LOWER COLUMBIA RIVER AQUATIC NONINDIGENOUS SPECIES SURVEY 2001-2004

Final Technical Report

Mark D. Sytsma
Center for Lakes and Reservoirs
Portland State University
Portland OR 97207

Jeffery R. Cordell
Wetland Ecosystem Team
University of Washington
Seattle WA 98195

John W. Chapman
Hatfield Marine Science Center
Oregon State University
Newport OR 97365

Robyn C. Draheim
Center for Lakes and Reservoirs
Portland State University
Portland OR 97207

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Executive Summary

The National Invasive Species Act of 1996 identified the need to conduct an ecological survey of aquatic nonindigenous species (ANS) in the Columbia River and authorized funding for this purpose. The Lower Columbia River Aquatic Nonindigenous Species Survey (LCRANS) was initiated to provide comprehensive information about the nonnative species present in the lower Columbia River. A comprehensive list of nonnative species distribution is the first step to understanding invasions, assessing impacts, and developing effective management actions. This investigation provides a baseline for evaluating the rate of species introductions to the river that will allow assessment of the efficacy of ballast water management regulations and contribute important new information to ongoing regional aquatic nonindigenous species (ANS) studies. Despite the considerable volume of shipping received by the five major freshwater and brackish ports on the lower Columbia River it had not been previously surveyed explicitly for nonnative species.

The objective of the LCRANS was to provide a comprehensive survey and analysis of all ANS present in the tidally influenced, 234-kilometer reach of the lower Columbia River from Bonneville Dam to the Pacific Ocean and the tidal portions of the major tributaries. The project included a review of literature, conducted in 2001-2002, and field surveys, conducted in 2002-2003.

Due to the size and diversity of habitats the taxonomic scope of the LCRANS, field surveys were limited to free-living plants and animals. The geographic area surveyed encompassed brackish and freshwater marshes, low salinity mudflats, polyhaline beaches, rocky shorelines, protected embayments, large river habitats, tidally influenced agricultural drainages, and urban sloughs.

We sampled at 134 stations and documented 269 aquatic species (and 55 other distinct organisms that we were unable to identify at the species level) in the lower Columbia River. Of the 269 species identified, 54 (21%) were introduced, 92 (34%) were native, and 123 (45%) were cryptogenic.

The literature review and field survey revealed that at least 81 organisms have been introduced into the lower Columbia River since the mid 1800s. The majority of these species were fish (28%), aquatic plants (23%) and crustacea (15 %). The remaining 18% was a combination of mollusks, annelids, bryozoans, cnidaria, amphibians, reptiles and an aquatic mammal. Due to the limitations of this survey, inadequate taxonomic resolution in prior studies, and the abundance of unresolved and cryptogenic taxa, our results are likely a conservative estimate of the ANS invasion of the lower Columbia River.

From the 1880s to the 1970s a new introduced species was discovered in the lower Columbia about every five years. The frequency of new discoveries ANS is increasing worldwide (OTA 1993, Ruiz et al. 2000), however, and the rate of discovery of introduced invertebrates in the lower Columbia River mirrors this trend. Over the past ten years a new invertebrate species was discovered about every five months. The increasing rate of new discovery is due to increasing frequency of introductions and to the number and type of surveys conducted. It is not possible to separate these effects from the available data.

In contrast to the increasing rate of invertebrate discovery, the rate of fish discovery peaked in the 1950s. This trend was likely due to a decline in intentional fish introductions by both individuals and fish and game agencies to increase the diversity of food and game fishes.

The majority of introduced species in the lower Columbia originated in North America. Introduced fish accounted for most of the species with North American origin, while Asia was the native region of 34 percent of the invertebrates introduced via shipping mechanisms in the Columbia River. The high proportion of Asian invertebrates in the Columbia River fauna may be related to shipping patterns. Asian ports are the last port of call for most arrivals to the Columbia River from outside the Exclusive Economic Zone (EEZ). These patterns, however, are based on estimates of both origin and vectors of dispersal. For many species precise vectors and origins remain uncertain.

The Columbia River receives more port calls from vessels from domestic ports (59 percent) than it does from international ports (Flynn and Sytsma 2004). About 25 percent of coastal vessel traffic entering Oregon estuaries originated in the highly invaded San Francisco Bay/Sacramento/San Joaquin Delta (Flynn and Sytsma 2004). Short transit times, established populations of introduced invertebrates possibly selected for dispersal by shipping vectors in several domestic ports on the West Coast, and abundant shipping traffic suggests that domestic shipping is a highly important vector for ANS introduction to the Columbia River.

This report establishes a baseline on ANS in lower Columbia River. Additional monitoring and sampling is necessary to detect new invasions and to document invasion rate, impacts, and efficacy of management efforts. We recommend a multiple-purpose sampling approach to maximize the potential of detecting additional species and new arrivals. Sampling should target habitats and taxa that are likely to contain new invaders every year; a synoptic survey of the lower Columbia River should be conducted every five years; and additional sampling should target data gaps and survey limitations of this project.

Acknowledgements

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List of Abbreviations and Acronyms

ANS	Aquatic Nonindigenous Species
BSWQP	Bi-State Water Quality Program
CREDDP	Columbia River Estuary Data Development Project
CREST	Columbia River Estuary Studies Taskforce
IUCN	The World Conservation Union also known as the International Union For Conservation of Nature and Natural Resources
LCRANS	Lower Columbia River Aquatic Nonindigenous Species Survey
LCREP	Lower Columbia River Estuary Project
NAISA	National Aquatic Invasive Species Act, 1996
NMFS	National Marine Fisheries Service, also known as NOAA Fisheries
NOAA	National Oceanic and Atmospheric Administration
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
OSU	Oregon State University
OTA	Office of Technology and Assessment
SERC	Smithsonian Environmental Research Center
TAC	Technical Advisory Committee (part of LCRANS) (see Appendix A)
USACE	United States Army Corps of Engineers
USFC	United States Fish Commission (predecessor to USFWS and NOAA Fisheries) also known as United States Commission of Fish and Fisheries
USFWS	United States Fish and Wildlife Service
WEMAP	West Coast Environmental Monitoring and Assessment Program
WDE	Washington State Department of Ecology
WDFW	Washington Department of Fish and Wildlife

Chapter 1: Introduction

Overview

Rates of aquatic nonindigenous species (ANS) introductions and their social, economic, and ecological impacts are increasing (OTA 1993, Ruiz et al. 2000). Introductions of nonnative marine organisms have increased exponentially over the last two centuries and expenditures on outreach, control, and research exceed millions of dollars per species for several invaders of particular concern to the United States (Carlton 2001)[1]. These trends suggest that major changes are occurring in the freshwater, estuarine, and marine ecosystems of North America (OTA 1993, Cohen and Carlton 1995), but their magnitude is probably underestimated. For every well-documented impact of notorious invaders, such as intake-pipe fouling by the zebra mussel,*Dreissena polymorpha* (OTA 1993), water quality decline caused by hydrilla, *Hydrilla verticillata* (Langeland 1996), and mudflat conversion by the smooth cord grass, *Spartina alterniflora* (Daehler and Strong 1996), there are unknown numbers (likely thousands) of nonnative species with undocumented ecological and economic impacts.

Basic information on species presence is necessary for ecosystem management. A comprehensive list of nonnative species distribution is the first step to understanding invasions, assessing impacts, and developing effective management actions. Several estuaries, bays and other protected coastal habitats of the northeast Pacific have been the subject of rapid assessment surveys (Cohen and Carlton 1995, Cohen et al. 1998, Mills et al. 2000 and Cohen et. al. 2001). Studies of ANS and ballast water release on the West Coast of North America have focused on ports in higher salinity estuaries and bays such as San Francisco Bay and Coos Bay. Freshwater-dominated estuaries and large river systems have received little attention. Discharge of ballast water into marine and aquatic systems has become a significant pathway for ANS introductions worldwide as a result of a substantial increase in the speed and volume of global trade over the past century

[1] Recent estimates place the cost of the introduction of *Driessna polymorpha* between $750 million and $1 billion from 1989 and 2000 (Carlton 2001); state and federal funding for understanding impacts and eradicating *Spartina alterniflora* in the Pacific Northwest total over $4.5 million in the past 5 years; $1 million of federal funding went to *Eriocheir sinensis* control and research efforts in California in 2000-2001; and control and monitoring of *Caulerpa taxifolia* in southern California cost $2.33 million.

(Cohen & Carlton 1995, Cohen 1998). Despite the considerable volume of shipping received by the five major freshwater and brackish ports on the lower Columbia River (LCR), it has never been surveyed explicitly for nonnative species.

The United States Congress remedied this disparity in 1996 when they re-authorized the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, renamed the National Invasive Species Act (NISA). The authors of NISA specifically identified the need to conduct an ecological survey of ANS in the Columbia River and authorized funding for this purpose. In the fall of 2001, the Lower Columbia River Aquatic Nonindigenous Species Survey (LCRANS) was initiated.

LCRANS was undertaken to provide comprehensive information about the ANS present in the lower Columbia River. The results of this investigation will serve as a baseline for evaluating the rate of species introductions to the river and the efficacy of ballast water management regulations, and contribute important new information to ongoing regional ANS studies. In addition, the data may be useful for determining where the lower Columbia River is vulnerable to invasion and for evaluating effects of introductions on important ecological processes.

The project was implemented in consultation with the LCRANS Technical Advisory Committee (TAC). The TAC consisted of local, regional, and national experts on biological invasions of aquatic systems, taxonomy, and regional resource management (see Appendix A for a complete list of TAC participants). The role of the TAC was not supervisory; rather the TAC reviewed, evaluated, and assisted LCRANS in achieving the following goals:

- Develop a database for relevant information including timeframe of introduction, native and source regions of introduced species, modes of introduction, etc.
- Review existing literature on ANS in the lower Columbia River.
- Perform field surveys for ANS to complete and/or extend existing records –i.e. focusing on habitats and taxa not well represented in literature.
- Design and implement replicable monitoring protocols for detecting new or expanding invasions.
- Complete a written report including at minimum 1) an examination of the attributes and patterns of invasions of ANS in the LCR, and 2) a discussion of the effectiveness of ballast water management in abating ANS invasions in LCR.

Structure and Scope

The objective of the LCRANS was to provide a comprehensive survey and analysis of all ANS present in the lower Columbia River - the tidally influenced 234-kilometer reach from Bonneville Dam to the Pacific Ocean, and the tidal portions of the major tributaries. This geographic area encompassed brackish and freshwater marshes, low salinity mudflats, polyhaline beaches, rocky shorelines, protected embayments, large river habitats, tidally influenced agricultural drainages, and urban sloughs. Due to the size and diversity of habitats the taxonomic scope of the LCRANS project was limited to free-living macrophytes and animals. The project included three components:

- A literature review of Columbia River ANS,
- Field surveys to characterize the ANS present
- A comprehensive analysis and summary of the results of the previous components.

The field survey focused on species and habitats that were not well studied previously. For example, nonnative fish were recorded when captured in the course of sampling but were not specifically targeted during the field surveys. Much of the information in this report about nonnative fishes comes from the initial literature review that, unlike many of the invertebrate taxa, have been well studied.[2]

This report summarizes the work performed by the LCRANS team between October 2000 and July 2004. Some sections reference previously released LCRANS reports. These reports are available upon request from the corresponding author or in Adobe PDF format from the website http://www.clr.pdx.edu under the link “LCRANS.” In order to further understand the ANS present in the lower Columbia River in a regional context, this report also describes the timeframe, source, vector, distribution, and impacts of invasion where possible. In the Conclusion, we discuss our major findings and their implications for regional ANS management, and identify data gaps and further research needs.

[2] There are several types of fish such as gobies and blennies that have been documented as introduced unintentionally and are associated with habitats (such as rocky cervices) that are not typically targeted during routine fish sampling. These habitats may need to be specifically targeted in future ANS surveys (Andy Cohen, personal communication).

Chapter 2: The Lower Columbia River

The Columbia River is the largest river in the Pacific Northwest and the second largest in the United States (in terms of volume discharged). Its drainage basin covers 671,000 km^2 in seven states and one Canadian province. Tidal influence of the Pacific Ocean is evident 234 km upriver to Bonneville Dam, the lowest of many impoundments on the river (Figure 1). The tidal influence also extends 207 km from the Pacific Ocean to Willamette Falls on the Willamette River, the largest tributary entering the lower river. The lower Columbia, from Bonneville dam to the mouth, drains approximately 46,600 km^2. Although it represents only seven percent of the entire Columbia Basin, it is the most developed and urbanized portion of the watershed.

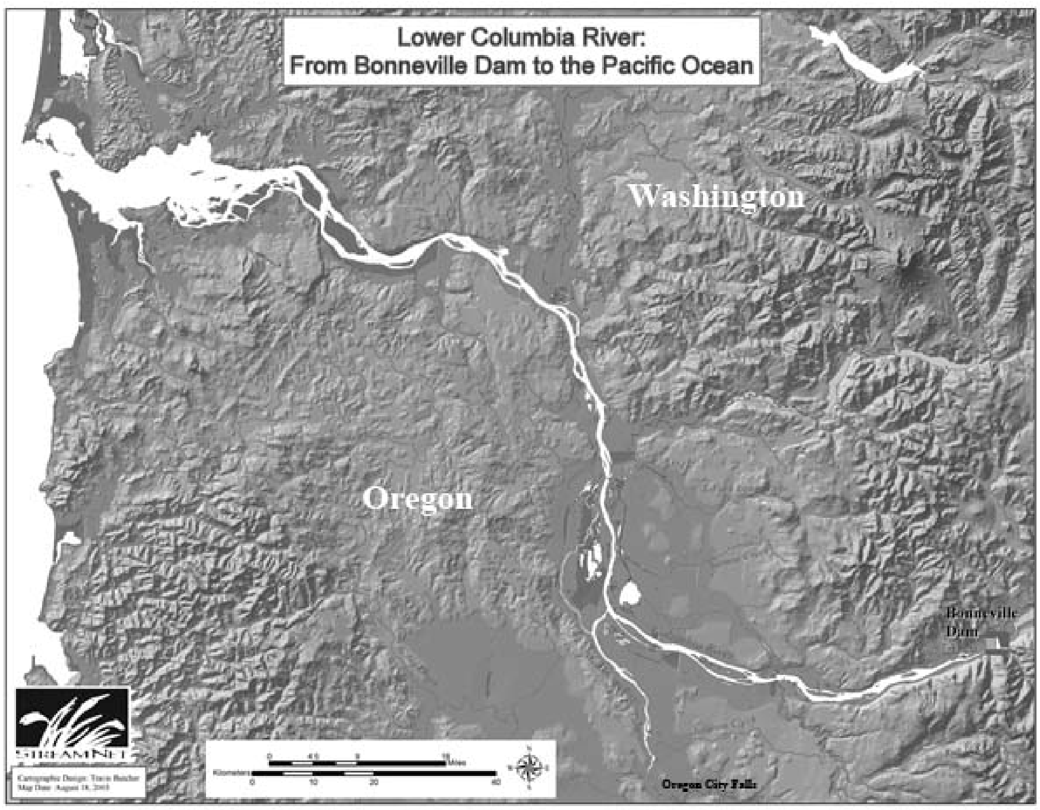

Figure 1. The LCRANS study area – the tidally influenced portions of the lower Columbia and Willamette Rivers (map created by StreamNet)

The Lower Columbia River Basin

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 1800s ushered in two centuries 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 1840s, 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 along the West Coast, the lower Columbia River became a busy port, with ships arriving daily bearing supplies and immigrants, and leaving with timber, furs and fish. Since then, the population of the lower Columbia River basin has continued to grow, accompanied by increased demands on the river.

The lower Columbia River delineates the boundary between Oregon and Washington. Three major tributaries enter the Columbia River downstream of Bonneville Dam; the Willamette River on the Oregon side, and the Lewis and Cowlitz rivers from Washington. There are five 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 (LCREP 1999).

