2007

Middle Columbia River Aquatic Nuisance Species Survey

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Final Report

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Executive Summary

Aquatic nonindigenous species (ANS) in the middle Columbia and lower Snake rivers were surveyed during the summer of 2006. The project area included eight reservoirs and the free-flowing, Hanford Reach on the Columbia River. We also conducted a literature review to create a complete list of ANS for the study area. We tested the following hypotheses:

1) Barge operations results in introduction of ANS to port facilities in the middle Columbia River
2) Habitat modification through dam construction facilitates ANS establishment in the middle Columbia River

The literature review and field sampling found that 50 ANS were introduced to the middle Columbia River since the 1880s. Most of these ANS were fish (54%), aquatic plants (14%), and crustacea (12%). The remaining 24% were mollusks, bryozoans, hydrozoans, annelids, one amphibian, and one aquatic mammal. We believe that 50 is a conservative assessment of the number of ANS in the system because of temporal and spatial limitation on our field sampling, inadequate taxonomic resolution in prior studies, and the abundance of unresolved and cryptogenic taxa.

Intentional stocking for fisheries and wildlife enhancement was the most common vector for species introduction. Ballast water and intentional release by individuals were also import vectors for introduction. Interestingly, recreational boating was associated with only a small number of ANS in the middle Columbia River. North America, East of the Rocky Mountains was the most common source area of ANS in the river, primarily because of the high number of fish introduced to the Columbia from that region. Europe was the second most common source region, particularly for plants.

We found only anecdotal evidence for barge transport of ANS in the river; there was no clear association between abundance of ANS and proximity to port facilities. Most barges do not utilize ballast water when operating in the river, and fouling organisms are much less abundant in freshwater than in marine systems, which reduces the importance of hull fouling as a vector for transport of ANS in the river.

We found no clear relationship between proximity to boat launches and abundance of ANS, nor did we find a difference in the number of ANS in samples from the free-flowing Hanford Reach and the reservoirs sites. Lack of spatial evidence of vector effects and habitat alteration on the abundance or ANS may be expected in systems with relatively high current velocities and mixing, even in impounded areas. Low sampling intensity may also have limited the capability of our study to reveal site differences. Despite the lack of association between perceived vector strength (e.g., proximity to ports and boat launches) and ANS abundance, focused sampling of these areas for early detection of new introductions, particularly for sessile organisms, is a reasonable strategy.

Additional surveys of the river are recommended. The upper reaches of the Columbia have not been the subject of a synoptic survey for ANS to establish a baseline for evaluating the rate of ANS introduction. The lower Columbia was surveyed previously to establish a baseline and periodic follow-up surveys are recommended. Repeated surveys of the lower, middle, and upper Columbia River on a six-year cycle would allow complete coverage of the most important

water resource in the Pacific Northwest and permit estimation of ANS invasion rate, which should decrease if current management strategies are effective.

Research is needed to better manage ANS in the Columbia and Snake Rivers. Study of the importance of multiple stressors, e.g., pollution, water withdrawals, impoundment, and global climate on the biological communities in the system and the facilitation of ANS invasion would aid in management of salmon stocks as well as ANS in the river. Impacts of ANS, including those that are already well-established in the system, are poorly understood. The role of hull fouling in transport of organisms, particularly on slow-moving barges, between the Columbia and other estuaries and between upper and lower reaches of the Columbia also requires additional study to effectively manage this potentially important vector for ANS. Similarly, other vectors such as trade in ornamental and aquarium species and intentional stocking activities require more stringent control to prevent introduction of ANS to the Columbia River.

Acknowledgements

This project was funded by the US Fish and Wildlife Service and the Pacific Marine Fisheries Commission. Paul Heimowitz and Stephen Phillips were instrumental in securing funds for the work. Assistance in the field was provided by Tim Counihan, Jill Hardiman, Rich Miller, Wayne Fields, Blaine Parker and the Columbia River Intertribal Fish Commission, Mary Pfauth, Vanessa Howard, Steve Wells, and Jeff Adams and the Xerces Society.

