M. Damkaer. 1986. A new nicothoid copepod parasitic on mysids from northwestern North America. Journal of Crustacean Biology. 6(4)652-665.

Hershler, R., and T.J. Frest. 1996. A review of the North American freshwater snail genus *Fluminicola* (Hydrobiidae). Smithsonian Contributions to Zoology. 583:1-41.

Higley, D.L. and R.L. Holton. 1975. Biological baseline data Youngs Bay, Oregon, 1974. School of Oceanography, Oregon State University. 91pp.

Higley, D.L., R.L. Holton and P.D. Komar. 1976. Analysis of benthic infauna communities and sedimentation patters of a proposed fill site and nearby regions on the Columbia River estuary. Final Report to Port of Astoria, Astoria, Oregon.

Higley, D.L., and R.L. Holton. 1978. A grab-sample study of the benthic invertebrates of the Columbia River estuary. Supplemental Data Report 1975-1976 submitted to the Port of Astoria.

Higley, D.L., S.L. Wilson, K.K.Jones and R.L. Holton. 1983. Distribution and community structure of benthic infauna in channel and protected flat habitats of the Columbia River estuary. Report to U.S. Army Corp of Engineers. 77pp.

Hinton S.A., G.T. McCabe and R.L. Emmett. 1990. Fishes, Benthic Invertebrates, and Sediment Characteristics in Intertidal and Subtidal Habitats at Five Areas in the Columbia River Estuary. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 93pp.

Hinton S.A., R.L. Emmett and G.T. McCabe Jr. 1992a. Benthic invertebrates and sediment characteristics in subtidal habitat at Rice Island, Columbia River estuary, December 1991 and March 1992. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 22pp.

Hinton S.A., R.L. Emmett and G.T. McCabe Jr. 1992b. Fishes, shrimp, benthic invertebrates and sediment characteristics in intertidal and subtidal habitats at Rice Island and Miller

Sands, Columbia River estuary, 1991. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 53pp.

Hinton S.A., and R.L. Emmett. 1994. Juvenile salmonid strandings in the lower Columbia River, 1992 and 1993. U.S. Dept. Commerce. NOAA Tech. Memo. NMFS-NWFSC-20. 48pp.

Hinton S.A., G.T. McCabe and R.L. Emmett. 1995. In-water restoration between Miller Sands and Pillar Rock Island, Columbia River: environmental surveys, 1992-1993. U.S. Dept. Commerce NOAA Tech. Memo. NMFS-NWFSC-23. 48pp.

Hinton S.A., and R.L. Emmett. 2000. Biological surveys of the Trestle Bay enhancement project 1994, 1996-1997. U.S. Dept. Commerce NOAA Tech. Memo. NMFS-NWFSC-39. 72pp.

Hinton, S.A., 1998. Benthic infauna and sediment characteristics offshore from the Columbia River, October/November 1995 and June 1996. Fish Ecology Division, NMFS-NWFSC. Seattle, WA. 51pp.

Hjort, R.C., P.L. Hulett, L.D. LaBolle and H.W. Li. 1984. Fish and invertebrates of revetments and other habitats in the Willamette River, Oregon. Report to the Army Corps of Engineers, Vicksburg MS.

Holton, R.L. and D.L. Higley. 1976. Gammaridean amphipods in the Columbia River Estuary. Proceedings of the 5th Technical Conference: Estuaries of the Pacific Northwest, April 1976. Oregon State University, Engineering Experiment Station Circular. p 9-12.

Holton, R.L. 1984. Benthic Infauna of the Columbia River Estuary. Columbia River Estuary Data Development Program, Astoria, Oregon. 179pp.

Howerton, J. 1984. Key Mammals of the Columbia River Estuary. Columbia River Estuary Data Development Program, Astoria, Oregon. 116pp.

Hutchinson, J.M., and W.W. Aney. 1964. The fish and wildlife resources of the lower Willamette basin, Oregon, and their water use requirements. A report with recommendations to the Oregon State Water Resources Board. Federal Aid to Fish Restoration Progress Report. Fisheries Stream Flow Requirements Project F-69-R-1, Job Number 2, Portland, OR, June 1964.

Ingram, W.M. 1948. The larger freshwater clams of California, Oregon and Washington. Journal of Entomology and Zoology.

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. Progress in Oceanography. 25:211-241.

Kirn, R.A., R.D. Ledgerwood, and A.L. Jensen. 1986. Diet of subyearling chinook salmon (*Oncorhynchus tshawytscha*) in the Columbia River estuary and changes effected by the 1980 eruption of Mount St. Helens. Northwest Science 67(3)170-1870.

Kujala, N. 1966. Columbia River sampling program. pp 15-20. In: J.E. McCauley (ed.) Progress Report: Ecological Studies of Radioactivity in the Columbia River Estuary and Adjacent Pacific Ocean, 1965-1966. Department of Oceanography, Oregon State University. 293pp.

Kujala, N. 1975. Columbia River fish and invertebrates. Unpublished report to Columbia River Estuary Studies Taskforce.

Lampman, B.H. 1946. The Coming of the Pond Fishes; an Account of the Introduction of Certain Spiny-Rated Fishes, and Other Exotic Species, into the Waters of the Lower Columbia River Region and the Pacific Coast States. Binfords and Mort, Portland, Oregon. 177pp.