According to the Lower Columbia River Estuary Project (LCREP 1999) “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.” (Figure 2). In 1932, construction began on the first of many dams that altered the flow regime of the Columbia. In 1938, Bonneville Dam was completed. Located 233 kilometers from the mouth, Bonneville Dam marked the new upper boundary of tidal influence on the river. By the mid 1970s, 18 dams had been erected on the main stem of the Columbia and its main tributary, the Snake River. Today, the river supports numerous commercial and recreational activities including fishing, hydroelectric power generation, irrigation, aquaculture, shipping, and boating.

From the mouth to Skamokawa, WA (~ river km 56) the lower Columbia River is a coastal plain estuary[3]. Sand deposition in the middle reach of the estuary has formed vast areas of sand flats and shoals. Dredge disposal has built up some of these areas into islands. There are four large, shallow embayments in the estuary (Grays, Baker, Youngs and Cathlamet bays) (Holton 1984). Upstream of Skamokawa, from Puget Island to Longview, WA and the confluence of the Cowlitz River, the Columbia is primarily a single channel bordered by steep valley walls (Holton 1984). Further upstream, from Longview to the start of the Columbia River Gorge below Bonneville Dam, the river valley widens into a low-elevation flood plain.

The volume of water discharged by the Columbia River varies seasonally according to runoff, snowmelt, and hydropower demands. Mean annual discharge is estimated to be 7,500 m^3/s, but may range from lows of 2,000-3,000 m^3/s to highs of 15,000 m^3/s (Hamilton 1990; Prahl *et al.* 1998; NOAA 1998; USACE 1999). Naturally occurring maximum flows on the river occur in May, June and July as a result of snowmelt in the headwater regions. Minimum flows occur from September to March with periodic peaks due to heavy winter rains (Holton 1984). The discharge during May-June has been reduced by more than 50 percent since impoundment for water storage, hydropower generation, and irrigation diversion in the middle and upper basin[4] (Ebel et al. 1989) (Figure 3).

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[3] This delineation of the estuary is a simplification. The boundaries of the Columbia River estuary can be viewed as fluctuating daily, seasonally, and annually. Further complicating any generalization is ongoing dredging for navigation, which creates a narrow, deep channel that restricts salt water penetration into the estuary. Simenstad et al. (1990) give a more detailed discussion of the physical and chemical characteristics of the Columbia River estuary.

[4] There are over 250 dams and reservoirs and 150 hydroelectric projects in the Columbia River watershed, including 18 main-stem dams on the Columbia and Snake rivers (USACE 2001). Extensive development has turned the main stem of the Columbia River into a series of slow-moving reservoirs impounded by 11 large dams, the lowest of which is Bonneville Dam (Sherwood et al. 1990, Prahl et al. 1998, USACE 1999).

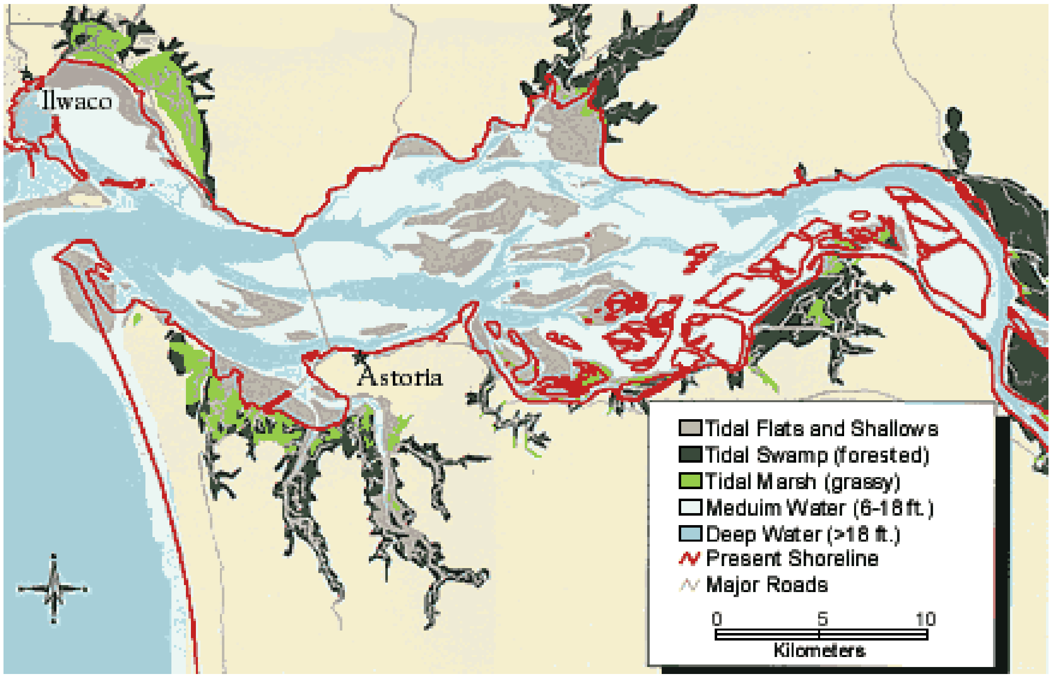

Figure 2. Habitat alteration along the Columbia River estuary contrasting the shoreline position in 1868-1875 with the present shoreline shown in outline. (Source: Lower Columbia River Bi-State Water Quality program http://www.ecotrust.org)

Interannual variability in stream flow is strongly correlated with two recurrent climate phenomena, the El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (USGS 2003). Historically, flooding has occurred primarily during the cool phase of ENSO. A major exception was the devastating 1948 Vanport flood that occurred when ENSO was in its neutral phase. Droughts have usually occurred during the warm phase of ENSO.

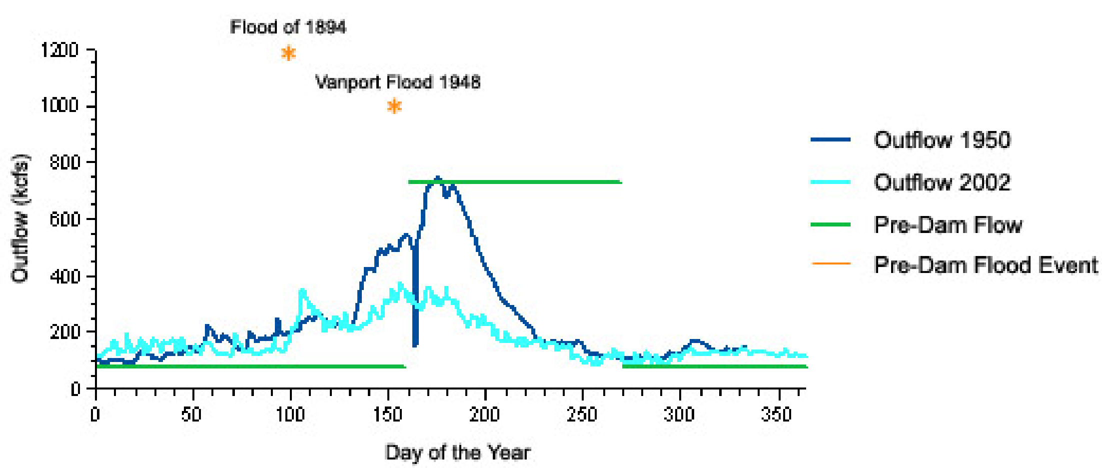

Figure 3. Past and present flow data for the lower Columbia River collected at the Bonneville Dam. (The straight line demonstrates average estimated flow of the Columbia River prior to the

construction of dams and other impoundments. Two extreme flood events are starred. Data from the Columbia Basin Research team at the University of Washington http://www.cbr.washington.edu/dart/riverclimate.html with additional pre-dam data from Pruter and Alverson (1972)).

Salinity intrusion is flow dependent but typically extends to around 50 km from the mouth and is largely confined to the two main channels; the southern one is the dredged shipping channel that extends from the mouth to Portland, OR (Hamilton 1990). Vertical stratification varies from fully mixed to salt wedge conditions depending on both the volume of flow and tidal heights (Hamilton 1990). At the river mouth the estuary is considered partially mixed except at extreme low flows when it can become vertically homogeneous at high tide (Neal 1972, Hamilton 1990). Further upstream at river kilometer 30 the estuary behaves as a partially mixed estuary except during high flows at low tide when it can become vertically stratified or completely freshwater (Neal 1972).

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). Aside from catch data of commercially important species, however, few biological records exist for the lower Columbia Basin that pre-date the construction of the dams (Weitkamp 1994). Today the main stem of the lower Columbia River is considered depauperate in species (Ebel et al 1989). The biological integrity of the river may be further degraded by pollution, destruction of wetlands, and other impacts related to industrialization, navigation improvement, and urbanization. While many adjustments to the impoundment of 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 the physical characteristics of riverine systems may mean that the lower Columbia River biota is still adjusting to anthropogenic changes. This adjustment period may have benefited ANS (Weitkamp 1994).

The Changing Nature of Invasions

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. It is ironic to note that, while the early settlers rapidly took advantage of the abundance of salmon in the region and made 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). Today, the region faces the rapid decline of native salmon stocks.

> “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 1800s, the United States Fish Commission (the precursor to the US Fish and Wildlife Service) became active 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, popular, game fish have been successfully introduced to the lower Willamette and Columbia rivers.

One early fish introduction to the lower Columbia River Basin was the carp, *Cyprinus carpio* (Smith 1896, Lampman 1946). Lauded as a European delicacy 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 Captain John Harlow and, with the arrival of a vigorous spring freshet that swelled the waters of the Sandy River and freed the fish, they 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*, were released in California in 1871. They rapidly dispersed 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 were enacted by the National Marine Fisheries Service (NMFS) to reduce American shad populations in the Columbia River because they are believed to prey on, and compete with, juvenile salmon (Rishi Sharma, personal communication 2002; NMFS 1995). American shad appear to have benefited from the construction of 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 bullfrogs resulting from the above planting were shipped to Portland for further distribution (Lampman 1946). Today, mature bullfrogs are responsible for significant levels of predation on native aquatic species, particularly the Western pond turtle and the spotted frog (Crayon 2002).

While many of the earliest non-native species introductions to the lower Columbia River were the result of intentional plantings, more recent arrivals appear to be the result of unintentional introductions[5]. It has been hypothesized that the physical and biological changes to the lower Columbia River promote the establishment of new ANS (Cordell et al 1992, Weitkamp 1994).

Three of the most recent ANS that 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*, differ from earlier invaders in that they are invertebrates with little or no food or recreational value. As such, none of these species were likely to have been intentionally introduced and no clear documentation of the dates and vectors of introduction exists. *P. inopinus* is believed to have been introduced between 1980 and 1990 via ballast water released from ships arriving from Asia (Cordell et al. 1992). When first captured in 1995, *E. modestus* was immediately recognized as an invasive species because there are no true freshwater shrimp native to the Columbia River (Emmett et al. 2002). This prawn may also have arrived in ballast water (Emmett et al. 2002). The arrival of *P.*

[5] This does not exclude the possibility that several species now present in the lower Columbia River were the result of early unintentional introductions facilitated by shipping traffic. These early wooden sailing ships transported numerous wood boring and fouling organisms (see Carlton and Hodder 1995 for a discussion of wooden ships and the dispersal potential of fouling organisms), and at least one species, the barnacle *Balanus improvisus*, is thought to have arrived in the Columbia via this vector. Cohen and Carlton (1995) estimate that 26% of introductions into San Francisco Bay are the result of hull fouling. In addition, throughout the 1800s many vessels carried solid ballast made up of sand or rock dredged from the nearby shoreline, and solid ballast has been implicated in the introduction of several marine species on the West Coast, e.g. Cohen and Carlton (1995) link 3% of invasions into San Francisco Bay to this vector.

antipodarum[6], was initially misidentified as the native snail *Fluminicola virens* in benthic surveys. When its abundance increased significantly it was correctly identified as an invasive species (Rod Litton personal communication). It is not known how this snail arrived in the lower Columbia River, but the lower Columbia population has the same genotype as those in the Snake River and other western aquatic systems (Mark Dybdahl personal communication).

Introductions

Part of the global trend of increasing rates of introductions (see Ruiz et al. 2001, Cohen 2002) may be the result of increasing awareness of, and efforts to find and report, introductions, particularly among the lesser-studied taxa. The trend may also reflect increasing opportunities for, and success of, introductions. For example the increasing speed and geographic range of global trade may facilitate the survival of species being transported (intentionally or unintentionally) as well as the volume and variety of potential colonists. It has yet to be determined whether changes in vector management (such as the US ballast water guidelines for international shipping) have had an effect on the rate of introductions.

While management regulations aimed at reducing the threat of ANS invasions in the United States have improved, the Pacific Northwest is nevertheless an at-risk region for further introductions. Many long-established pathways and vectors are unregulated or remain open due to a lack of enforcement of existing rules. Also, increased efficiency of trade and transportation, new trade opportunities, and new trade dimensions (e.g. internet trade) may have opened new pathways for ANS introduction. As the region experiences ecological alterations from global climate change, increased use of natural resources such as water and timber, and urbanization, modifications in the aquatic biological communities are likely. Effects of these changes on ANS introductions in the region are unknown but probably significant.

[6] Recorded in the benthic sampling reports of the Clatsop Economic Development Council's salmon net pen operation in Youngs Bay (See Litton 2000).

Vectors

A vector is the vehicle or activity by which a nonnative species is transported (intentionally or unintentionally) and introduced to a new habitat. A fundamental understanding of the diversity and patterns of vectors operating in a region is essential to reducing new introductions.

There may be a wide range of vectors operating at many spatial scales (i.e., between watersheds, estuaries, oceans, etc.) that impact a given system and result in substantial transfer of biological material. Tens of thousands of species are in transit globally on a daily basis (Carlton 2001). Some introductions may be the result of numerous vectors while others may be limited to one specific mechanism or action. The success of some vectors may be limited by environmental factors like climate or seasonality. The wide diversity of potential vectors makes them a complex management issue, and identifying them is an essential step in managing invasions. It is important to note that the vectors listed for each species should be considered merely best estimates of the means of dispersal. For many species the precise vectors of dispersal are unknown. Facing a lack of unequivocal evidence regarding which species came in via which vector, the vectors assigned to each species represent "possible" vectors based primarily on life history characteristics of species. In the following section we detail several categories of vectors that may play a significant role in the introduction of aquatic nonindigenous species into the lower Columbia River.

Commercial Shipping and Maritime Vessels

The introduction of nonnative organisms into the lower Columbia River by sailing vessels has been possible since the European discovery of the river by Capt. Robert Gray in 1792 - the first known arrival of a foreign sailing ship, but the imposing bar at the mouth of the Columbia River deterred numerous large vessels from entering the river. In 1875, however, the U.S. Army Corps of Engineers began construction of a jetty that, along with dredging, turned the lower Columbia River into a major port system.

In the early 1800s sailing ships entering the lower river arrived bearing supplies and immigrants and leaving with timber, furs, and fish. These ships may have introduced new species in the form of fouling and wood boring invertebrate and plants. Other organisms may have been introduced from anchor chains, sea chests, solid ballast, and later, water ballast. With the advent of metal-hulled ships wood boring aquatic invertebrates were no longer transported on the hulls of commercial vessels. The introduction of anti-fouling paint and other hull-coating efforts has further reduced hull-fouling communities but the contribution of hull-fouling communities to nonnative species introductions is not well known.[7]

Although numerous aspects of commercial shipping have been implicated in the introduction of ANS, ballast water, because of its sheer volume, remains the primary method by which ANS are believed to be transported globally (Carlton 2001)[8]. . As ships continue to get bigger and faster the total volume of ballast transported will continue to increase as travel times decrease, thus increasing the probability that potential invaders will survive their journey.

In addition to trans-oceanic ballast transport, transport of organisms in ballast water from domestic, coastal ports is also a threat. Ships in-ballast from heavily invaded locations, such as San Francisco Bay, may spread nonnative species along the West Coast. These introductions may have a high probability of establishment because transit times are short and they have already been challenged by transport in ballast tanks and local factors such as climate and competition.