Table of Contents

List of Figures

List of Tables

Introduction

Establishment of aquatic non-indigenous species (ANS) beyond their native range can have significant ecological and economic impacts (Pimental 2000). Successful establishment of ANS populations are based on introduction rates, suitable habitat, and interspecific competition. Human activities have increased introduction rates, altered habitats, and affected native species populations.

The Columbia River Basin is no exception with significant habitat changes from impoundment and land use changes; increased ANS introductions through shipping, nursery trade, and fishery enhancements; and native species population changes through exploitation and competition with and predation by prior ANS introductions. As a result, established populations of non-indigenous fish (smallmouth bass, *Micropterus dolomieue*; walleye, *Stizostedion vitreum*), aquatic plants (eurasian watermilfoil, *Myriophyllum spicatum*), and mollusks (Asian clam, *Corbicula fluminea*; New Zealand mud snail, *Potamopyrgus antipodarum*), have been documented throughout the system. By conservative measures, 82 ANS have invaded the tidally influenced section of the lower Columbia River since the mid 1800's (Sytsma et al. 2004, *USGS NAS Database*) while fewer non-indigenous fish species have been documented in the unimpounded Hanford reach of the middle Columbia River (Li et at. 1987). Other portions of the Columbia River system have not been surveyed as thoroughly although habitat changes and human caused vectors are just as prevalent.

The objective of the middle Columbia Aquatic Non-indigenous Species Survey (MCRANS) was to provide a comprehensive survey and analysis of all ANS present in the middle portion of the river system, an area delineated by Bonneville Dam (RKM 235) to Priest Rapids Dam (RKM 639) along the Columbia River and from the mouth of the Snake River to the pool formed by the lower Granite Dam (RKM 224) for a total of 628 river kilometers. 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 in the middle Columbia River. This information will provide a baseline for evaluating the rate of future species introductions by barge traffic, recreational boaters, and other pathways in the Columbia Basin.

The MCRANS project included a review of available literature and a comprehensive field collection of targeted taxa conducted in summer 2006. The study was designed to build on the Lower Columbia River Aquatic Non-indigenous Species Survey (Sytsma et al. 2004), which began in 2001. Like LCRANS, MCRANS was undertaken to provide comprehensive information about the ANS present in the Columbia River. The results of this mid-basin investigation will serve as a baseline for evaluating the rate of species introductions to the river and the efficacy of management action, and contribute important new information to ongoing regional ANS studies. In addition, the data may be useful for determining where the middle Columbia River and lower Snake River systems are vulnerable to invasion and for evaluating effects of introductions on important ecological processes.

Literature Review

The first stage of this project consisted of a comprehensive literature review of historical records, relevant technical reports, published works and gray literature from research done on the main stems of the Middle Columbia (MC) and Lower Snake (LS) Rivers. This literature review was used to establish a list of aquatic species native to the middle Columbia and lower Snake Rivers and a preliminary list of introduced and cryptogenic species present in the river systems. Historical records compiled from surveys conducted from the late 1800s to the present were used to evaluate invasion rates and to identify site habitat, and time period sampling gaps. The historical record was also used to assist in the development of a sampling plan of the river systems that built on existing data and filled data gaps in the sampling record.

Field sampling

We conducted a survey for ANS in the middle Columbia River and lower Snake River to evaluate the current status of ANS invasions in the study area. We also assessed the influence of vectors and habitats on spatial patterns of invasions. The survey results can be used to support assessments of the ecological impacts of invasions and ANS management policies throughout the basin.

Taxonomic scope

The taxonomic scope of the MCRANS field sampling was limited to organisms that have not been well surveyed by previous investigations and could be accurately and efficiently identified by staff. Surveyed organisms included zooplankton, epi-benthic and benthic organisms, and macrophytes. The survey intentionally excluded fishes for two reasons. Firstly, they have already been extensively studied in the survey area, and second, by using gear that would not target fishes we could minimize our impacts to threatened and endangered species in the basin. Phytoplankton were not included in this study because efficient and accurate identification to species was beyond the scope of the project. Organisms collected were identified to species when possible. The level of identification of taxa such as aquatic insects was limited in most cases, as adult collections are often necessary for identification to species. The majority of the sampling took place during summer 2006 by a dedicated field crew; however opportunistic sampling (such as plankton tows) occurred, when feasible, throughout 2005 and 2006.