Lara-Lara, J.R., B.E. Frey, and L.F. Small. 1990a. Primary production in the Columbia River Estuary I. Spatial and temporal variability of properties. Pacific Science. 44(1)17-37.

Lara-Lara, J.R., B.E. Frey and L.F. Small. 1990b. Primary production in the Columbia River Estuary II. grazing losses, transport, and a phytoplankton carbon budget. Pacific Science. 44(1)38-50.

Litton, R.K. Unpublished data from the Clatsop Economic Development Council Fisheries Project, Astoria, OR.

Litton, R.K. 2000. Youngs Bay Benthic Invertebrate Studies. Report by Clatsop Economic Development Council Fisheries Project, Astoria, OR for Oregon Department of Environmental Quality. 20 pp.

Lower Columbia River Estuary Program (LCREP). 1999. Lower Columbia River Estuary Plan: Comprehensive Conservation and Management Plan, Vol. 1., June 1999. The Lower Columbia River Estuary Program, Portland, Oregon. 222pp.

MacDonald, K.B., and Winfield. 1984. Tidal Marsh Plant Production in the Columbia River Estuary. Columbia River Estuary Data Development Program, Astoria, Oregon. 108pp.

McCabe, G.T. Jr., R.L Emmett, W.D. Muir, and T.H. Blahm. 1986. Utilization of the Columbia River estuary by subyearling chinook salmon. Northwest Science 60(2)113-124.

McCabe, G.T. Jr., and S.A. Hinton. 1990. Benthic infauna and sediment characteristics on the Columbia River near Westport, Oregon, August 1989. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 14pp.

McCabe, G.T. Jr., 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. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 17pp.

McCabe, G.T. Jr., and S.A. Hinton. 1993. Benthic invertebrates and sediments in vegetated and non-vegetated habitats at three intertidal areas of the Columbia River estuary, 1992. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 37pp.

McCabe, G.T. Jr., R.L. Emmett and S.A. Hinton. 1993. Feeding ecology of juvenile white sturgeon (*Acipenser transmontanus*) in the lower Columbia River. Northwest Science. 67(3)170-180.

McCabe, G.T. Jr., S.A. Hinton and R.L. Emmett. 1993. Benthic and epibenthic invertebrates, fishes and sediments at and adjacent to a proposed new site for Area D, and in-water dredged-material disposal site in the lower Columbia River, 1991. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 42pp.

McCabe, G.T. Jr., S.A. Hinton and R.L. Emmett. 1993. In-water Restoration Between Miller Sands and Pillar Rock Island, Columbia River: Biological Surveys, 1992. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 60pp.

McCabe, G.T. Jr., and S.A. Hinton. 1996. Benthic invertebrates and sediment characteristics in freshwater beach habitats of the lower Columbia River, 1994-1995. NOAA Technical Memo. NMFS-MWFSC-26. 111p.

McCabe, G.T. Jr., S.A. Hinton and R.L. Emmett. 1996. Benthic invertebrates and sediment characteristics in subtidal areas adjacent to Rice Island and Miller Sands, 1993-1994. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 25pp.

McCabe, G.T. Jr., S.A. Hinton and R.L. Emmett. 1996. Benthic invertebrates and sediment characteristics in Wahkium County ferry channel, Washington, before and after dredging. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 32pp.

McCabe, G.T. Jr. 1997. Fishes in Bottom Habitats in Six Flowlane Disposal Areas of the Lower Columbia River. Coastal Zone and Estuarine Studies, NMFS. Seattle, WA. 28pp.

McCabe, G.T. Jr., S.A. Hinton, R.L. Emmett, and B.P. Sanford. 1997. Benthic invertebrates and sediment characteristics in main channel habitats in the lower Columbia River. Northwest Science. 71(1)45-55.

McCabe, G.T. Jr., S.A. Hinton and R.L. Emmett. 1998. Benthic invertebrates and sediment characteristics in a shallow navigation channel of the lower Columbia River, before and after dredging. Northwest Science. 72(2)116-126.

McConnell, R.J., J.T. Durkin, D.A. Misitano and H.R. Sanborn. 1973. Checklist of aquatic organisms in the lower Columbia and Willamette Rivers. NWFSC. 5pp.

McConnell, R.J., S.J. Lipovsky, D.A. Misitano, D.R. Craddock and J.R. Hughes. 1978. Habitat development field investigation Miller Sands marsh and upland habitat development sites, Columbia River, Oregon. National Marine Fisheries Service. Prescott, OR. Final Report to United States Army Corps of Engineers, Waterways Experimental Station.

McIntire, C.D. 1982. The diatom flora as a salinity indicator in the Columbia River estuary. Report to the United States Army Corp of Engineers. DACW57-82-M-2324.

McIntire, C.D. 1984. Benthic Primary Production in the Columbia River Estuary. Columbia River Estuary Data Development Program, Astoria, Oregon. 103pp.

Misitano, D.A. 1973. A checklist of zooplankton in the lower Columbia and Willamette rivers. July to October 1973. Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA.

Misitano, D.A. 1974. Zooplankton, water temperature, and salinities in the Columbia River estuary, December 1971 through December 1972. U.S. Dept. Commerce. NOAA Data Report. NMFS-DR-92. 31pp.