The commercial shipping industry is an important component of the Oregon economy. Exports from Oregon to Asian-Pacific markets alone amounted to $5.1 billion in 2001 (Oregon Bluebook Website 2004). Major exports include wheat and cereal, vehicles, soda ash and pot ash, (Oregon Economic and Community Development Department 2004, Port of Portland 2004). The Portland metro region is the leader in export sales for the

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[7] On January 1, 2003 the International Convention Convention on the Control of Harmful Anti-Fouling Systems went into effect prohibiting the use of harmful organo-tins (which act as biocides and over time leach into surrounding water) in anti-fouling paints used on ships. It also established a mechanism to prevent the future use of other harmful substances and pollutants in anti-fouling systems. By January 1, 2008 all organo-tin anti-fouling compounds must be removed from vessels and platforms or coated with an approved sealant to prevent further leaching. (see http://www.imo.org for more information).

[8] Detailed investigation throughout the US has shown that ballast water transfer has acted as a major vector of ANS but, by comparison, much less research has been conducted on ships' hulls and their potential to act as vectors of ANS in coastal waterways. On going research at SERC and elsewhere is beginning to suggest that the threat of ANS dispersal posed by ships hulls could be greater than previously attributed.

state, and ranks 11th of 253 in sales for U.S. metropolitan regions (U.S. Department of Commerce 2001). In 2000, the shipping industry produced a total earnings and consumption impact in Oregon of about $1.7 billion (Port of Portland 2004).

A sustainable economy requires effective and efficient management of pathways of invasive species introduction that are associated with shipping. To protect Oregon water resources from the risk of ballast water-related introductions the legislature enacted SB 895 during the 2001 session., revising it with HB 3620 in 2003. The bills regulate ballast water discharge into Oregon waters, prohibiting all transoceanic and coastal vessels from discharging unexchanged ballast water with a few exceptions. Oregon law allows discharges of unexchanged ballast water from vessels traveling within defined common waters. Common waters are defined as waters between the parallel 40 degrees north latitude and the parallel 50 degrees north latitude (ORS 783.630). Currently, Oregon law only allows the discharge of ballast water treated in a manner approved of by the U.S. Coast Guard, which creates potential problems for vessels with Washington-approved treatment technology that visit both Washington and Oregon ports on the Columbia River. Ballast water regulatory changes have occurred at international, federal, and regional levels and necessitate changes in Oregon regulations to ensure compatibility with new federal regulations, proposed regulations in California, and existing Washington regulations.

Vessels entering the Columbia River discharge ballast water in three locations (Monaca Noble personal communication). Some might dump a portion of their ballast while at anchorage outside of Astoria, Oregon to adjust their draft before coming upriver. This anchorage area runs approximately three km alongside the main shipping channel. Vessels sometimes dump ballast while traveling up the lower river to port, again to adjust their draft as necessary. The majority of vessels, however, appear to dump their ballast while in port (Monaca Noble personal communication). Ballast water release sites likely differ by both vessel type and draft requirements. Ballast water uptake for vessels off loading cargo at ports along the Columbia River likely mirrors this pattern in reverse.

Fishery Enhancement

Intentional legal and illegal introductions of nonnative species to enhance local fishing opportunities have occurred in the lower Columbia River for nearly 150 years. In addition, several fishery enhancement actions may have led to unintentional species introductions in the region. The late 1800s and early 1900s were characterized by many intentional plantings by the USFC, local fishery managers, and private citizens to improve commercial, recreational and sustenance fishing in the region (see Lampman 1946). Legal and illegal releases of sport fish into public and private ponds (and their subsequent escape) still occur, but the state wildlife agencies are becoming more reluctant to stock nonnative species in the region (Dailey 2003). Fish stocking activities in the middle and upper Columbia River also may have contributed species to the system that subsequently spread down-stream.

Mariculture, especially of oysters, is associated with numerous detrimental ANS introductions on the West Coast[9] (Cohen and Carlton 1995). However, there are no records of shellfish mariculture in the lower Columbia River. The low salinity of the estuary is unsuitable for most commercially desirable shellfish, with the exception of the soft-shell clam *Mya arenaria*. This species rapidly spread up the West Coast from San Francisco Bay (1874) to Puget Sound (by 1889). The arrival of *M. arenaria* to the lower Columbia may have been the result of intentional introduction or it may have spread unintentionally in hull fouling communities (see Cohen and Carlton 1995).

Other fishery enhancement activities associated with ANS introductions include freshwater aquaculture and hatchery stocking both on the lower river and upstream of the Bonneville Dam. There are no aquaculture activities on the lower Columbia River that involve nonnative species.

Fishing and Recreational Water Use

Recreational anglers and other water users may unintentionally transport ANS (primarily aquatic weeds, snails and other small invertebrate species) as they move from watershed to watershed. Some organisms may move as "hitchhikers", in damp gear or boat wells,

[9] It has been proposed that the arrival of the Asian clam *Corbicula fluminea* may have been the result of an intentional introduction to establish a food source in the Columbia River but McMahon (1982) argues that this species spread naturally down the coast from Vancouver Island.

others may be transported as fouling organisms on boat hulls or as weeds trapped in boat propellers. The spread of zebra mussel, *Driessenia polymorpha,* throughout much of the United States has been attributed to movement by recreational boaters, etc. Although the practice of dumping left-over live bait has not been implicated in ANS introductions in the lower Columbia River, it is a potential vector for ANS introductions. The bait itself may be an ANS, as could be its packing material or other associated "hitchhiking" organisms (see live aquatics industry below). The risk of bait as ANS may increase with the availability of exotic bait species available for purchase on the internet (e.g. the Vietnamese "nuclear" worm)[10].

Live Aquatics Industry

The commercial transport of live aquatic species (for aquaculture, mariculture, bait, aquaria trade, water gardens, fisheries, scientific supply, etc.) is a vector for both intentional and accidental introductions of aquatic organisms. Plant and animal shipments may also include "hitchhikers", species that are accidentally included with the shipment as parasites or pathogens and in shipping water and packaging (Olson and Linen 1997). Organisms in the live aquatics industry have the potential to be dispersed across broad geographical areas and thus can be released or escape to many different habitats (Chapman et al. 2003). In spite of this risk, the live aquatics industry (especially trade in live seafood) receives less attention than other activities that introduce nonindigenous species, such as ballast water (Chapman et al 2003).

Ornamentals – the Nursery and Aquarium Trades

Within the live aquatics trade ornamental species, defined here as those species sold for use in ponds and aquariums, pose additional risks. Numerous nonnative aquatic plants, fish, and aquatic invertebrates are offered by nurseries and aquarium stores for use in indoor and outdoor displays. Intentional introductions into the wild may be the result of releases by individuals to "enhance" a natural area, to develop a harvestable population for resale, to humanely dispose of/or "free" species, or to conveniently dispose of unwanted organisms. According to the Southwest Florida Watershed Council, aquarium

[10] The 2004 Oregon Fishing Regulations ban the import and transport of live bait fish 1) It is unlawful to transport live (fish) bait between bodies of water, 2) Live fish may not be used or held for use as bait, except live nongame fish may be used in the ocean, bays and tidewaters when taken from the waterbody in which they will be used. http://www.dfw.state.or.us/ODFWhtml/Regulations/2004_fishregs.pdf

dumping is the leading cause of ANS introductions into the state of Florida. While many ornamental species may be unable to overwinter in the lower Columbia River (such as fish in the family Characidae – including piranhas – which have been repeatedly released into the system, see Farr and Ward 1993) there are several established species that are the result of intentional releases. These include popular aquarium and pond species such as oriental weatherfish *Misgurnus anguillacaudatus*, and goldfish *Carassius auratus*, aquatic plants like *Cabomba caroliniana* and *Egeria densa*, and the Chinese mystery snail *Cipangopaludina chinensis malleatus*. Unintentional introductions also result from flooding or other escapes from outdoor ponds, failure of commercial rearing operations, or improper disposal of species (especially via flow-through drainage system sometimes found in research labs, hatcheries, etc.). One examples of an accidental introductions into the lower Columbia River is the escape of nutria, *Myocaster coypus* from a fur farm in Tillamook, Oregon during a flood (ODFW 2001).

Biological Control

There is little information on early efforts at biological control but the practice likely originated with the observation that predation by some animals and/or insects led to the reduction of unwanted species. Certainly the domestication of small felines by the Egyptians to reduce the presence of small rodents is such an example. By 900 AD the Chinese had begun successfully introducing predatory ants into their citrus groves to protect against worm-infested oranges. Official attempts at biological control in North American aquatic systems range from the failed introduction of muskellunge, *Esox masquinongy*, into a drinking water reservoir in San Francisco in the 1880s to rid the lake of introduced carp, *Cyprinus carpio* (which were later successfully removed after the introduction of sea lions, Smith 1896), to the release of nutria in Louisiana in the late 1930s by state and federal agencies to control unwanted nonnative aquatic plants such as water hyacinth, *Eichhornia crassipes*, and alligator weed, *Alternanthera philoxeroides* (USGS 2000).

Grass carp, *Ctenopharygodon idella*, and mosquito fish, *Gambusia affinis*, are still in use as aquatic biological control organisms and are found throughout the lower Columbia River. Purple loosestrife, *Lythrum salicari,* is currently the target of a biological control in the lower Columbia using insects (see http://www.oda.state.or.us for more information on this project).

Pathways

A pathway is the geographic pattern of an invasion. Some pathways may be more successful than others (Chapman 2000). Due to climate compatibility and life history ranges of potential invaders the temperate shorelines of continents are more likely to be invaded by species from less temperate climates. Pathway analysis may also reflect long-established trade routes or patterns of repeated, high-volume inoculations from particular locations. Such information could be vital to making management decisions about which vectors presented the greatest risks to a region. For example, if introduced species populations are dominated by species transported by a particular vector from a particular location, management actions could be taken to target that pathway rather than the entire vector.

The lower Columbia River is part of an established trade route between eastern Asia and western North America. Commercial shipping traffic routinely arrives at the five major deep-water ports in the lower river from destinations such as Korea, China, Taiwan and Japan. This pathway encompasses the high-risk transport of species from less temperate climates to the temperate western coast of North America.

Occasional events may increase risk of transportation of nonindigenous species. One example that is relevant to the lower Columbia River is the observance of the bicentennial of the Lewis and Clark Expedition. As part of the observance boaters are encouraged and expected to re-create the journey of Lewis and Clark from the Midwest to the Pacific Ocean. This activity is a potential conduit for transporting zebra mussels, *Dreissena polymorpha,* and other ANS from infested waters to the Columbia. More frequently occurring events such as conventions and fairs where live aquatics may be displayed, sold or bartered, etc. may also be events that sporadically increase the risk of introductions.

Chapter 3: Literature Review

Methods

Publications, reports, and collection records referring to projects conducted on the lower Columbia River were reviewed to compile a list of nonnative species reported in the study area and to identify gaps in the taxa and/or habitats studied. The goals of the literature review were to: 1) compile a list of non-native species already reported from the Columbia River, 2) identify taxa that have been poorly studied or represented in previous studies, and 3) identify areas of potential ANS hot-spots such as habitats associated with previously reported ANS and cryptogenic species, as well as habitats that have been under studied. All results were entered into a database.

Due to a dearth of information on ANS in the lower Columbia River the literature review was expanded to include all species collections in the study area. The expansion of the review encompassed many reports that do not discern between native and nonnative species. The compiled species list was distributed to the TAC and other taxonomic experts for review.

Personal contacts and electronic database searches were conducted for information on ANS in the lower Columbia. Two electronic databases were searched for journal articles: BIOSIS Previews and ASFA (Aquatic Science and Fisheries Abstracts). The online catalog ORBIS (Orbis Cascade Alliance) allowed a search of participating Pacific Northwest academic libraries including but not limited to Portland State University, Oregon State University and the University of Washington. In addition the libraries and references published by the following organizations were searched: Columbia River Estuary Studies Task Force (CREST), Lower Columbia River Estuary Project (LCREP), Portland General Electric, National Marine Fisheries Service (NMFS), Army Corps of Engineers, and the Oregon Department of Fish and Wildlife (ODFW). Informal interviews of natural resource personnel were conducted at many of the above organizations. Other reports were retrieved from a variety of sources using the Interlibrary Loan Program at Portland State University.

Results

The complete results of the LCRANS Literature Review were published previously and are available at the Center for Lakes and Reservoirs website (http://clr/pdx/edu). Copies of the LCRANS database are available upon request from the authors.

Database

The format of the database was developed in coordination with SERC. The LCRANS database includes all of the relevant categories proposed by SERC including: timeframe of introductions, native and source regions, modes of introduction, taxonomy and synonymy, etc. The LCRANS database differs from the SERC database in two major ways - the database includes fields for information collected on native species in the lower Columbia River and several fields that appear in the SERC database were omitted or renamed because they were not applicable to the freshwater ANS present in the LCRANS survey (e.g. biogeographic ocean provinces). All data entered into the database is cross-referenced with a full list of bibliographic sources.

Literature Review

With the exception of fishes, there is little historical information available on the flora and fauna of the Columbia River. Many of the invertebrate taxa, such as oligochaetes and epibenthic meiofauna were poorly studied. Information on species present in the literature was complicated by potential misidentifications (Leslie Harris personal communication). Such errors can result in false conclusions on their origins (e.g., Carlton 1979, Rotramel 1972, Chapman 1988, Chapman and Carlton 1991, 1994). The nonindigenous status of a species occurring in the Columbia River or elsewhere in northeast Pacific may not be apparent until the organism is discovered and described as indigenous in its native habitat, or until the synonymies of the local species with populations in other parts of the world are resolved (a time consuming undertaking that is outside the scope of most parochial biological surveys)[11].

[11] Published information associated with a species is only accessible under the scientific name of that species. The names of species change as errors in taxonomy are corrected. Few species that have been recognized for long periods or are widely distributed have been static in their nomenclature; most species bear many epithets. Widely distributed species are often misidentified as new species when they are found far away from the localities where they were originally described. Tracking the synonymies and name changes is complicated but necessary to allow for searches for information on a species under its previous

Three projects have comprehensively surveyed the fauna of 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 1990s the Bi-State Water Quality Program published its findings on the state of the lower Columbia River. Lastly, in 1999, the Environmental Protection Agency conducted a two-year sampling effort in the lower Columbia River as part of its Environmental Monitoring and Assessment Program West Coast Project (EMAP).

Using these three comprehensive surveys and several site-specific studies (Table 1), we compiled an inventory of the flora and fauna of the lower Columbia River. Many of the previous studies were limited in taxonomic and geographic scope.

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names. Each error in the taxonomy of a species prevents access to information under the correct names. Without continuous revisions, local taxonomic literature does not include information on new discoveries elsewhere in the world. The taxonomy of ANS therefore requires continuous reevaluation, based on the world taxonomic developments.

Table 1. Principal biological surveys of the lower Columbia River consulted by the literature review.