Geographic extent

The survey area stretches from Bonneville Dam (235 kilometers upstream of the Columbia River mouth, RKM 235) to Priest Rapids Dam (RKM 639) and from the mouth of the Snake River to the Washington-Idaho border (RKM 224) for a total of 628 river kilometers (Figure 1). The area includes eight run-of-the-river reservoirs and the free-flowing, Hanford Reach of the Columbia River. Bonneville Dam was the first dam (1938), and the Lower Granite Dam on the Snake River was the last dam (1975), completed within the survey area. The reservoirs are used for hydroelectric power generation, shallow draft barge shipping, fishing, boating, and irrigation. An average annual flow of approximately 182,000 cfs leaves the survey area, 65% of which is contributed by the watershed upstream of Priest Rapids Dam and 31% is contributed by the Snake River (USGS historical data).

Figure 1. Columbia River watershed and MCRANS study area

Sampling site selection criteria

In addition to covering the geographic extent of the survey area, sampling sites were selected to 1) assess invasion rates through re-visiting sampling sites established for previous surveys and 2) assess invasion vectors through sampling sites both near and far from potential vectors. The accessibility of sampling sites (proximity to launch sites) was also a consideration in selecting sampling sites given frequent high winds and strong currents present in many reaches. A minimum of three sampling sites were located along each stretch or reach (terms referring to the length of river between dams) of the survey area.

Two reaches of the survey area received additional sampling effort or comparative purposes: the free flowing Hanford reach and the Bonneville Pool. Cooperation with USGS habitat mapping efforts allowed for additional sampling effort in the Bonneville Pool and the ability to target a greater diversity of habitats. In addition to being the only free flowing stretch of the Mid-Columbia, the Hanford Reach is one of the most extensively studied stretches of the river. The Department of Energy's (DOE) Hanford Declassified Document Retrieval System contains over 125,000 documents, many of which contain species lists and survey information on aquatic species that were used in this survey; however, some surveys remain classified and could not be accessed.

Data management and analysis

All new data collected, data from previous surveys in the study area, and biogeographical information on the surveyed organisms was entered into a Microsoft Excel database and for transfer into an existing Access database. Classification of species as nonindigenous, cryptogenic and native was based on criteria developed by Sytsma et al. (2004) modified from Lindroth (1957), Carlton (1979), Webb (1985), Chapman (1988), and Chapman and Carlton (1991, 1994). Application of these criteria to each species required detailed information on their taxonomy, biogeography, ecology, and life histories. Taxa for which this information does not exist (e.g. poorly known groups) were difficult to classify. Taxonomic expertise was sought for all specimens collected. Taxonomic expertise outside the scope of the authors' experience was provided by Wayne Fields (Hydrozoology), Mary Pfauth (Portland State University) and Vanessa Howard (Portland State University).

The Middle Columbia and Lower Snake Rivers

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 2). In 2006 the Environmental Protection Agency (EPA) designated the Columbia River Basin as one of the Nation's "Great Water Bodies", joining the Chesapeake Bay, Great Lakes, Gulf of Mexico, South Florida Ecosystem, Long Island Sound and Puget Sound. The goal of this designation is to, by 2011, prevent water pollution and improve and protect water quality and ecosystems in the Columbia River Basin to reduce risks to human health and the environment (EPA 2006).

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 around 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[1] (Ebel et al. 1989).

Inter-annual 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. Droughts have usually occurred during the warm phase of ENSO.

[1] 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 Columbia River Basin Dam System (map courtesy of USACE 2001).