Misitano, D.A. 1977. Species composition and relative abundance of larval and post-larval fishes in the Columbia River Estuary, 1973. Fishery Bulletin. 75:218-222.

Montagne and Associates. 1976. Natural resource base and physical characteristics of the proposed offshore oil platform fabrication site. For Pacific Fabricators Inc., Warrenton, OR. 91pp.

Morgan, C.A., J.R. Cordell and C. A. Simenstad. 1997. Sink or swim? Copepod population maintenance in the Columbia River estuarine turbidity-maxima region. Marine Biology. 129:309-317.

Muir, W.D., and R.L Emmett. 1988. Food habits of migrating salmon smolts passing Bonneville Dam in the Columbia River, 1984. Regulated Rivers: Research and Management. 2:1-10.

Muir, W.D., R.L. Emmett and R.J. McConnell. 1988. Diet of juvenile and subadult white sturgeon in the lower Columbia River and its estuary. California Fish and Game. 74(1)49-54.

Muir, W.D. 1990. Macroinvertebrate drift abundance below Bonneville Dam and its relation to juvenile salmonid food habits. Masters Thesis, Portland State University, Portland, Oregon. 40.

National Marine Fisheries Service (NMFS). 1981. Salmonid and Non-Salmonid Fish 1981, Columbia River Estuary Data Development Program Report. Columbia River Estuary Data Development Program Report.

Neal, V.T. 1972. Physical aspects pf the Columbia River and its estuary. p 14-40 In: A.T. Pruter and D.L. Alberson (eds.), The Columbia River Estuary and Adjacent Ocean Waters, Bioenvironmental Studies. University of Washington Press. Seattle, WA.

Nigro, A.A. 1988. Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam. Annual Progress Report, July 1987 – March 1988. For Bonneville Power Administration, Division of Fisha nd Wildlife, Project Number 86-50, Portland, OR.

North, J.A., L.C. Burner, B. S. Cunningham, R. A. Farr, T.A. Friesen, J. C. Harrington, H. K. Takata and D. L. Ward. 2002. Relationships between bank treatment/nearshore development and anadromous/resident fish in the lower Willamette River, Annual Report May 2000-June 2001. Report to the City of Portland-Bureau of Environmental Services.

Portland General Electric Company. 1971. Preoperational Ecological Monitoring Program for the Trojan Nuclear Plant; Annual Report. Portland General Electric Company, Portland OR.

Portland General Electric Company. 1979 Operational Ecological Monitoring Program for the Trojan Nuclear Plant; Annual Report. Portland General Electric Company, Portland OR.

Pruter, A.T. and D.L. Alberson (eds.). 1972. The Columbia River Estuary and Adjacent Ocean Waters; Bioenvironmental Studies. University of Washington Press. Seattle, WA.

Reimers, P.E. 1964. Distribution of fishes in the tributaries of the Lower Columbia River. MS Thesis, Oregon State University. 74pp.

Reimers, P.E., and C.E. Bond. 1967. Distribution of fishes in tributaries of the Lower Columbia River. Copeia. 3:541-550.

Robeck, G.C., C. Henderson and R.C. Palange. 1954. Water Quality Studies on the Columbia River. US Department of Health, Education and Welfare.

Sanborn, H.R. 1973. A list of benthic animals in the lower Willamette and Columbia Rivers August to October 1973. Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA. 6pp.

Sanborn, H.R. 1975. An investigation of the benthic infauna at two dredge and four dredge disposal sites adjacent to the mouth of the Columbia River. Environmental Conservation Division NMFS-NWFSC. 19pp.

Sanborn, H.R. 1975. Benthic infauna observed at five sites in the Columbia River from August 1973 to July 1974. Environmental Conservation Division NMFS-NWFSC. 19pp.

Seaman, M.H. (ed). 1977. Columbia River Estuary: Inventory of Physical, Biological and Cultural Characteristics. For Columbia River Estuary Studies Taskforce, Astoria, OR. 302pp.

Sherwood C.R. and J.S. Creager. 1990. Sedimentary geology of the Columbia River Estuary. Progress In Oceanography. 25: 15-80.

Sherwood, C.R., D.A. Jay, R.B. Harvey, P. Hamilton and C.A. Simenstad. 1990. Historical changes in the Columbia River estuary. Progress in Oceanography. 25:299-352.

Simenstad, C.A., and J.R. Cordell. 1985. Structural dynamics of epibenthic zooplankton in the Columbia River delta. Verh. Internat. Verein. Limnol.

Simenstad, C.A., L.F. Small, C.D. McIntire, D.A. Jay and C. Sherwood. 1990. Columbia River Estuary studies: an introduction to the estuary, a brief history, and prior studies. Progress In Oceanography. 25:1-13.

Simenstad, C.A., L.F. Small, and C.D. McIntire. 1990. Consumption Processes and food web structure in the Columbia River Estuary. Progress in Oceanography.

Simenstad, C.A., D.A. Jay, and C.R. Sherwood. 1992. Impacts of watershed management on land-margin ecosystems: the Columbia River Estuary. In: R.J. Naiman (ed.) Watershed Management: Balancing Sustainability and Environmental Change. Springer Velag.