Sampling Period	Organisms Targeted	Sites	Agency or Program (Published References)
1962-1963	Fish	Lower Willamette	(Hutchinson and Aney 1964)
1963-1964	Fish	freshwater tributaries of the lower Columbia	(Reimers 1964, Reimers and Bond 1967)
1963-65	fish, benthic invertebrates, zooplankton	sites on the mainstem to Harrington Point	(Osterberg 165, Haertel & Osterberg 1967, Haertel 1970)
1971-1972	Zooplankton	Columbia River estuary	NMFS (Misitano 1974)
1973	fish, benthic invertebrates, zooplankton	Lower Columbia River	NMFS & USACE (McConnell *et al.* 1973; Durkin 1973; Durkin & McConnell 1973; McConnell et al. 1973; Misitano 1973; Sanborn 1973)
1973-75	fish, benthic infauna	Youngs Bay and tributaries	OSU (Higley & Holton 1975; CREDDP 1980a,b)
1975-1977	fish, benthic invertebrates, plants	Miller Sands	USACE (Clairain et al. 1977)
1975-77?	fish, benthic invertebrates	Estuarine beaches of Columbia River	NMFS (Durkin *et al.* 1977)
1975-78	Benthos	Alder Creek in Youngs Bay	(Montagne & Assoc. 1977, in CREDDP 1980a)
1975-78	benthos	lower estuary	OSU (Higley *et al.* 1976; Higley & Holton 1978); CREDDP 1980a)
1978-80	tidal marsh plants	Columbia River estuary	CREDDP (MacDonald & Winfield 1984)
1980-81	Fish	primarily in the main stem of the Columbia River estuary	CREDDP, NMFS & ODFW (Bottom *et al.* 1984, Bottom and Jones 1990)
1980s	Mammals	lower Columbia River	CREDDP (Howerton 1984)
1978-80	benthic infauna	lower Columbia River	CREDDP (Holton 1984)
1978-80	epibenthic organisms	lower Columbia River	CREDDP (Simenstad 1984)
1980-81	benthic invertebrates	Baker Bay near Ilwaco	NMFS (Furota & Emmett 1993)
1980s	benthic invertebrates	Cathlamet Bay	NMFS & USFWS (Emmett *et al.* 1986; Durkin *et al.* 1982)
1987-1992	benthic invertebrates, demersal fishes	freshwater mainstem of the lower Columbia River	NMFS (McCabe and Hinton 1990, McCabe et al. 1990, McCabe and Hinton 1993, McCabe et al. 1993, McCabe et al. 1997)
1990-92	benthic invertebrates	mouth to Bonneville Dam	BSWQP (Ellis & DeGasperi 1994)
1991-1994	fish, benthic invertebrates	Rice Island, Miller Sands	NMFS (Hinton et al. 1992a, Hinton et al. 1992b, McCabe et al. 1993, McCabe et al. 1996)
1990-1992	Fish	lower Willamette River	ODFW (Ward and Nigro 1992)
1995	fish, benthic invertebrates	Trestle Bay	USACE (Hinton & Emmett 2000)
1998	freshwater bryozoans	Willamette River	(Marsh and Wood 2002)
1999-2000	benthic invertebrates	mouth to Bonneville Dam	WEMAP[12], WDE & ODEQ
2001-2002	fish, benthic invertebrates	lower Willamette River	ODFW, City of Portland (North et al. 2002)
2002	Plants	lower Columbia River	LCREP
2003	Plants	Astoria shoreline	CREST (CREST 2003)

[12] Portions of the 1999-2000 WEMAP Survey data from the did not become available until the literature review was completed and are not reflected in the previous LCRANS Literature Review release.

The literature review revealed uneven coverage of taxa. Nonnative fishes and aquatic plants (submersed, floating, emergent and marsh) were the most abundant introduced taxa of the lower Columbia (Table 2). Native and non-native fishes of the lower Columbia River and its tributaries have been well described (Hutchinson and Aney 1964, Reimers and Bond 1967, McConnell et al. 1973, Bottom et al. 1984, Ward and Nigro 1992, North et al. 2002, but there was little information on nonnative and cryptogenic invertebrates. These species were poorly-studied and rarely identified as introduced or potentially introduced species. A complete species list is available in Appendix B.

Intentionally and unintentionally introduced species are present in the lower Columbia River. The non-native fishes were dominated by intentionally introduced species. The invertebrates were considered primarily unintentional introductions.

Table 2. Summary of nonindigenous and cryptogenic species compiled during the literature review,listed by major taxonomic category.

Taxon	**Nonindigenous Species**	**Cryptogenic Species**
* Indicates species counts that include introductions that failed or are thought to have failed to become established, for example: *Homerus americanus* has been introduced intentionally with no known surviving populations. # May include native species that were misidentified.		
Plants	23	5
Mammals	1	0
Herptiles	3	0
Fishes	36*	1
Annelids	6	37#
Amphipods	1	3
Copepods	6	12#
Decapods	4*	0
Isopods	1	1
Bivalves	2	0
Gastropods	2	0

The cryptogenic species list compiled during the literature review includes species, that have been identified as non-native, but for which the validity of the identifications is uncertain and unverifiable. This is principally suspected of species in poorly studied taxonomic groups (e.g., polychaete worms, aquatic insects, oligochaetes). Consulting taxonomists concluded that many of these species were not correctly identified in the papers and reports surveyed. Mis-identifications could have resulted from the use of inaccurate local keys, inexperienced taxonomists, or attempts to fit unrecognized non native species into local species keys.

From the literature review we concluded that there are biological communities and habitats within the lower Columbia River that are poorly studied. Patchy habitats and poorly characterized areas exist in the estuary as well as further upriver. Several ANS such as the anthozoa, *Nematostella vectensis*, and Japanese eelgrass, *Zostera japonica*, 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, EMAP unpublished data) but no follow up information exists on these populations. Although common along the main-stem, tidal freshwater sloughs are also poorly characterized and many exist adjacent to major deep-water ports, features that made them of special interest to this survey. We hypothesized that such areas may provide protection from strong flushing events and could therefore provide non-native aquatic macrophytes, insects and epibenthic invertebrates opportunities to establish. Other sites of interest to us had records where a variety of poorly characterized organisms, i.e. oligochaetes, were collected but not identified to species.

Chapter 4: Field Sampling

Methods

The 2002 and 2003 field surveys were guided by sampling plans built on prior knowledge and reviewed by the TAC. The literature review was integral to the development of a stratified and adaptive sampling plan. Limited resources and the relatively large area required that we identify areas of interest such as locations closely associated with ballast water release, habitats with previously reported ANS and cryptogenic species, and areas that have been understudied previously. It was also deemed important to avoid duplication of new and ongoing projects, (i.e. the EMAP survey conducted by the EPA, ODEQ and WDOE); we wanted to conduct sampling complementary to these efforts.

The 2002 survey focused on taxa and habitats that were poorly represented in the literature, sites that could be re-sampled at regular intervals in a long-term monitoring program, and/or sites that had a reliable historical record to permit evaluation of invasion rates. In 2003, we re-sampled those stations identified as potential long-term monitoring stations, and some additional new stations. Whenever appropriate, members of the TAC were asked to comment on the targeted sampling efforts, species identifications, and regional ANS information. When sampling was limited by access and weather we either arranged to return to those stations or attempted to sample as near to those locations as possible.

The taxonomic scope of the LCRANS project was limited to free-living macrophytes and animals, except in unmistakable cases of disease causing organisms and parasites, which were noted when they were observed. Taxa that have not been well studied by previous investigators were the primary focus of these surveys. We did not conduct surveys of the fishes, which are the most studied fauna of the lower Columbia River, or the insects, which we could not identify to species reliably.

Locations

Seventy-two stations were sampled from the Bonneville Dam to the Pacific Ocean between April 2002 and October 2002 (Figure 4). Fifty-three sites were sampled by invertebrate and aquatic macrophyte experts. The remaining nineteen stations were sampled specifically for nonindigenous aquatic macrophytes (although the presence of nonnative mollusks was also noted when apparent at these sites). In 2003, 62 stations were sampled (Figure 4). Invertebrate communities were sampled at 36 stations and plant surveys conducted at more than 30 stations between May and September. In 2003, phytoplankton surveys were conducted at seven stations in the lower river. Gaps in the spatial distribution of 2002 sampling were also addressed, including the Willamette River and parts of the mainstem of the lower Columbia that had not been adequately sampled in 2002. In 2003 we devoted more sampling effort to the mainstem of the Columbia in the estuary, between Portland and Bonneville Dam, and on the Willamette River. In addition, special effort was made to sample and identify soft-bodied benthic organisms such as polychaete worms. A more thorough aquatic macrophyte survey was also conducted that noted macroinvertebrate communities associated with both native and nonnative aquatic plants (Figure 5). At some locations only nonnative species of aquatic plants were noted.

Techniques

The major substrates and microhabitats sampled included intertidal and subtidal mud, sand, gravel, cobbles, rocks, banks, artificial substrates such as floats and pilings, and aquatic plants. Every accessible habitat at each sampling station was sampled. Sampling was conducted at various lengths of time at each location, depending on the number of habitats present; sampling usually occurred during low tide. Estuary sampling was scheduled to coincide with negative low tides during daylight hours to increase access to hard substrates. Tidal amplitudes in the freshwater reach of Columbia River above Longview did not affect access to substrates. A variety of sampling methods were employed including collection by hand, scraping substrata using a 2-mm mesh stainless steel mesh sieve attached to a long pole developed specifically for sampling vertical fouling communities, a 0.0225-m2 Petite Ponar grab sampler, 700-µm epibenthic sled, a 250-µm mesh zooplankton net, a 80-µm mesh phytoplankton net, a plant rake, several types of kick and dip nets. Sampling was conducted to obtain the best qualitative coverage possible. Quantitative sampling protocols and precise species counts were not deemed necessary in order to develop a comprehensive list of species present.

Benthic organisms were collected by vigorously agitating mud, sand, gravel and rock samples in water to suspend organic material and small invertebrates. The suspensions were decanted through a series of mesh sieves (2-mm, 1-mm mesh, and 0.5-mm) to retain suspended organisms. The washing and decanting procedure was repeated until the majority of organisms in the samples were removed. Sub-samples were made only when the total volume of organisms retained on the sieves exceeded the volume of the largest sample containers.

In 2003 many samples were collected specifically for oligochaete analysis by Steve Fend. Depending on field conditions these samples were either picked live and un-sieved or preserved un-sieved for later sorting with 200-µm sieves. Live specimens were preserved by first anaesthetizing the sample in dilute alcohol for 10 minutes, then fixing by slowly adding a formalin-alcohol-acetic acid (FAA) solution.

Bulky samples of aquatic plants, peat, rocks or gravel or other similarly course substratums, were washed on a 4-mm or 2-mm mesh sieve in a 20-liter dishpan. Large organisms and unique organisms were removed directly to sample containers. Smaller organisms were captured by decanting the wash water through 0.5-mm and 1-mm mesh sieves. This procedure was repeated until most of the invertebrates in the sample were acquired

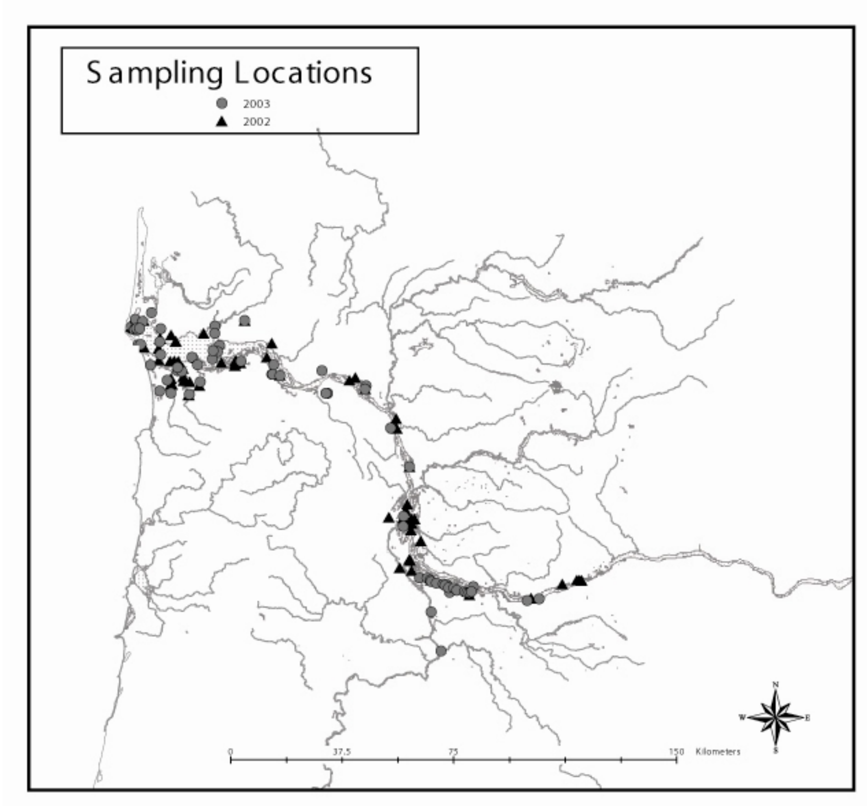

Figure 4. LCRANS sampling locations 2002, 2003

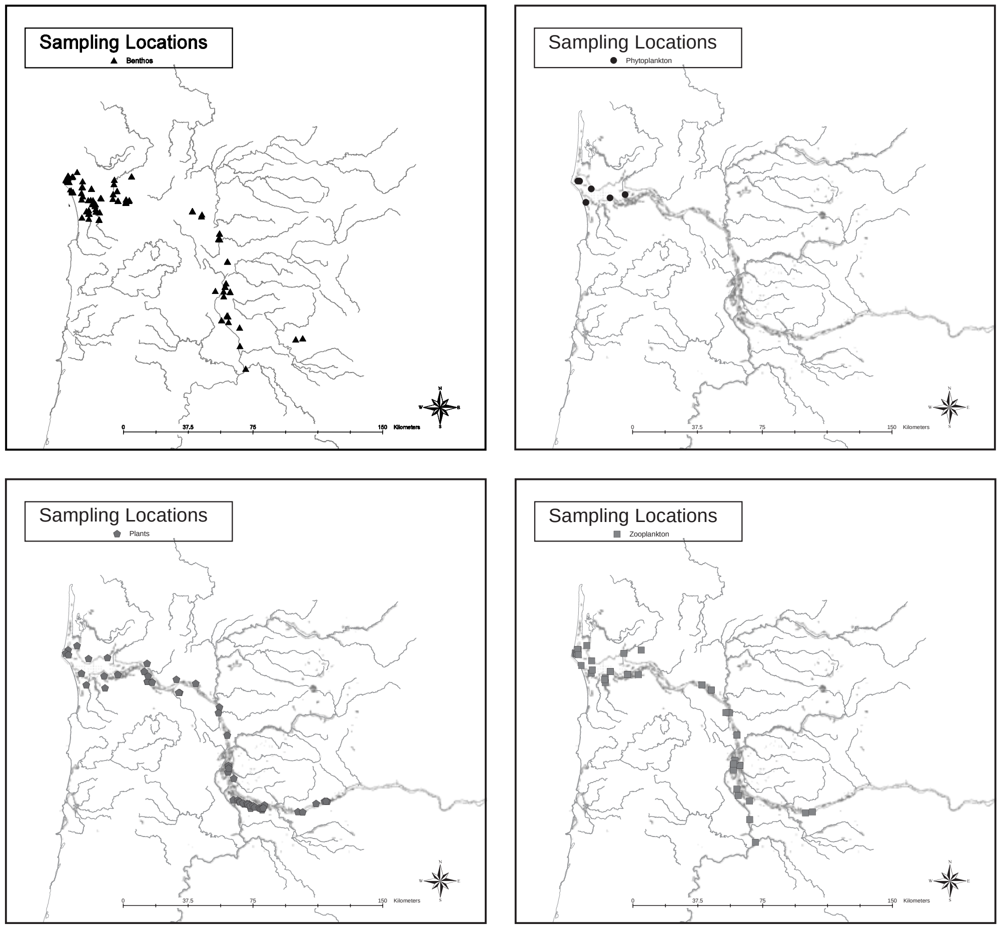

Figure 5. Distribution of LCRANS sample types 2002-2003

Organisms retained on the sieves or picked out of samples were placed into plastic bags or jars of water from the sample location for later examination and sorting in the laboratory. Live samples were kept on ice and processed on the same day they were collected. These collection methods usually produced large numbers of undamaged invertebrates suitable for taxonomic identifications.

Zooplankton and phytoplankton were collected with water column plankton hauls made either off a dock or from a boat with a 0.25-m diameter, 250-µm mesh plankton net (zooplankton) and an 80-µm mesh plankton net (phytoplankton). The net was lowered to the bottom, and after several minutes was slowly pulled to the surface. In the laboratory, each plankton sample was examined under a dissecting microscope, and representatives of each species were removed. If necessary for identification, diagnostic parts (e.g., fifth legs of copepods) were removed and examined under a compound microscope.