For the purpose of this survey, the middle Columbia River is defined as the stretch of the Columbia River between the Bonneville Dam (River kilometer [Rkm] 234) and the Priest Rapids Dam (Rkm 639). The Lower Snake River is defined as the stretch from its confluence with the Columbia River (Rkm 523) up to the Lower Granite Dam in Washington (Snake Rkm 173). The system studied includes a series of five major dams and four reservoirs on the middle Columbia and four dams and three major reservoirs on the Lower Snake (Figure 2). The Bonneville Dam was the first dam constructed on this part of the Columbia River, coming into service in 1938. The disastrous 20-day flood of 1948 accelerated the demand for multipurpose dams on the Columbia River and its tributaries and the rest of the middle Columbia dams were put into service during the 1950s and 1960s (Table 1). Construction of the Lower Snake River dams was completed in the 1960s and 1970s (Table 2).

Table 1. Middle Columbia and Lower Snake River Dams and Reservoirs.

Dam	Impoundment	In-service date	Rkm (RMile)	Reservoir length km(miles)	Project control	Elevation (at dam) m (ft)
Bonneville	Bonneville Reservoir	1938	234 (145)	74 (46)	USACE	22 (7.2)
The Dalles	The Dalles Res./ Lake Celilo	1957	308 (192)	39 (24)	USACE	48 (160)
John Day	John Day Res./ Lake Umatilla	1968	347 (216)	123 (76)	USACE	80 (265)
McNary	McNary Reservoir Lake Walula	1953	470 (292)	169(61)	USACE	102 (340)
Priest Rapids	Priest Rapids Reservoir	1959	639 (397)	29 (18)	Grant Co. PUD	221 (738)

Table 2. Lower Snake River dams and reservoirs.

Dam	Impoundment	In-service date	Rkm (RM)	Reservoir length km(miles)	Project control	Elevation (at dam) m (ft)
Ice Harbor	Ice Harbor Reservoir Lake Sacagawea	1961	16 (10)	49 (32)	USACE	132 (440)
Lower Monumental	Lower Monumental Res./ Lake West	1969	67 (42)	44 (29)	USACE	162 (540)
Little Goose	Little Goose Res./ Lake Bryan	1970	113 (70)	60 (37)	USACE	191 (638)
Lower Granite	Lower Granite Reservoir	1975	173 (108)	62 (39)	USACE	221 (738)

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). Today the main stem of the Columbia River is considered depauperate in species (Ebel et al 1989).

Few systematic surveys have been conducted for aquatic nonindigenous species (ANS) on the MC and LS systems. The U.S. Geological Survey (USGS) and the Washington State Dept. of Ecology (DOE) have online databases listing Nonindigenous Aquatic Species and Freshwater Nonnative Plants, respectively. Other sources of information included an 1895-1896 U.S. Fish Commission Publication (Smith, 1896.) on introduced fishes in the Columbia, various government agency reports, academic research theses, gray literature from both governmental sources and consultants that contain lists or survey information on various aquatic species, and peer-reviewed literature. For the purpose of this survey, we searched for literature that contained taxonomic listings to at least genus, and preferably to species, level. Most of the available literature is related to studies of anadromous fishes in the river systems; some of these documents included detailed lists of taxa other than fish.

One of the most extensively studied stretches of the rivers is the Hanford Reach of the Columbia. The U.S. Atomic Energy Commission conducted intensive studies beginning in the 1940s, many of which investigated the effects of radiation and the effects of water heating on the biota of the river. Several of these studies included detailed species lists of collected organisms.

The rivers can be navigated upstream to Richland, Washington on the Columbia, and to Lewiston, Idaho on the Snake, which are 639 km 748 km upstream from the Pacific, respectively. Four Federal dams on the main stem of the Columbia; Bonneville, The Dalles, John Day and McNary, have navigation locks through which boats and barges can pass. Locks at Ice Harbor, Lower Monumental, Little Goose and Lower Granite dams on the Lower Snake can also accommodate river traffic. All the dams covered in this study are controlled by the U.S. Army Corps of Engineers (USACE), except for the Priest Rapids Dam which is owned by the Grant County Public Utilities District (PUD). The USACE and the U.S. Bureau of Reclamation planned, designed, constructed and currently own all the Federal water projects in the northwest. The Coordinated Columbia River System (CCRS) plans and operates all aspects of the dam and reservoir systems. The CCRS also coordinates projects operating under separate arrangements including the Pacific Northwest Coordinating Council, the Columbia River Treaty, Federal flood control statutes, and several environmental and fish and wildlife statutes.