Simenstad, C.S. 1984. Epibenthic Organisms of the Columbia River Estuary. CREDDP, Astoria, Oregon. 55pp.

Small, L.F., C.D. McIntire, K.B. MacDonald, J.R. Lara-Lara, B.E. Fey, M.C. Amspoker and T. Winfield. 1990. Primary production, plant and detrital biomass, and particle transport in the Columbia River Estuary. Progress in Oceanography. 25:175-210.

Smith, H.M. 1896. A review of the history and results of the attempts to acclimatize fish and other water animals in the Pacific States. Bulletin of the United States Fish Commission. 15: 379-472.

Stober, Q.J., M.R. Griben, R.V. Walker, A.L. Setter, I. Nelson, J.C. Gislason, R.W. Tyler and E.O. Salo. 1979. Columbia River Irrigation Withdrawal Environmental Review: Columbia River Fishery Study. Army Corps of Engineers, Portland. 244pp.

Tabor, J.E. 1976. Inventory of riparian habitats and associated wildlife along the Columbia River, Volumes 2a,b: Lower Columbia River. United States Army Corps of Engineers, Portland, OR.

Tetra Tech. 1993. Lower Columbia River Bi-State Program Reconnaissance Survey Tasks 1-7. For Lower Columbia River Bi-State Water Quality Program.

Vorderstrasse, R.E. Unpublished letter. Key Species of the Columbia River. To the United States Army Corp of Engineers by the United States Fish and Wildlife Service. 33pp plus appendices.

Ward, D.L., and A.A. Nigro. 1992. Differences in fish assemblages among habitats found in the lower Willamette River, Oregon: application of and problems with multivariate analysis. Fisheries Research. 13:119-132.

Weitkamp, L. 1994. A review of the effects of dams on the Columbia River estuarine environment, with special reference to salmonids. Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration.

Weston, R.F. 1998. Portland harbor sediment investigation report Multnomah County, Oregon. Prepared for U.S. EPA, Region 10, Seattle, WA. Roy F. Weston, Inc., Seattle, WA.

Williams, G.T. 1983. Distribution and Relative Abundance of Major Epibenthic Crustacea in the Columbia River Estuary. Masters Thesis, University of Washington. 98pp.

Williamson, G.R., and O. Tabeta. 1991. Search for *Anguilla* eels on the West Coast of North America and on the Aleutian and Hawaiian Islands. Japanese Journal of Ichthyology. 33(3)315-317.

6.4 APPENDIX D Draft Species List for the Lower Columbia River

A complete copy of the Access databased used to compile this species list is available by request on CD-ROM by contacting the author.

Mammals		Status (ANS, CRYPT)
	Myocaster coypus	ANS

Amphibians		Status (ANS, CRYPT)
	Rana catesbeiana	ANS

Fishes		Status (ANS, CRYPT)
	Acipenser or Scaphirhynchus sp.	ANS
	Acipenser medirostris	
	Acipenser transmontanus	
	Acrocheilus alutaceus	
	Allosmerus elongatus	
	Alosa sapidissima	ANS
	Ambloplites rupestris	ANS
	Ameiurus catus	ANS
	Ameiurus melas	ANS
	Ameiurus natalis	ANS
	Ameiurus nebulosus	ANS
	Ammodytes hexapterus	
	Amphistichus rhodoterus	
	Anguilla sp.	ANS
	Artedius fenestralis	
	Carassius auratus	ANS
	Catostomus macrocheilus	
	Catostomus platyrhynchus	
	Citharichthys sordidus	
	Citharichthys stigmaeus	
	Clupea pallasii	
	Cottus aleuticus	
	Cottus asper	
	Ctenopharyngodon idella	ANS
	Cymatogaster aggregata	
	Cyprinus carpio	ANS
	Embiotoca lateralis	
	Engraulis mordax	
	Enophrys bison	
	Esox lucius x masquinongy	ANS
	Fundulus diaphanus	ANS

Gambusia affinis	ANS
Gasterosteus aculeatus	
Hemilepidotus hemilepidotus	
Hemilepidotus spinosus	
Hexagrammos decagrammus	
Hyperprosopon anale	
Hyperprosopon argenteum	
Hyperprosopon ellipticum	
Hypomesus pretiosus	
Ictalurus furcatus	ANS
Ictalurus punctatus	ANS
Isopsetta isolepis	
Lampetra aryesi	
Lampetra richardsoni	
Lampetra tridentata	
Lepidogobius lepidus	
Lepomis cyanellus	ANS
Lepomis gibbosus	ANS
Lepomis gulosus	ANS
Lepomis macrochirus	ANS
Lepomis microlophus	ANS
Leptocottus armatus	
Liparis fucensis	
Liparis pulchellus	
Liparis rutteri	
Lota lota	ANS
Lumpenus sagitta	
Merluccius productus	
Microgadus proximus	
Micropterus dolomieu	ANS
Micropterus salmoides	ANS
Misgurnus anguillicaudatus	ANS
Morone chrysops	ANS
Morone chrysops x saxatilis	ANS
Morone saxatilis	ANS
Mylocheilus caurinus	
Occella verrucosa	
Oncorhynchus clarki	
Oncorhynchus clarki x mykiss	ANS
Oncorhynchus keta	
Oncorhynchus kisutch	
Oncorhynchus mykiss	
Oncorhynchus mykiss gairdneri	
Oncorhynchus nerka	UNK
Oncorhynchus tshawytscha	