Sorting thousands of specimens collected in some of the fouling and benthic samples was impractical and unnecessary for the purposes of the survey. Therefore, in the final sorting, abundant and highly visible species were collected only during the first 40-60 minutes and then an additional 40-60 minutes of sorting was performed under a stereomicroscope to collect rarer or inconspicuous species. Live sorting of the samples allowed identification of species that were unique in behavior or coloration, and that might have been overlooked in fixed samples. The large size of the benthic samples greatly increased the probabilities of collecting all species present.

Classification of species

Distinctions between nonindigenous, cryptogenic and native species were based on criteria for introduced species developed by Lindroth (1957), Carlton (1979), Webb (1985), Chapman (1988), and Chapman and Carlton (1991, 1994) (Table 3). Application of these criteria to each species required detailed information on their taxonomy, biogeography, ecology, and life histories. Therefore, taxa for which this information did not exist (e.g., non-commercial species, poorly known groups) were difficult to assess.

Species were considered native when most of the criteria were not met and introduced when most of the criteria were met. The degree of certainty of the classification of each species was assessed from the number of criteria that applied, and the quality of the data used to assess the criteria. Satisfaction of a single criterion was rarely sufficient evidence that a species is introduced. Satisfaction of multiple criteria, however, was considered definitive for the nonindigenous or native origins of species even though the criteria are largely subjective. Species for which evidence of these criteria was mixed or unclear were defined as cryptogenic (Carlton 1996). All specimens that were identified to species level were classified according to the native vs. nonnative criteria. Species that could not be identified to species were classified as cryptogenic. Application of the criteria relied on the quality of associated systematic, ecological, and historical data. Pertinent information was often lacking, and species were included in these analyses only when they were confidently identified.

Table 3. Criteria for introduced species modified from Chapman and Carlton (1991, 1994) and Lindroth (1957), Carlton (1979), Webb (1985), Chapman (1988).

(1) Historical records of introduction. (Game, aquaculture, agriculture or otherwise intentionally introduced species are commonly recorded upon entry.)
(2) Association with human mechanisms of introduction. (Species are associated with particular mechanisms of introduction by timing and location of arrival and direct observations of association such as organisms that occur in the fouling communities on the hulls of ships or oysters or in ballast water discharged from ships, aquarium pets.)
(3) The absence from fossil deposits or from Native American shell middens in regions where the species is present. (Species with hard parts, such as angiosperms, diatoms, sponges, mollusks, bryozoans, echinoderms, and vertebrates leave fossil remains that can be of sufficient quality for species identifications. Their presence in prehuman fossil deposits is evidence of native origins. Therefore, their absence in fossil assemblages of communities in where they presently occur is evidence of their recent appearance. Fossils are not as useful for species of genera such as the bivalves *Mytilus* and *Ennucula* that are extremely difficult to distinguish by morphologically and peracaridan fossils are all but unknown.)
(4) Insufficient natural dispersal mechanisms to create the entire global distribution of a species. (Many species do not have specialized adult or larval dispersal stages or associations with natural dispersal mechanisms that could transport them across major geographic barriers. The occurrence on both sides of dispersal barriers by such species is evidence of their nonindigenous status.)
(5) Appearance in regions where not found previously. (Recent appearances of conspicuous species such as the green crab and the Chinese mitten crab in the northeast Pacific or a charismatic species such as the cholera bacterium, *Vibrio cholerae* in the southeast Pacific where they would not be overlooked previously are evidence that they were introduced by human activities.)
(6) Discontinuous or otherwise incomplete local distributions relative to those of ecologically similar endemic species. (Incomplete dispersal by the mechanism of introduction, poor adaptation to the range of local conditions, and early stages of invasion within new geographic ranges create disjunct distributions that are uncommon among native species.)
(7) Recent spread from one or a few locations to broad geographical areas. (Introductions invariably begin in isolated areas due to the uneven occurrences of the mechanisms of dispersal. Thus, ballast water introductions spread from shipping ports and aquaculture introductions spread from areas where aquaculture activities occur.)
(8) Close associations with other introduced species. (Spatial associations of introduced species result, in small part, from their common mechanisms of dispersal and possibly in greater part from the patchy, aggregated distributions of introductions due to poorly understood ecological and biological factors. The fouling communities of floats in San Francisco Bay are dominated by ANS that are identified by other criteria. Additionally, the specialization of some parasites and predators on a single introduced species can reveal their nonindigenous origins.)
(9) Restriction to new or artificial environments. (Introduced aquatic species commonly are restricted to substratums or habitats, such as cement or styrofoam floats, pilings, rip-rap over mudflats, and boat hulls, that were absent, uncommon or ephemeral before European settlement. A complete dependence on such artificial substratums is unlikely among native species.)
(10) Conspecific with geographically isolated populations. (All recent introductions are geographically isolated from their native populations and therefore, all recently introduced species are conspecific with geographically isolated native populations.)
(11) Non-endemic evolutionary origins apparent from membership in a non-indigenous taxonomic group. (Introduced species are often morphologically or genetically most similar to geographically isolated taxonomic groups rather than local groups.)
(12) Non-endemic evolutionary origins apparent from ecological or physiological adaptations. (Many introduced species are from climates were temperature ranges exceed those in the new location or where they escape parasites or diseases. Some introduced species tolerate temperatures, for instance, that do no exist in the new locations. Other ANS are vulnerable to nonindigenous parasites, such as the green crab to the parasitic barnacle *Sacculina carcini*, to which the native northeast Pacific species are not vulnerable.

Transportation vectors, dates of discovery and the definition of native range relied heavily on available ecological and historical data and may not represent the definitive pattern of introduction (i.e. when it arrived, how it arrived, and where it came directly from), information which remains unknown for many species. When more than one vector was found in the literature or determined from species' life history characteristics all of them were included in the results. The following vectors were assigned to each introduced species where appropriate.

- Aquarium - intentional aquarium disposal by an individual into waters of the basin
- Ornamental - ornamental species escape (e.g. flooding of a private pond), release, or improper disposal by an individual
- Release by individual - other types of release by individuals (i.e. does not include aquarium or ornamental species or actions taken by state or federal agencies) release my be intentional or accidental (e.g. dumping of bait or bait packing material into water, unintentional transport of species in recreational gear, release of live food species for religious or humane purposes, etc.
- Accidental - accidental introduction accompanying intentional introduction of a different species by a state or federal agency (does not include introductions associated with oyster planting;
- Escape - escape from commercial cultivation
- Fishery enhancement - intentionally introduced for fishery or wildlife enhancement by an agency rather than an individual
- Solid ballast - entrained with solid ballast used by ships in the 1800s before ballast water became prevalent
- Ballast water – collected and transported in ballast water taken on to stabilize commercial, military and other vessels
- Ship fouling - transported as part of the fouling community on the hulls of ships, anchor chains, etc.
- Gradual spread – species arrived via natural mechanisms of spread from introduced populations outside of the lower Columbia River (i.e. transported by birds, wind, water, etc.) often associated with Japanese or Atlantic Oyster introductions in other estuaries
- Biological control – species introduced intentionally by an agency or an individual for biological control purposes

Chapter 5: Results and Discussion

Field Survey Results

Samples were collected from the field at the 134 sampling stations. We documented 269 aquatic species (and 55 other distinct organisms that we were unable to identify at the species level and are labeled as "unknown" in the following figures) in the lower Columbia River. Of the 269 species identified, 54 (21%) were introduced, 92 (34%) were native, and 123 (45%) were cryptogenic. It is important to note that vertebrates were not intentionally targeted in our sampling and not all native plants (especially emergent and marsh species) were recorded during plant surveys.

The introduced, native, and unknown species collected from the lower Columbia River were mostly invertebrates (Figure 6). There were slightly more cryptogenic phytoplankton than cryptogenic invertebrates. The cryptogenic phytoplankton and invertebrates accounted for nearly half of all the species collected. The low number of vertebrates collected can be attributed to sampling methods and does not reflect the actual number of vertebrates (especially fish) present in the lower river. In addition, these data do not reflect all of the native plants present (primarily emergent and marsh species) because those species were not recorded during plant surveys.

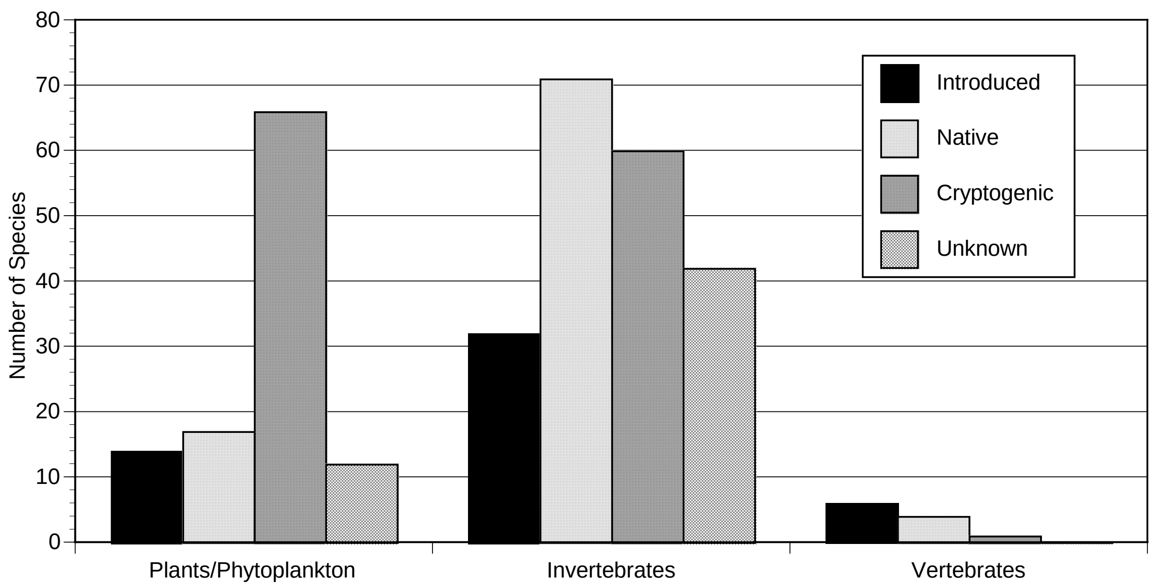

Figure 6. LCRANS field survey species collections broken down by major taxonomic group and origin.

Crustaceans were the most abundant introduced invertebrates (42%) followed by annelids (30%) (Figure 7). The introduced invertebrates were dominated by benthic organisms. Benthic invertebrates accounted for 61% of all introduced invertebrates collected and 36% of the total number of introduced species. Fouling organisms (organisms capable of attaching to surfaces like stone, concrete, wood, piers, docks, and boat hulls) comprised 23% of the introduced invertebrates. Pelagic organisms accounted for the remaining invertebrates.

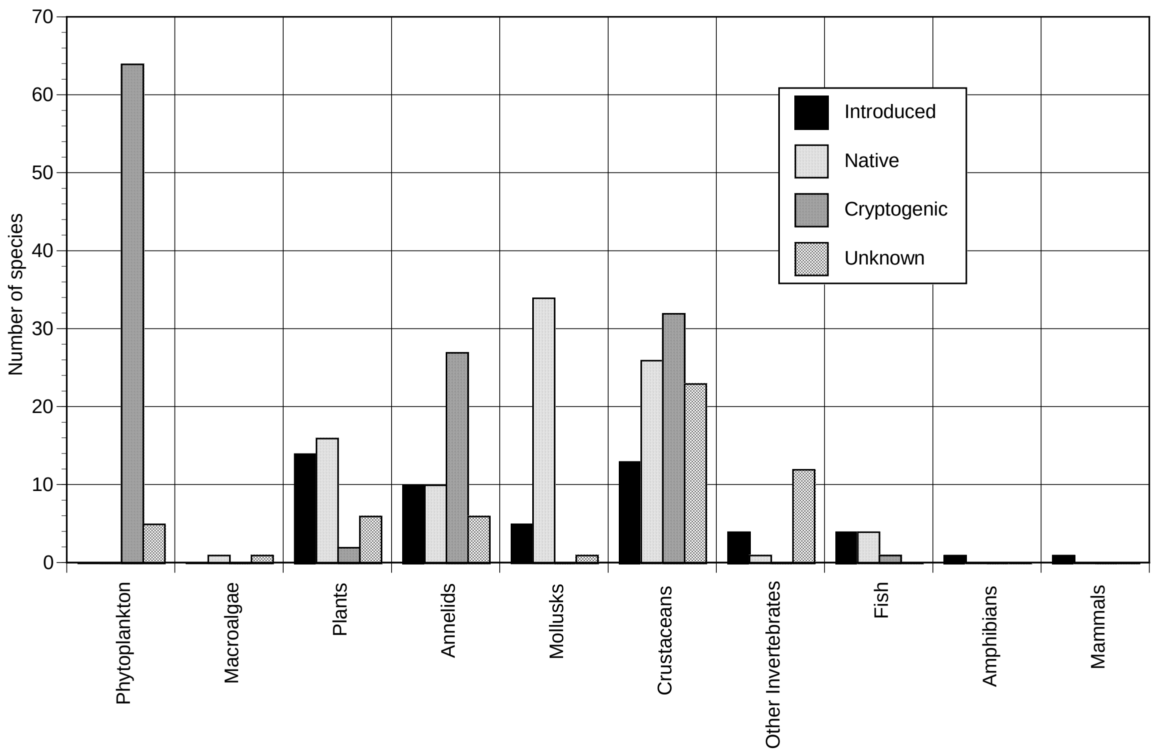

Figure 7. LCRANS field survey species collections broken down by minor taxonomic group and origin

Although vertebrates were not specifically targeted by this effort five introduced fishes and one mammal were documented (Figure 7). The single introduced mammal was the nutria, *Myocaster coypus*, a semi-aquatic rodent that was seen at numerous stations along the Willamette River.

Cryptogenic species numbers were dominated by phytoplankton, oligochaetes and many types of zooplankton (Figure 7) for which little information is available on native range. All of diatoms, dinoflagellates, and other phytoplankton collected were classified as cryptogenic in this study. In addition, several of the species collected, such as *Gasterosteus aculeatus* or *Branchiura sowerbyi*, are subject to changing expert opinions on origin.

Eight of the 54 introduced species collected were new records for the lower Columbia River. One of these species, the oligochaete *Eukerria saltensis*, appears to be a new record for the West Coast. The other seven species, the oligochaetes *Branchiura sowerbyi, Chaetogaster diaphanous*, *Paranais frici*, and *Stylodrilus heringianus*, the purple varnish clam, *Nuttallia obscurata*, the Chinese mystery snail, *Cipangopaludina chinensis malleatus,* and the crustaceans *Limnoithona tetraspina* and *Melita cf. nitida* have been reported previously at other West Coast locations.

Literature Review and Field Survey Results

Combing the results from both the field surveys conducted in 2002 and 2003 with the results of the earlier literature review (complete literature review results available at http://www.clr.pdx.edu/) we determined that at least 81 new organisms have been introduced into the lower Columbia River since the mid 1800s (Figure 8, Table 4).[13] The majority of these species were fish (28%), aquatic plants (23%) and crustacea (15%). The remaining 18% was a combination of mollusks, annelids, bryozoans, cnidaria, amphibians, reptiles and an aquatic mammal.

[13] Those species not collected by LCRANS in 2002 or 2003 are species collected either by WEMAP in the lower Columbia in 1999 and 2000 and validated by the same team of taxonomists as used by LCRANS, or species noted in the LCRANS literature review and confirmed by regional taxonomists or our team of experts.