Ophiodon elongatus	
Oregonichthys crameri	
Pallasina barbata	
Parophrys vetula	
Perca flavescens	ANS
Percopsis transmontana	
Phanerodon furcatus	
Pholis ornata	
Piaractus brachypomus	ANS
Pimephales promelas	ANS
Platichthys stellatus	
Pleuronichthys coenosus	
Pomoxis annularis	ANS
Pomoxis nigromaculatus	ANS
Prosopium williamsoni	
Psettichthys melanostictus	
Ptychocheilus oregonensis	
Raja binoculata	
Rhacochilus vacca	
Rhinichthys cataractae	
Rhinichthys falcatus	
Richardsonius balteatus	
Salmo trutta	ANS
Salvelinus confluentus	
Salvelinus malma	
Scorpaenichthys marmoratus	
Sebastes melanops	
Sebastes miniatus	
Sebastes spp.	
Spirinchus starksi	
Spirinchus thaleichthys	
Squalus acanthius	
Stellerina xyosterna	
Stizostedion vitreum	ANS
Syngnathus leptorhynchus	
Thaleichthys pacificus	
Theragra chalcogramma	
Tinca tinca	ANS
Trichodon trichodon	

<u>Insects</u>

Arthropoda	**Status (ANS, CRYPT)**
Agraylea sp.	

Antocha monticola?
Aphididae
Arachnida
Araneae
Ceratopogonidae
Cheumatopsyche spp.
Chironomidae
Chironomus spp.
Coenagrionidae
Coleoptera
Collembola
Corixidae
Cryptochironomus spp.
Culicidae
Diptera
Dolichopodidae
Dubiraphia sp.
Empididae
Ephemeroptera
Ephydridae
Gerridae
Glyptotendipes spp.
Gomphidae
Gomphus spp.
Heleidae
Hemiptera
Heptagenia sp.
Hexagenia sp.
Homoptera
Hydracarina
Hydrobaenus sp.
Hydropsychidae
Narpus sp.
Neureclipsis spp.
Odonata
Oecetis spp.
Orthocladinae
Paracladius spp.
Paratanytarsus
Perlodidae
Plecoptera
Procladius spp.
Robackia spp.
Sialis sp.
Stenonema spp.

Stichochironomus spp.
Stylurus olivaceus
Tanytarsus spp.
Tipulidae
Trichoptera

Invertebrates

Annelida		**Status (ANS, CRYPT)**
	Ampharetidae	
	Aphelochaeta spp.	
	Armandia brevis	
	Barantolla nr americana	
	Capitella capitata complex	CRYPT
	Capitella sp.	
	Capitellidae	
	Chaetozone spinosa	CRYPT
	Cirratulidae	
	Cirratulus cirratus	CRYPT
	Enchytraeus spp.	
	Eteone columbiensis	CRYPT
	Eteone dilatae	
	Eteone lighti	CRYPT
	Eteone longa	CRYPT
	Eteone spilotus	
	Eteone spp.	
	Eulalia sp.	
	Euzonus williamsi	
	Exogone spp.	
	Glycera americana	CRYPT
	Glycera macrobranchia	
	Glycera nana	CRYPT
	Glycera spp.	
	Glycera tenuis	
	Glycinde armigera	
	Glycinde picta	
	Glycinde polygnatha	CRYPT
	Glycinde spp.	
	Hediste limnicola	
	Hemipodus borealis	
	Hesionella mccullochae	
	Heteromastus filiformis	CRYPT
	Heteromastus filobranchus	
	Heteromastus spp	

Hirudinea	
Hobsonia florida	ANS
Leitoscoloplos pugettensis	
Leitoscoloplos spp.	
Limnodrilus hoffmeisteri	ANS
Lumbrineridae	
Magelona hobsonae	
Magelona pitelkai	
Magelona sacculata	
Magelona spp.	
Malacoceros fulginosus	CRYPT
Manayunkia aestuarina	CRYPT
Manayunkia sp.	
Manayunkia speciosa	CRYPT
Mediomastus acutus	
Mediomastus californiensis	CRYPT
Mediomastus spp	
Naididae	
Nephtys caecoides	
Nephtys californiensis	
Nephtys cornuta	
Nephtys ferruginea	
Nephtys parva	
Nephtys spp.	
Nereis sp.	
Oligochaeta	
Ophelia limacina	CRYPT
Ophelina acuminata	CRYPT
Ophelina breviata	CRYPT
Ophelina spp.	
Owenia fusiformis	
Paraonella platybranchia	
Phyllodoce spp.	
Podarkeopsis brevipalpa	
Polychaeta	
Polydora brachycephala	CRYPT
Polydora cornuta	CRYPT
Polydora spp.	
Polygordius spp.	
Prionospio lighti	
Prionospio spp.	
Pristina osborni?	
Pseudopolydora kempi	CRYPT
Pseudopolydora kempi v. japonica	CRYPT
Pygospio californica	

Pygospio elegans	CRYPT
Scolelepis cirratulus	CRYPT
Scolelepis foliosa	CRYPT
Scolelepis spp.	
Scolelepis squamata	CRYPT
Scoloplos armiger	CRYPT
Spio butleri	
Spio filicornis	CRYPT
Spio spp.	
Spionidae	
Spiophanes berkeleyorum	
Spiophanes bombyx	CRYPT
Spiophanes spp.	
Streblospio benedicti	CRYPT
Syllis spp.	
Tharyx spp.	
Tubificidae sp. 1	
Tubificidae sp. 2	

Arthropoda	**Status (ANS, CRYPT)**
Acanthocyclops vernalis	
Acanthomysis macropsis	
Acarina	
Acartia clausi	
Acartia longiremis	
Acartia sp.	
Acartia tonsa	
Acartiella sinensis	ANS
Alienacanthomysis macropsis	
Allorchestes angustus	
Alona affinis	
Alona costata	
Alona guttata	
Alona quadrangularis	
Alona rustica	
Alona sp.	
Alonella sp.	
Amphipoda	
Anisiogammarus sp.	
Archaeomysis grebnitzkii	
Argeia pugettensis	
Asellidae	
Attheyella sp.	
Atylus tridens	

Balanus amphitrite amphitrite	ANS
Balanus crenatus	
Balanus sp.	
Bathycopea daltonae	
Bosmina longirostris	
Bosmina sp.	
Brachyura	
Bryocamptus hiemalis	
Bryocamptus sp.	
Byblis spp.	
Caecidotea occidentalis	
Caecidotea racovitzai	ANS
Caecidotea tomalensis	
Calanoida	
Calanus finmarchicus	
Calanus sp.	
Callianassa sp.	
Camptocercus reticrostris	
Cancer magister	
Cancer oregonensis	
Cancer spp.	
Candona sp.	
Caprella spp.	
Centropages abdominalis	
Centropages mcmurrichi	
Centropages sp.	
Ceriodaphnia pulchella	
Ceriodaphnia quadrangula	
Ceriodaphnia reticulata	
Ceriodaphnia sp.	
Chydorus sp.	
Chydorus sphaericus	
Cirripedia	
Cladocera	
Clausocalanus arcuicornis	
Clausocalanus parapergens	
Colurostylis occidentalis	
Colurostylis spp.	
Copepoda	
Corophium acherusicum	ANS
Corophium brevis	
Corophium salmonis	
Corophium spinicorne	
Corophium spp.	
Corycaeus affinis	

Corycaeus anglicus	
Corycaeus sp.	
Coullana canadensis	
Crangon franciscorum	
Crangon nigricauda	
Crangon nigromaculata	
Crangon spp.	
Crangonyx floridanus subgroup	CRYPT
Crangonyx spp.	
Ctenocalanus vanus	
Cumacea	
Cumella vulgaris	
Cyclopoida	
Cyclops bicuspidatus thomasi	
Cyclops sp.	
Cyclops vernalis	
Cylindroleberididae	
Cypria sp.	
Cyprinotus spp.	
Daphnia galeata	
Daphnia longispina	
Daphnia parvula	
Daphnia pulex	
Daphnia retrocurva	
Daphnia rosea	
Daphnia sp.	
Darwinula stevensoni	
Decapoda	
Diacyclops thomasi	
Diaphanosoma brachyurum	
Diaptomus ashlandi	
Diaptomus franciscanus	
Diaptomus novamexicanus	
Diaptomus sp.	
Diarthrodes sp.	
Diastylidae	
Diastylopsis dawsoni	
Diastylopsis spp.	
Ectinosoma sp.	
Eogammarus confervicolus cmplx	
Eogammarus oclairi	
Eogammarus sp.	
Eohaustorius estuaris	
Eohaustorius sawyeri	
Eohaustorius sp.	

Eohaustorius washingtonianus	
Epicaridea	
Epilabidocera amphitrites	
Epilabidocera longipedata	
Epischura nevadensis	
Eriocheir japonicas	ANS
Eriocheir sinensis	ANS
Eucalanus bungii	
Eucalanus sp.	
Eucypris sp.	
Eudorellopsis sp.	
Euhaustorius sawyeri	
Eurycercus lamellatus	
Eurycercus sp.	
Eurytemora affinis	
Eurytemora americana	
Eurytemora hirundoides	
Eurytemora sp.	
Evadne nordmanni	
Exacanthomysis spp.	
Exopalaemon modestus	ANS
Gammaridea	
Gnorimosphaeroma lutea	
Gnorimosphaeroma oregonensis	
Gnorimosphaeroma spp.	
Grandidierella japonica	ANS
Grandifoxus grandis	
Halicyclops sp.	
Hansenulus trebax	
Harpacticoida	
Harpacticus sp.	
Hemigrapsus oregonensis	
Hemileucon comes	
Hemileucon spp.	
Heptacarpus brevirostris	
Hippomedon denticulatus	
Homerus americanus	ANS
Huntemannia jadensis	CRYPT
Hyalella azteca	CRYPT
Hyperoche spp.	
Idotea fewkesi	
Illyocryptus sordidus	
Ilyocryptus sp.	
Isocypris spp.	
Isopoda	