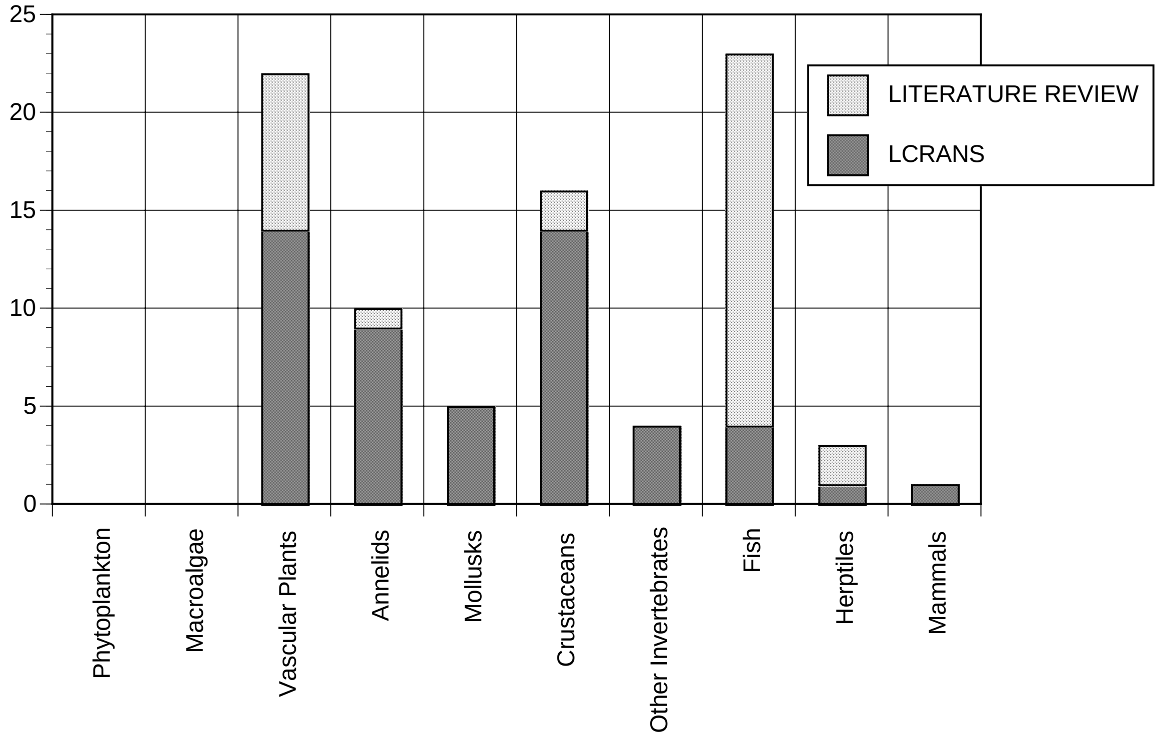

Figure 8. Number of introduced species in various taxa in the lower Columbia River from the literature review and field survey.

Table 4. Invasion dates and mechanisms of introduction for all introduced species present in the lower Columbia River. This table does not include one-time unsuccessful introductions or seasonally limited introductions such as piranha, lobster, etc. reported from the literature review. All species included on this list as a result of the literature review appear without bold lettering and were reviewed for inclusion on this list by field and taxonomic experts before labeling them as present in the lower Columbia River basin.

Species	Common Name	Native Range	1st Western Collection	1st LCR Collection	Vector	Record
Mechanism abbreviations: AQ = aquarium disposal, OR = ornamental species (escape, release, disposal), RI = release by individual (not considered an aquarium or ornamental species nor released by a state or federal agency), AX = accidental introduction accompanying intentional introduction, ES = escape from commercial cultivation, FS = fisheries or wildlife enhancement, intentional by a state or federal agency, SB = solid ballast, BW = ballast water, SF = ship fouling, GS = gradual spread from other introduction locations outside of the river, and BC = biological control organism						
PLANTS						
Vascular						
Cabomba caroliniana	Carolina fanwort	NA, SA		?	AQ	LCRANS
Callitriche stagnalis	pondwater starwort	EUR-ASIA	1871, 1902	?	BW,SB	LCRANS
Cotula coronopifolia	brass buttons	AF	1878	?	SB	LCRANS
Egeria densa	elodea	SA	?	1944	OR	LCRANS
Iris pseudocorus	yellow flag iris	EUR	1860s	?	OR	LCRANS
Lythrum salicaria	purple loosestrife	EUR	1880s	?	OR, GS, SB	LCRANS
Myriophyllum aquaticum	parrot's feather	SA	<1957	?	OR	LCRANS
Myriophyllum spicatum	Eurasian milfoil	EUR, AF	1976	?	AQ	LCRANS
Mentha aquatica	water mint	EUR	?	?	GS, OR, RI	LIT REV
Mentha aquatica x spicata	peppermint	EUR	?	?	GS, RI	LIT REV
Ludwigia uruguayensis	water primrose	SA	?	1956	OR	LIT REV
Nymphaea odorata	fragrant water lily	NA	?	?	OR, RI	LCRANS
Phalaris arundinacea	reed canary grass	NA	?	?	GS	LCRANS
Phragmites australis	common reed	NA	?	?	GS	LCRANS
Potamogeton crispus	curly leaf pondweed	EUR-ASIA	?	1947	RI, OR, AX, ES	LCRANS
Sagittaria subulata	awl-leaf arrowhead	NA	?	?	AQ	LCRANS
Typha angustifolia	narrow-leaf cattail	EUR-ASIA	1951	?	OR	LCRANS
Vallisneria Americana	water celery	NA	1900s	?	FS	LCRANS
Zostera japonica	Japanese eelgrass	NW Pacific	?	?	GS	LCRANS

Table 4. cont.

Species	Common Name	Native Range	1st Western Collection	1st LCR Collection	Mechanism of Introduction	Record
Mechanism abbreviations: AQ = aquarium disposal, OR = ornamental species (escape, release, disposal), RI = release by individual (not considered an aquarium or ornamental species nor released by a state or federal agency), AX = accidental introduction accompanying intentional introduction, ES = escape from commercial cultivation, FS = fisheries or wildlife enhancement, intentional by a state or federal agency, SB = solid ballast, BW = ballast water, SF = ship fouling, GS = gradual spread from other introduction locations outside of the river, and BC = biological control organism						
INVERTEBRATES						
Bryozoa						
Fredericella indica		NA	?	1999	GS, AX, RI	LCRANS
Pectinatella magnifica		NA	?	1999	GS, AX, RI	LCRANS
Anthozoa						
Nematostella vectensis		NW Atlantic	1946	1994	SB, BW	LCRANS
Hydrozoa						
Cordylophora lacustris		EUR	ca 1920	1965	BW, SF	LCRANS
Oligochaeta						
Branchiura sowerbyi		Black-Caspian Sea	1950	2002	SB, BW, RI	LCRANS
Chaetogaster diaphanous		not known	2002	2003	SB, BW, RI	LCRANS
Eukerria saltensis		SA	?	2003	SB, ?	LCRANS
Paranais frici		EUR	1961	2003	SB, BW, RI	LCRANS
Stylodrilus heringianus		EUR	?	2003	SB, BW, RI	LCRANS
Polychaeta						
Hobsonia florida		NA	1940	1975	BW, AX	LCRANS
Manayunkia aesturina		NA	?	1981	BW	LCRANS
Manayunkia speciosa		NA	1961	1999	AX, BW	LCRANS
Polydora cornuta		N. Atlantic	1932	1981	BW, SF, GS	LCRANS
Pseudopolydora kempi		NW Pacific	1951	1991	BW, SF, GS	LIT REV
Streblospio benedicti		N Atlantic	1932	1999	BW, SF, GS	LCRANS
Gastropoda						
Cipangopaludina chinesis malleatus	Chinese mystery snail	ASIA	1950s	2002*	OR, AQ	LCRANS

Table 4. cont.

Mechanism abbreviations: AQ = aquarium disposal, OR = ornamental species (escape, release, disposal), RI = release by individual (not considered an aquarium or ornamental species nor released by a state or federal agency), AX = accidental introduction accompanying intentional introduction, ES = escape from commercial cultivation, FS = fisheries or wildlife enhancement, intentional by a state or federal agency, SB = solid ballast, BW = ballast water, SF = ship fouling, GS = gradual spread from other introduction locations outside of the river, and BC = biological control organism

	Species	Common Name	Native Range	1st Western Collection	1st LCR Collection	Mechanism of Introduction	Record
	Potamopyrgus antipodarum	New Zealand mudsnail	AUS-NZ	1980s	<1995	AX, GS	LCRANS
Bivalvia							
	Corbicula fluminea	Asian clam	ASIA	1924	1932	RI	LCRANS
	Mya arenaria	soft-shell clam	NA, EUR	1874	<1900	SB, BW, GS	LCRANS
	Nuttallia obscurata	purple varnish clam	ASIA	1990	2003	BW, RI	LCRANS
Crustacea							
	Balanus improvisus	bay barnacle	NA, EUR	1853	<1900	SF, SB, BW	LCRANS
	Acartiella sinensis		ASIA	1979	1997	BW	LIT REV
	Limnoithona sinensis		ASIA	?	1979	BW	LIT REV
	Limnoithona tetraspina		ASIA	1993	2003	BW	LCRANS
	Pseudodiaptomus forbesi		ASIA	?	1999	BW	LCRANS
	Pseudodiaptomus inopinus		ASIA	?	1990	BW	LCRANS
	Sinocalanus doerri		ASIA	1978	1999	BW	LCRANS
	Tachidius (Neotachidius) triangulari		ASIA	?	1990s	BW	LCRANS
	Nippoleucon hinumensis		ASIA	1979	1999	BW	LCRANS
	Caecidotea racovitzai racovitzai		EUR	1972	1999	BW	LCRANS
	Crangonyx pseudogracilis		EUR	1998	1999	BW	LCRANS
	Grandidierella japonica		ASIA	1966	1999	BW, SF	LCRANS
	Exopalaemon modestus	Siberian prawn	EUR-ASIA	1995	1995	BW, RI	LCRANS
	Sinelobus cf. stanfordi		not known	1943	1943	BW, SF	LCRANS
	Melita cf. nitida		NA	1941	2003	BW, SF	LCRANS

Table 4. cont.

Species	Common Name	Native Range	1st Western Collection	1st LCR Collection	Mechanism of Introduction	Record
Mechanism abbreviations: AQ = aquarium disposal, OR = ornamental species (escape, release, disposal), RI = release by individual (not considered an aquarium or ornamental species nor released by a state or federal agency), AX = accidental introduction accompanying intentional introduction, ES = escape from commercial cultivation, FS = fisheries or wildlife enhancement, intentional by a state or federal agency, SB = solid ballast, BW = ballast water, SF = ship fouling, GS = gradual spread from other introduction locations outside of the river, and BC = biological control organism						
VERTEBRATES						
Fish						
Lepomis gibbosus	pumpkinseed	NA	?	1893	FS	LIT REV
Lepomis gulosus	warmouth	NA	?	1893	FS	LIT REV
Lepomis macrochirus	bluegill	NA	?	1893	FS	LIT REV
Micropterus dolomieu	smallmouth bass	NA	1874	1923	FS	LIT REV
Micropterus salmoides	largemouth bass	NA	?	1888	FS	LIT REV
Pomoxis annularis	white crappie	NA	?	1893	FS	LCRANS
Pomoxis nigromaculatus	black crappie	NA	?	1893	FS	LIT REV
Alosa sapidissima	American shad	NA	1871	1880s	FS	LIT REV
Misgurnus anguillicaudatus	Oriental weatherfish	ASIA	?	1980s	AQ	LIT REV
Carassius auratus	goldfish	ASIA	?	1933	AQ, RI, OR	LCRANS
Ctenopharygodon idella	grass carp	ASIA	1960s	1960s	BC	LIT REV
Cyprinus carpio	common carp	EUR-ASIA	1872	1880	ES, FS	LIT REV
Fundulus diaphanous	banded killifish	NA	?	1971	RI, AQ	LIT REV
Ameiurus catus	white catfish	NA	1874	1880s	FS, RI	LIT REV
Ameiurus melas	black bullhead	NA	1874	1894	RI	LIT REV
Ameiurus natalis	yellow bullheard	NA	1874	1905	FS	LIT REV
Ameiurus nebulosus	brown bullhead	NA	1874	1880s	RI	LIT REV
Ictalurus punctatus	channel cat	NA	?	1920s	RI, FS	LIT REV
Morone chrysops	white bass	NA	1895	?	RI	LIT REV
Morone saxatilis	stripped bass	NA	1879	1900s	FS,RI	LIT REV
Perca flavescens	yellow perch	NA	?	1894, 1905	FS	LCRANS
Sander vitreus	walleye	NA	1874	1940s	FS	LIT REV
Gambusia affinis	mosquitofish	NA		1960s	BC, OR	LCRANS
Herptiles						
Chelydra serpentina serpentina	Eastern snapping turtle	NA	?	?	RI, AQ, OR	LIT REV
Rana catesbeiana	bullfrog	NA	?	1914, 1924	RI	LCRANS
Trachemys scripta elegans	red eared slider	NA	?	?	RI, AQ, OR	LIT REV
Mammals						
Myocaster coypus	nutria	SA	?	1937	ES	LCRANS

Due to the limitations of this survey, inadequate taxonomic resolution in prior studies, and the abundance of unresolved or cryptogenic taxa, our results are likely to represent a conservative estimate of the ANS invasion. Some areas or habitat types in the lower Columbia were not well-sampled previously or in this study. Because our surveys were shore-based or conducted using small boats, the deep, main channel of the river and the salt wedge at the mouth of the estuary were not sampled. We sampled riverbanks, sandy islands, and the benthos adjacent to industrial and port facilities, but these areas should be subjected to more intensive sampling to better characterize these habitats.

Some taxa were either under-sampled or were not identified to species. The Nemertea, Porifera, Ostracoda, Acarina, Kamptozoa, and aquatic insects were collected but not identified to species in most cases. Other data gaps were revealed during analysis of the results. We concluded that oligochaetes were under-sampled because 46% (18 of the 39) (including native, cryptogenic and introduced species) were collected at only one of the 134 sampling locations visited over two years. Such a large number of rare species suggests that we undersampled a patchy oligochaete habitat (Steve Fend, personal communication). In addition, several native oligochaete species reported in our literature survey (including one described from the lower Columbia River) were not found in any of our samples.

Other species previously reported in the Columbia but not recorded in our surveys included the mysid *Alienacanthomysis macropsis* (McCabe et al. 1993*);* a copepod, *Hansenulus trebax*, which is parasitic in the brood chamber of the native mysid *Neomysis mercedis* and described from the Columbia River by Daly and Damkaer (1986)*;* and several endemic mollusk species (Appendix B). Experts who evaluated our species lists also concluded that some taxa lists may be incomplete because they included few mesohaline and marine species, particularly phytoplankton and polychaetes, which should be found near the mouth of the river. Our survey results are supplemented by the results of the literature review, but some poorly resolved taxa (such as the oligochaetes) are still not well-documented in the lower Columbia River.

The large percentage of cryptogenic species (45%) complicates evaluation of the magnitude of aquatic bioinvasion of the lower Columbia River, but it is a consequence of our strict adherence to precise protocols for assigning organisms to classes. The majority of the cryptogenic species were found to belong to taxa that are poorly resolved in the Columbia River and elsewhere. The distribution of many species is reported as widespread or cosmopolitan without discussion of the possibility that these species were spread by human activity. Clarifying the status of cryptogenic species in the Columbia River will be difficult until their worldwide distributions are known and evaluations are made about where they are native and where they are introduced. For example, prior to the publication of Kathman and Brinkhurst (1998) that first described a distribution throughout North America, the oligochaete, *Amphichaeta sannio*, was considered by some to be a European estuarine species. In addition, its taxonomy remains in doubt (some consider *A. sannio*, to be synonymous with *A. raptisae)*, which further complicates resolution of the classification of this species. As a species with unknown origin and a holarctic distribution, we considered it cryptogenic.

Patterns of Introduction

Most invertebrates reported from the Columbia River also occur in San Francisco Bay but not all of these species are distributed throughout other major West Coast estuaries (Table 5)[14]. San Francisco Bay has the highest recorded number of nonindigenous species in the region (Cohen and Carlton 1995) and nearly all ANS reported elsewhere in the eastern Pacific occur in San Francisco Bay (Chapman 2000); however, the importance of dispersal of introduced species from San Francisco Bay to other West Coast estuaries is unclear (Wasson et al. 2001). Twenty-eight of the 35 introduced invertebrates in the lower Columbia River have not been reported in other major bays and estuaries on the West Coast. This distinctive assemblage could be the result of unique hydrological and physical characteristics of the lower Columbia River. Alternatively, it could be a result of differences in sampling effort. For example, rapid assessments surveys – those surveys that are conducted over a limited period of time (usually less than a week) by a team of species experts to identify both native and introduced species found

[14] These data were assembled from several major introduced species surveys undertaken in the past 10 years but may not reflect the current, largely unpublished, state of knowledge on species distributions.

at selected sites - have produced much of the information on introduced species in other estuaries, and oligochaetes are rarely identified during rapid assessment surveys.