Lampropidae	
Lamprops sp. A	
Leimia vaga	
Leptodiaptomus novamexicanus	
Leptodora kindtii	
Leucon sp.	
Leydigia acanthocercoides	
Leydigia quadrangularis	
Leydigia sp.	
Limnocletodes behningi	
Limnocythere sp.	
Limnoithona sinensis	ANS
Limnoria lignorum	
Lircerus sp.	
Liriopsis pygmaea	
Lissocrangon stylirostris	
Lysianassidae	
Macrocyclops albidus	
Macrothrix spp.	
Mandibulophoxus gilesi	
Mandibulophoxus uncirostratus	
Melphidippidae	
Mesochra alaskana	
Mesochra lillijeborgi	
Mesochra pygmaea	
Mesochra sp.	
Mesocyclops edax	
Metridia lucens	
Microarthridion littorale	
Microarthridion sp.	
Microcalanus sp.	
Microsetella sp.	
Moina spp.	
Monoculodes spinipes	
Monoculodes spp.	
Monoporeia affinis	CRYPT
Monospilus dispar	
Mysidacea	
Neocrangon alaskensis	
Neomysis awatchensis	
Neomysis integer	
Neomysis kadiakensis	
Neomysis mercedis	
Neomysis rayii	
Neomysis spp.	

Neotrypaea californiensis	
Nippoleucon hinumensis	ANS
Nitocra sp.	
Oithona similis	
Oithona sp.	
Oithona spinirostris	
Oniscoidea	
Onychocamptus mohammed	
Ostracoda	
Pacifastacus leniusculus	
Pacifastacus leniusculus klamathensis	
Pacifastacus leniusculus trowbridgii	
Paracalanus parvus	
Paracalanus sp.	
Paracyclops fimbriatus	
Paraleptastacus sp.	
Paraphoxus milleri	
Paraphoxus obtusidens	
Paraphoxus sp.	
Paronychocamptus cf. huntsmani	
Photis macinerneyi	
Photis spp.	
Pleopsis polyphaemoides	
Pleuroxus denticulatus	
Pleuroxus striatus	
Podon leuckartii	
Podon polyphemoides	
Podon sp.	
Pontoporeia affinis	
Pontoporeia hoyi	
Porcellanidae	
Porcellanidae	
Porcellio scaber	
Pseudobradya sp.	
Pseudocalanus minutus	
Pseudocalanus sp.	
Pseudochydorus globosus	
Pseudodiaptomus forbesi	ANS
Pseudodiaptomus inopinus	ANS
Rammellogammarus oregonensis	
Rammellogammarus spp.	
Rhepoxynius abronius	
Rhepoxynius daboius	
Rhepoxynius heterocuspidata	
Rhepoxynius spp.	

Rhepoxynius tridentatus	
Saduria entomon	CRYPT
Scapholeberis mucronata	
Schizopera knabeni	
Schizopera sp.	
Scolecithricella sp.	
Sida crystallina	
Sididae	
Synapseudes intumescens	
Synchelidium spp.	
Synidotea angulata	
Synidotea spp.	
Tachidius disciples	
Tachidius sp.	
Tachidius triangularis	
Tecticeps convexus	
Tortanus discaudatus	
Upogebia pugettensis	

Chaetognatha	**Status (ANS, CRYPT)**
Parasagitta elegans	
Sagitta sp.	

Chordata	**Status (ANS, CRYPT)**
Oikopleura sp.	

Cnidaria	**Status (ANS, CRYPT)**
Anthozoa	
Aurelia spp.	
Cordylophora lacustris	
Cordylophora sp.	
Hydra spp.	
Hydroida	
Hydrozoa	
Nematostella vectensis	
Obelia sp.	
Pegnatha spp.	
Sarsia spp.	

Ctenophora	**Status (ANS, CRYPT)**
Pleurobrachia	

Echinodermata	**Status (ANS, CRYPT)**

Dendraster excentricus
Echinodermata

Ectoprocta	**Status (ANS, CRYPT)**
Pectinatella magnifica	CRYPT

Mollusca	**Status (ANS, CRYPT)**
Anodonta californiensis	
Anodonta kennerlyi	
Anodonta nuttalliana	
Anodonta oregonensis	
Anodonta spp.	
Anodonta wahlametensis	
Axinopsida serricata	
Bivalvia (unidentified)	
Cerithiacea	
Clinocardium nuttallii	
Corbicula fluminea	ANS
Cryptomya californica	
Ferrissia parallelus	
Ferrissia rivularis	
Ferrissia rowelli	
Fisherola nuttalli nuttalli	
Fluminicola fuscus	
Fluminicola nuttallianus (likely extinct)	
Fluminicola sp.	
Fluminicola virens	
Gastropoda	
Gonidea angulata	
Gyraulus parvus	
Helisoma sp.	
Hydrobiidae	
Juga hemphilli	
Juga plicifera	
Juga plicifera bulimoides	
Juga plicifera oregonensis	
Juga silicula	
Juga sp.	
Littorinacea	
Lymnaea sp.	
Lymnaeidae	
Macoma balthica	
Macoma spp.	
Margaritifera (Margaritifera) falcata	

Menetus opercularis	
Modiolus spp.	
Mya arenaria	ANS
Mytilis edulis	
Mytilis spp.	
Octopus dofleini	
Olivella biplicata	
Olivella sp.	
Opisthobranchia	
Parapholyx	
Physa spp.	
Physella columbiana	
Physella gyrina	
Physella hordacea	
Physella lordi	
Physella propingua	
Physella propinqua nuttalli	
Physella sp.	
Physella traski	
Physella virginea	
Pisidium casertanum	
Pisidium compressum	
Pisidium spp.	
Pisidium variabile	
Planorbella columbiense	
Planorbella subcrenatum	
Planorbidae	
Potamopyrgus antipodarum	ANS
Promenetus umbilicatellus	
Pyrgulopsis n. sp. 6	
Radix auricularia	
Siliqua patula	
Sphaerium patella	
Stagnicola apicina	
Stagnicola elodes	
Tellina spp.	
Tresus capax	
Vorticifex effusa	
Vorticifex neritoides	

Nematomorpha	**Status (ANS, CRYPT)**
Nematomorpha	

Nemertea	**Status (ANS, CRYPT)**

Nemertea	
Tetrastemma candidum	CRYPT

Platyhelminthes	**Status (ANS, CRYPT)**
Platyhelminthes	
Turbellaria	

Rotifera	**Status (ANS, CRYPT)**
Asplanchna spp.	
Brachionus calyciflorus	
Brachionus plicatilis	
Keratella spp.	

Sipuncula	**Status (ANS, CRYPT)**
Sipunculidae	

Tardigrada	**Status (ANS, , crypt**
Tardigrada	

<u>Pathogens</u>

	Status (ANS, CRYPT)
Myxobolus cerebralis	ANS

<u>Macroalgae</u>

	Status (ANS, CRYPT)
Enteromorpha intestinalis maxima	
Fucus distichus edentatus	
Vaucheria	

<u>Plants</u>

	Status (ANS, CRYPT)
Achillea millefolium	
Agrostis alba	
Alisma plantago-aquatica	
Angelica lucida	
Argentina egedii ssp. egedii	
Aster modesta	
Aster sp.	
Beckmannia syzigachne	
Bidens cernua	

Boltonia asteroides	
Cabomba caroliniana	ANS
Callitriche sp.	
Callitriche stagnalis	ANS
Caltha asarifolia	
Carex lyngbyei	
Carex obnupta	
Castilleja ambigua ssp. ambigua	
Castilleja exserta ssp. exserta	
Ceratophyllum demersum	
Ceratophyllum sp.	
Cotula coronopifolia	ANS
Crassula aquatica	
Deschampsia caespitosa	
Dictyosphaerium sp	
Distichlis spicata	
Egeria densa	ANS
Eichhornia crassipes	ANS
Eleocharis minima	
Eleocharis palustris	
Eleocharis spp.	
Elodea canadensis	
Elymus glaucus	
Epilobium ciliatum ssp. watsonii	
Equisetum fluviatile	
Equisetum sp.	
Fontinalis sp.	
Galium sp.	
Galium trifidum ssp. columbianum	
Glyceria striata (? not found DW Thomas)	
Gratiola neglecta	
Helenium autumnale	
Helenium grandiflorum?	
Helenium sp.	
Heracleum lanatum	
Hordeum brachyantherum	
Hypericum formosum	
Iris pseudacorus	ANS
Iris sp.	
Isoetes spp.	
Isoetes tenella	
Juncus balticus	
Juncus effusus	
Juncus filiformis	
Juncus nevadensis	

Juncus oxymeris	
Lathyrus palustris	
Lathyrus palustris	
Lilaeopsis occidentalis	
Limosella aquatica	
Littorella sp.	
Lolium arundinacea	
Lotus corniculatus	
Ludwigia uruguayensis	ANS
Lupinus sp.	
Lycopodium spp.	
Lysichitum americanum	
Lythrum salicaria	ANS
Mentha arvensis	
Mentha piperita	
Mentha sp.	
Mimulus guttatus	
Murdannia keisak	ANS
Myosotis laxa	
Myriophyllum aquaticum	ANS
Myriophyllum spicatum	ANS
Najas sp.	
Nephrophyllidium crista-galli	
Nymphaea odorata	ANS
Oenanthe sarmentosa	
Phalaris arundinacea	CRYPT
Phragmites australis	CRYPT
Plantago lanceolata	
Platanthera dilatata var. dilatata	
Polygonum hydropiperoides	
Polygonum spp.	
Potamogeton crispus	ANS
Potamogeton foliosus	
Potamogeton perfoliatus richardsoni	
Prunella vulgaris	
Ranunculus sp.	
Rumex conglomeratus	
Rumex crispus	
Ruppiaceae spp.	
Sagittaria latifolia	
Salicornia europaea	
Salicornia virginica	
Salix hookeriana	
Schoenoplectus pungens spp. pungens	
Schoenoplectus tabernaemontani	

Scirpus americanus	
Scirpus maritimus	
Scirpus microcarpus	
Scirpus robutus	
Scirpus sp.	
Scirpus validus	
Senecio triangularis	
Sium suave	
Sparganium erectum	
Spartina spp.	ANS
Symphyotrichum subspicatus ssp. subspicatus	
Trifolium spp.	
Trifolium wormskjoldii	
Triglochin maritimum	
Typha angustifolia	ANS
Typha latifolia	
Typha sp.	
Vallisneria cf. americana	
Veratrum californicum	
Vicia nigricans ssp. gigantea	
Zannichellia palustris	
Zostera japonica	ANS
Zostera marina	