Table 5. West Coast distributions of all introduced invertebrates found in the lower Columbia River. (Additional data compiled from Cohen and Carlton 1995, Cohen et al. 1998, Ruiz et al. 2000, Cohen et al. 2001, CDFG 2004, and NAS 2004.)

Invertebrate Species	SFB	CB	LCR	WB	PS
Location abbreviations: SFB = San Francisco Bay CA, CB = Coos Bay OR, LCR = Lower Columbia River, WB = Willapa Bay WA, and PS = Puget Sound WA Table abbreviations: Lit = in literature review but not collected by LCRANS 1 = Found in Humboldt Bay and San Diego Harbor, 2 = Found along the northern California coast, 3 = Found in other Northwest freshwater sites, Bold species names indicates species distributed throughout all listed estuaries					
Fredericella indica[3]			x		
Pectinatella magnifica[3]			x		
Nematostella vectensis	x	X	x		x
Cordylophora lacustris	x	X	x	x	x
Branchiura sowerbyi	x		x		
Chaetogaster diaphanus	x		x		
Eukerria saltensis			x		
Paranais frici	x		x		
Stylodrilus heringianus	x		x		
Hobsonia florida			x	x	x
Manayunkia aestuarina			x		x
Manayunkia speciosa	x		x		
Polydora cornuta	x		x	x	
Pseudopolydora kempi	x	X	Lit	x	x
Streblospio benedicti	x	X	x	x	x
Cipangopaludina chinesis malleatus	x		x		
Potamopyrgus antipodarum	(drainage)		x		
Corbicula fluminea	x	X	x		x
Mya arenaria	x	X	x	x	x
Nuttallia obscurata		X	x		x
Balanus improvisus	x	X	x	x	
Acartiella sinensis	x		Lit		
Limnoithona sinensis	x		Lit		
Limnoithona tetraspina	x		x		
Pseudodiaptomus forbesi	x		x		
Pseudodiaptomus inopinus		X	x		
Sinocalanus doerri	x		x		
Tachidius (Neotachidius) triangulari			x		
Nippoleucon hinumensis	x	X	x	x	x
Caecidotea racovitzai racovitzai [1]			x		
Crangonyx pseudogracilis			x		
Grandidierella japonica	x	X	x	x	x
Exopalaemon modestus	x		x		
Sinelobus stanfordi [2]			x		x
Melita nitida	x	X	x	x	x

Comparisons between the Columbia River, San Francisco Bay and other invaded aquatic systems are difficult but inevitable. While they have similar habitat types, it is problematic to compare these systems because they differ considerably in their physical, chemical, and biological characteristics. Depending upon the taxonomic group considered, the lower Columbia River is more invaded than some systems and less than others (Figure 9). Unlike the lower Columbia, the Hudson River is dominated by introduced plants and mollusks. Except for a smaller number of introduced mollusks, the Columbia River appears to be "more invaded" than Puget Sound. These differences could result from differences in sampling methods, introduction vectors, invasion pressure, habitat types, climates, disturbance regimes, etc. For example, the comparatively large number of introduced vascular plants in the Great Lakes and Hudson River systems may be a result of longer histories of solid ballast discharge; the success of introduced invertebrates in San Francisco Bay could be facilitated by the temperate waters of the Eastern Pacific in (Chapman 1997); and the bathymetry of Puget Sound could decrease the success of benthic invertebrate establishment.

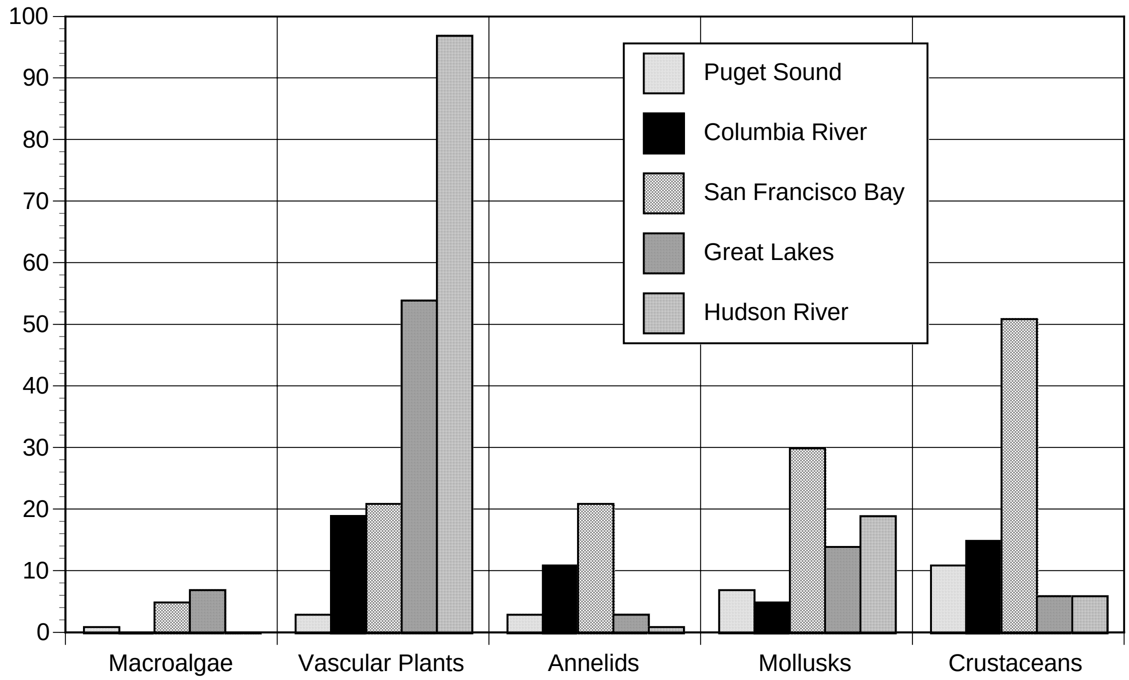

Figure 9. Comparison of invasive species in several North American systems (Mills et al. 1993, Cohen and Carlton 1995, Mills et al. 1995, Cohen et al. 1998, and Cohen at al. 2001).

Rates of Invasion

The number of introduced species found in the lower Columbia River is increasing (Figure 12), and mirrors similar trends observed elsewhere (Ruiz et al. 2001); however, the rate of introduced invertebrate discovery and reporting probably does not represent the actual introduction rates. The lower Columbia invertebrate community was poorly studied in the past and the presence of nonnative species may have been overlooked. Furthermore, some of the introduced species found in our survey were undoubtedly in the Columbia River for several years prior to recent reports. For example, the New Zealand mudsnail, *Potamopyrgus antipodarum*, was present in the Snake River since the mid 1980s and was almost certainly transported downstream from the Snake River at some earlier date than its first discovery near Astoria in 1995 (Wonham and Carlton unpublished). The Chinese mystery snail, *Cipangopaludina chinesis malletus,* has been a popular aquarium/pet species for well over 50 years (Cohen and Carlton 1995) and anecdotal evidence supports a presence in protected waters of the Columbia River basin long before our sighting in 2002. It is also probable that the invertebrate curve reflects sampling effort, in part, which has increased in the last 20 years.

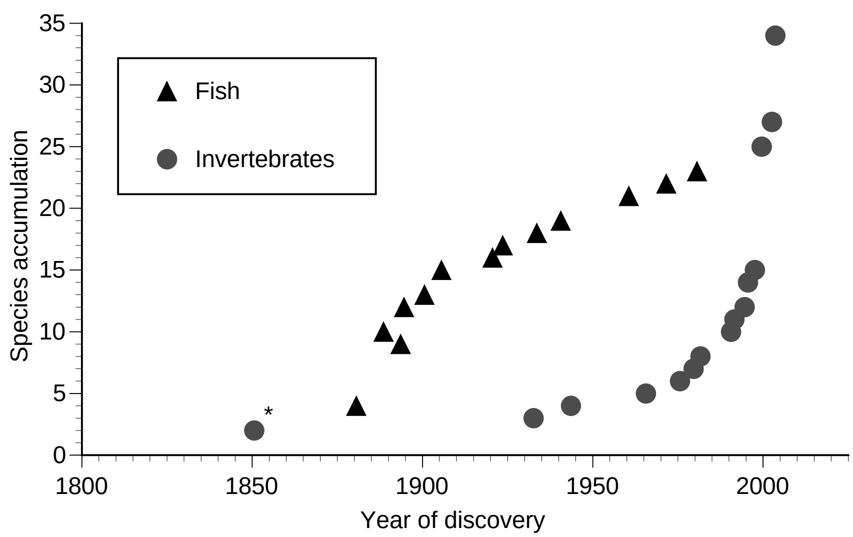

Figure 10. Accumulation of non-indigenous species in the lower Columbia by year of discovery.

In contrast to the rate of nonative invertebrate discovery, the rate of nonnative fish introductions in the river may approximate the actual in introduction rate. Prior to 1955, the majority of fish introductions were intentional, often conducted by the U.S. Fish

Commission, and well-documented (Smith 1896, Lampman 1946). After 1955, intentional sport fish introductions declined but new introductions for biological control, e.g., the mosquito fish, *Gambusia affinis* (Bond 1994), or illegal aquarium disposal, e.g., the oriental weather loach, *Misgurnus anguillicaudatus* (Logan et al 1996), continue to be reported. Furthermore, new and unusual species (e.g. piranha which cannot survive over winter in cold water and are not considered successful introductions) caught by anglers often receive media attention and are reported as novelties (Quinn 2002).

Vectors and Pathways

Nonnative species have been introduced into the lower Columbia River intentionally and unintentionally through a variety of vectors (Figure 10). Although vector determination is not precise, shipping-related vectors accounted for the largest number of introduced species. Ballast water alone was considered to be a possible mechanism of introduction for 29 out of 35 invertebrate species and one plant into the Columbia River. All shipping mechanisms together (fouling, solid ballast, and ballast water) accounted for 30 invertebrates and two aquatic plants. Intentional releases for wildlife enhancement by individuals and fisheries agencies accounted for 19 out of 23 fish introductions to the lower Columbia River. Similarly, many aquatic plant introductions could be attributed to intentional introduction but could also have escaped from ornamental cultivation (Figure 11, Table 4). Many species are associated with multiple mechanisms. For example, the population of the common goldfish, *Carassius auratus*, in the lower Columbia River may be the result of aquarium dumping, escape from ornamental ponds, and/or release by an individual for wildlife enhancement. Intentional introduction and escape from culture ponds were documented for the common carp, *Cyprinus carpio* (Lampman 1949).

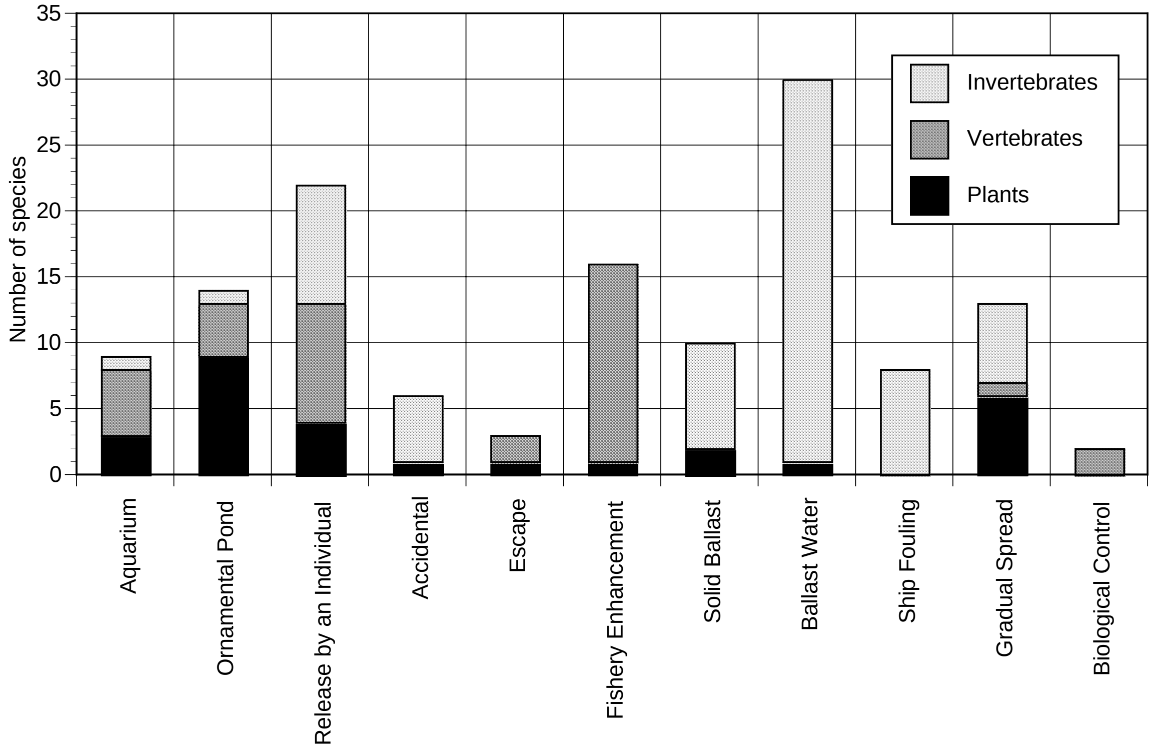

Figure 10. Invasions by type of introduction mechanism.

The importance of various vectors for introduction of invertebrates has changed over time (Figure 11). Shipping-related vectors have increased in importance since 1950. The increase in introductions associated with shipping corresponds with an increase in the volume and speed of shipping in the Columbia. Invertebrate introductions that could be attributed to aquarium dumping and individual release occurred only after 1999, although anecdotal evidence suggests that this vector was active earlier as well.

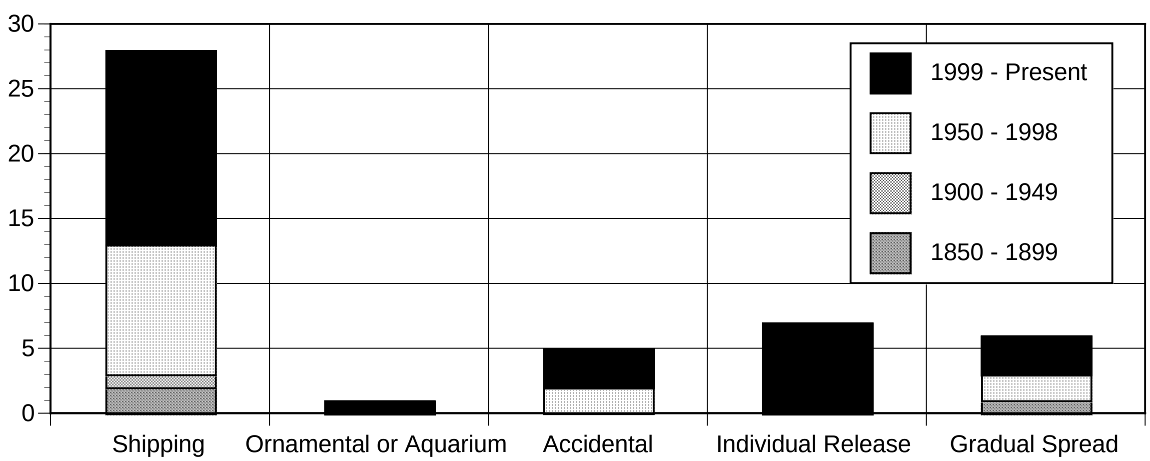

Figure 11 Changes in invertebrate introduction vectors over time.

The majority of introduced species in the lower Columbia originated in North America (Figure 12). Introduced fish accounted for most of the species with North American origin. Europe, Asia, and South America supplied similar numbers of plants as North America. Europe and Asia provided similar numbers of invertebrates as North America. No fish or invertebrates originated in Africa, and no fish or plants originated in New Zealand/Australia.

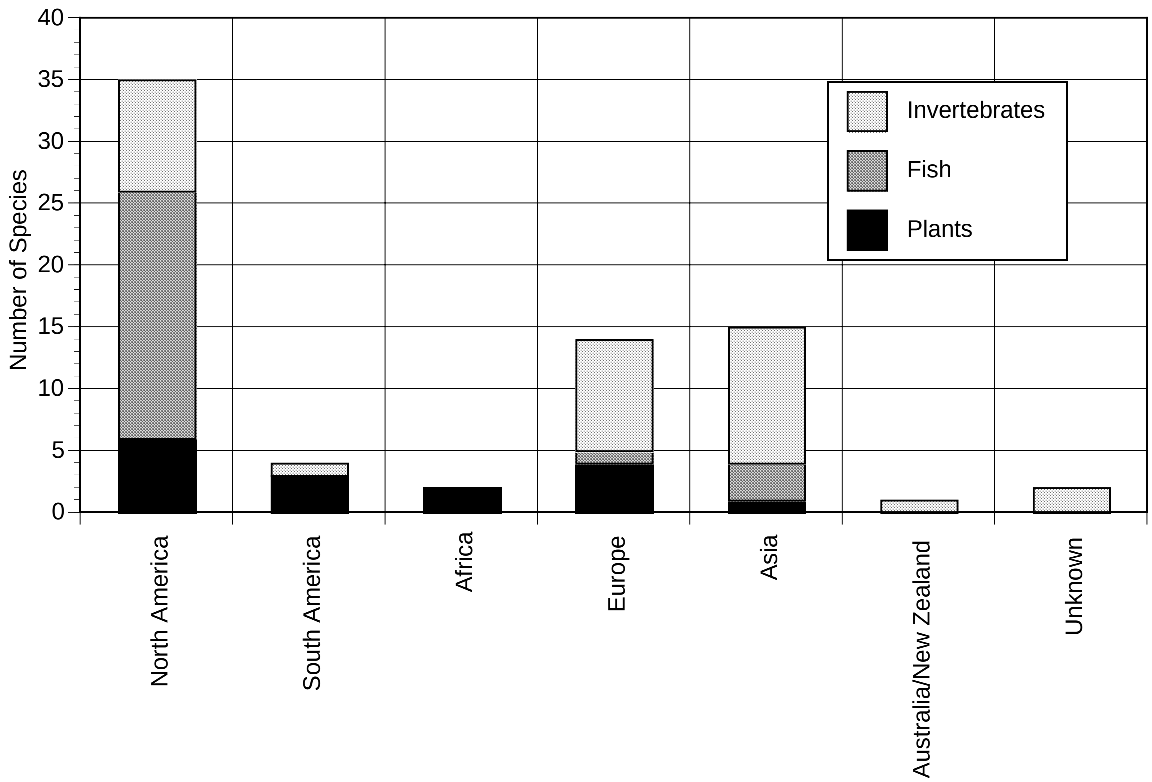

Figure 12. Invasions by region. This figure contains species collected by LCRANS as well as those species from the WEMAP study and the literature review that are considered valid.

Asia was the native region of 34% of the invertebrates introduced via shipping vectors in the Columbia River (Figure 13). The role of shipping in these introductions was supported by data on shipping traffic in the Columbia River. Ninety-four percent of all transoceanic voyages to Oregon ports originate in Asia, i.e., Japan, Korea, China and Taiwan (Flynn and Sytsma 2004).

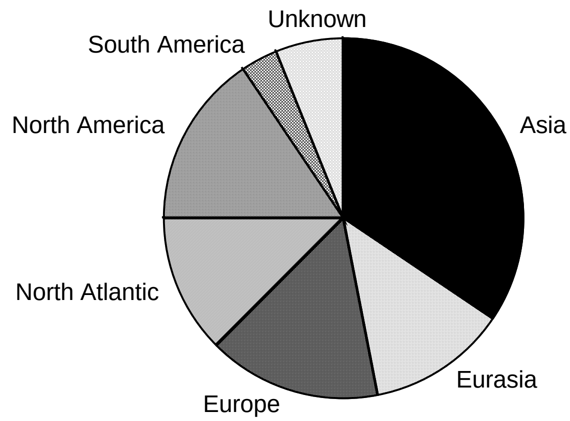

Figure 13. Origins of ballast water introduced invertebrate species in the lower Columbia River.

Despite an apparent correlation between volume of shipping from Asia and the preponderance of Asian species in the invertebrate community in the lower Columbia River, the source of these populations may not be their native ranges in Asia. Many recent ballast water introductions were previously established elsewhere on the West Coast (Table 5). The Columbia River receives more port calls from vessels from these domestic ports (59%) than it does from international ports (Flynn and Sytsma 2004). About 25 percent of coastal vessel traffic coming into Oregon estuaries originated in the highly invaded San Francisco Bay/Sacramento/San Joaquin Delta (Flynn and Sytsma 2004). Short transit times, established populations of introduced invertebrates possibly selected for dispersal by shipping vectors in several domestic ports on the West Coast, and abundant shipping traffic suggests that domestic shipping is a highly important vector for ANS introduction to the Columbia River. According to the dates of first discovery, most ANS in the lower Columbia River were reported earlier from other locations on the West Coast. Discovery dates, however, represent detection rather than arrival and are heavily influenced by sampling effort and regional ANS awareness.

The Columbia River is probably a net importer of ballast water and associated organisms. Columbia River ports are primarily bulk shipping ports, bulkers contain more ballast water than other ship types, and bulkers typically enter the Columbia River without cargo and in-ballast (Flynn and Sytsma 2004). Still, ships do take on ballast water in the Columbia. The role of the Columbia River in regional and global dispersal of ANS requires further investigation.

Chapter 6: Conclusions and Recommendations

We determined that 81 aquatic species were introduced into the lower Columbia River since the 1880s. The majority of these species were fish (28%), aquatic plants (23%) and crustacea (15 %). The remaining 18% was a combination of mollusks, annelids, bryozoans, cnidaria, amphibians, reptiles and an aquatic mammal. These results were likely a conservative estimate of the number of ANS in the river because of limitations of the survey, inadequate taxonomic resolution in prior studies, and the abundance of unresolved and cryptogenic taxa.

Over the course of our field survey we documented 269 aquatic species (and 55 other distinct organisms that we were unable to identify at the species level) in the lower Columbia River. Of the 269 species identified, 54 (21%) were introduced, 92 (34%) were native, and 123 (45%) were cryptogenic. From the 1880s to the 1970s a new introduced species was discovered in the lower Columbia about every five years. The frequency of new discoveries ANS is increasing worldwide (OTA 1993, Ruiz et al. 2000), however, and the rate of discovery of introduced invertebrates in the lower Columbia River mirrors this trend. Over the past ten years a new invertebrate species was discovered about every five months. The increasing rate of new discovery is due to increasing frequency of introductions and to the number and type of surveys conducted. It is not possible to separate these effects from the available data

In contrast to the invertebrates, the rate of fish discoveries in the lower Columbia declined after the 1950s. For fish, the rate of discovery may parallel introduction rates because many introductions were well-documented. The reduction in fish introductions was likely due to a decline in intentional fish stocking by individuals and fish and game agencies to increase the diversity of food and game fishes.

The majority of introduced species in the lower Columbia originated in North America. Introduced fish accounted for most of the species with North American origin, while Asia was the native region of 34 percent of the invertebrates introduced via shipping vectors.

Ballast water was the probable vector responsible for introducing 29 of 35 nonnative invertebrates. Most invertebrates reported from the Columbia River also occur in San Francisco Bay. Seven of the 35 invertebrates introduced into the lower Columbia River are widespread in major bays and estuaries of the West Coast. Additional surveys may increase this number.

The Columbia River receives more port calls from vessels from domestic ports (59 percent) than it does from international ports (Flynn and Sytsma 2004). About 25 percent of coastal vessel traffic coming into Oregon estuaries originated in the highly invaded San Francisco Bay/Sacramento/San Joaquin Delta (Flynn and Sytsma 2004). Short transit times, established populations of introduced invertebrates possibly selected for dispersal by shipping vectors in several domestic ports on the West Coast, and abundant shipping traffic suggests that domestic shipping is a highly important vector for ANS introduction to the Columbia River.

Additional surveys

This report establishes a baseline on ANS in lower Columbia River. Additional monitoring and sampling is necessary to detect new invasions and to document invasion rate, impacts, and efficacy of management efforts. We recommend a multiple purpose sampling approach to maximize the potential of detecting additional species and new arrivals. Sampling should target habitats and taxa that are likely to contain new invaders every year; a synoptic survey of the lower Columbia River should be conducted every five years; and additional sampling should target data gaps and survey limitations of this project. Regular comprehensive sampling of incoming ballast water is also needed to evaluate the probability of new introductions deriving from this vector.

Targeted sampling

Targeted sampling should focus on tracking changes in habitats that are highly invaded and are considered hot spots for detecting new arrivals. Targeted taxa include benthic crustaceans, mollusks, polychaetes, hydroids, zooplankton, and aquatic vascular plants. Sampling should replicate the protocols followed by in this survey. The locations in Table 9 are hot spots of invasion and/or have good, long-term records of species composition. These locations are recommended for targeted sampling.

Table 6. Suggested sampling locations proposed for targeted sampling.

Location	Sites	Prior Research	Comments
Youngs Bay	CEDC Net Pens	CREDDP, benthic surveys by CEDC, LCRANS, nearby surveys by NMFS, EMAP	Brackish water, benthic surveys demonstrate interactions between mudsnail invaders and native crustacean community.
	Youngs River Mouth	CREDDP, LCRANS, EMAP, Cordell et al.	Changes in freshwater and low salinity zooplankton community
Trestle Bay	Interior	NMFS, LCRANS	Protected embayment with soft sediment, salt marsh and rocky intertidal community along jetty.
Baker Bay	Sand Island	LCRANS	High salinity site, close to mouth but partially protected, several ANS found in island pools
	Eastern mud flats	LCRANS, EMAP	Extensive exposed meso-polyhaline mud flats, unique benthic invertebrate community vs. other mud flats in estuary
Miller Sands	Interior	NMFS, ACE, LCRANS	Artificially established freshwater sand habitat, interior is shallow, protected and adjacent to main shipping channel
Cathlamet Bay	Russian Island	NMFS, EMAP, LCRANS	Protected tidally influenced freshwater mudflats upstream of primary anchorage site for commercial vessels.
Port of Longview			Potential site for ANS introductions via ballast water
Port of Portland			Potential site for ANS introductions via ballast water
Sloughs	Wallace, Westport, Skamania, Fisher Island etc.	LCRANS	Slow, protected waters in the transition zone between the Willamette confluence and the estuary may retain species released at the Ports of Portand, Vancouver and Longview/Kelso
Sauvie Island	Multnomah Channel Side	LCRANS	Potential hot spot for aquarium and ornamental plant disposal, warm water area
Columbia Slough		ODFW, LCRANS	Potential hot spot for aquarium and ornamental plant disposal, high nutrient, warm water area with limited seasonal flushing, hot spot for *Exopalaemon modestus*, etc.

<u>Discrete sampling</u>

The goal of the discrete sampling should be to use intensive surveys resolve the data gaps and sampling limitations encountered in this survey. Sampling should focus on under-sampled taxa and areas such as the mouth and main channel of the estuary where LCRANS was unable to sample. Discrete sampling results should be used to modify targeted sampling if new hot spots or species are discovered.

Synoptic surveys

A repeat of the synoptic survey reported on here, should be conducted every five years. The goals of the survey should be to investigate potential new hotspots of invasion and to update the database on ANS developed through review of the literature. The synoptic survey should be used to fine-tune sampling methods and protocols to ensure complete coverage of taxa and habitats in the river.

Research Needs

Understanding the ecology, biology, dispersal of ANS is critical to management of invasions and protection of native plant and animal communities. Some research recommendations include investigation of:

- Facilitation – Major anthropogenic alteration of the physical, chemical, and hydrological characteristics of the lower Columbia River have occurred in the last century. Additional changes in these characteristics, as well as climate change, can be anticipated. The importance of various vectors of dispersal, human and natural, may also vary. Do these changes enhance establishment of ANS?
- Impacts – While economic and ecological impacts of ANS that are ecological engineers, like zebra mussels, are readily apparent, impacts of other species may be less obvious but still have significant ecological consequences. What are the economic and ecological effects of ANS? Do invaders at some trophic levels or in specific guilds have greater impacts than others?
- Taxonomy and biogeography– Taxonomic resolution of many species is poor, which limits conclusions about the number and rate of introduction of ANS. Biogeography of many species is also poorly documented. Taxonomic expertise on many taxa is limited. Are the large numbers of cryptogenic species found in the lower Columbia introduced or native? What is the number and importance of introduced disease organisms, parasites (plant and animal) and aquatic insects in the lower Columbia?
- Disperal of ANS – Movement of ANS in ballast water transferred between domestic ports is a particular threat to the Columbia River. Other vectors may be equally important, but are not well documented. What is the role of coastal shipping in dispersal of ANS on the West Coast? What is the role of shipping-related vectors other than ballast water, e.g., hull fouling, in dispersal of ANS?
- Management of ANS Prevention of new invasions requires interdiction of pathways through regulation of vectors. What methods can be used to manage populations of potential ANS in ballast water, hull fouling, live aquatics, ornamental and aquarium, and other vectors?

Management Needs

Invasive species management targets introduction, establishment, further spread and impacts of ANS. While the tools to control populations at the latter three stages include chemical, biological, and mechanical options – preventing introductions is the best and most cost effective way to limit the negative impacts of invasive species Eradication and often control of ANS in open systems has proved nearly impossible and many ANS management options are simply aimed at lessening the impacts of these species, usually by buffering the affected resource, without reducing overall population densities (i.e. retrofitting water-intake pipes to diminish zebra mussel fouling). In order to better focus ANS management of the lower Columbia River we have identified the following needs:

- Evaluation of vectors and pathways - While ballast water and other shipping activities appear to dominate recent ANS introductions into the lower Columbia River, other vectors, especially intentional releases, remain poorly quantified. New ballast water regulations (Flynn and Sytsma 2004) should reduce the frequency of ballast water introductions, which will lead to an increase in the relative importance of escape, release, and disposal of ANS by individuals will increase. We also need policies or guidelines that that address those individual behaviors that contribute to both intentional and unintentional introductions of ANS. .
- Compliance data - Without compliance numbers it is difficult to estimate the current effectiveness of ballast water management and other vessel management guidelines. Our study demonstrates the prominent role ballast water has played recently in the introduction of ANS into the lower Columbia River but because this represents the first comprehensive survey of ANS in the area it is difficult to determine if federal guidelines or state ballast water management legislation has had an effect on ANS introductions.
- Export risk evaluation - It is important that we view the lower Columbia River as a source of invaders and develop management actions aimed at preventing export as well as import. This includes not only native species that may be exported to other continents, but also nonnative species established in the lower Columbia River that may be transported to other nearby coastal waters
- Facilitation activity evaluation - As part of a comprehensive ANS management plan for the lower Columbia River it is vital that future and ongoing environmental modifications of the region be evaluated as actions that may enhance existing or facilitate new ANS invasions. This includes projects such as dredging, diking, flow alteration, water impoundment and removal, and even habitat restoration activities. Along with dramatic habitat disturbance, restoration, dredging and other ventures may require bringing in equipment and personnel that act as transportation vectors for hitchhiking ANS. In other instances the removal of pest species such as emergent aquatic

plants may just open up new habitat for other invasive species. An important step in the management of ANS is the evaluation of such projects in light of potential ANS impacts. This may require incorporating ANS into impact statements as well as monitoring plans. The more we know about how modifications to the Columbia River effect existing ANS populations the more tools we will have to manage future introductions.

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