The 1969 National Environmental Policy Act (NEPA) requires environmental scrutiny of all actions proposed by Federal agencies. Under NEPA, an environmental assessment, a finding of no significant impact or an environmental impact statement (EIS) must be prepared. Much of the literature reviewed for this survey was related to studies conducted due to NEPA requirements. Many of the available species surveys were conducted in preparation for dam draw-downs requested by various agencies.

Sources of Aquatic Nonindigenous Species

The global trend of increasing rates of biological introductions (see Ruiz et al. 2001, Cohen 2002) may, in part, be the result of increased awareness and efforts to find and report introductions, particularly among the lesser-studied taxa. The trend may also reflect greater opportunities for, and success of, introductions. For example, the increase in speed of global trade may facilitate the survival of species transported (intentionally or unintentionally), as well as the number and diversity of potential colonists. It has yet to be determined whether changes in vector management (such as the ballast water regulations) will have 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 may be significant.

The Lower Columbia River as a source of bioinvasions

This study extended the LCRANS survey, which was completed in 2004. Like MCRANS, the LCRANS survey was initiated to provide comprehensive information about the nonnative species present in the lower Columbia River. The LCRANS 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 (Sytsma et al. 2004). Due to survey limitations, inadequate taxonomic resolution in prior studies, and the abundance of unresolved and cryptogenic taxa, these results are likely a conservative estimate of the ANS invasion of the lower Columbia River.

The frequency of new discoveries ANS is increasing worldwide (OTA 1993, Ruiz et al. 2000) and the rate of discovery of introduced invertebrates in the lower Columbia River mirrors this trend. From the 1880s to the 1970s a new introduced species was discovered in the lower Columbia about every five years. Over the past ten years a new invertebrate species was discovered about every five months (Sytsma et al. 2004). Note that since the LCRANS survey was completed, at least one additional species has been detected in the lower Columbia River (USGS NAS Database).

The Columbia River is a source as well as a sink for introductions. As an invaded waterbody the lower Columbia River should be considered a viable source of new ANS introductions to other domestic and international estuaries via shipping and to upper reaches of the Columbia via human-mediated transport and natural dispersal through the system of locks and reservoirs. Similarly, ANS introduced initially into the upper reaches of the Columbia and Snake rivers can readily move downstream though passive movement with river flow or through active dispersal.

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. 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 middle Columbia River.

Commercial river traffic

Commercial river traffic includes tugs and barges for commodity movements in addition to cruise-ship traffic. Ballast water transfers, fouling communities, and other water movement associated with commercial traffic along the rivers have the potential to spread nonindigenous species throughout the river system. The large ports on the lower Columbia River are primarily bulk exporters, i.e., exported cargo tonnage considerably exceeds imported cargo tonnage.

Similarly, the upriver ports are primarily exporters of cargo; downriver movement of cargo is two – three times the upriver movement (Table 3).

Cargo for upriver transport, (e.g., petroleum products, chemicals, empty containers, manufactured equipment and goods, waste and scrap material, and radioactive materials) is generally loaded in the Portland-Vancouver area. Petroleum products move upriver to Umatilla, Clarkston, Pasco and Lewiston. One company (Tidewater Barge Lines, Inc) conducts essentially all the petroleum transport. In the late 1990s, the most recent data available, about 300 barges were transported upstream from Portland-Vancouver (WA.EFSEC, 1998). In addition, the U.S. Navy typically moves four to eight barges of radioactive materials from Bremerton, Washington to Hanford annually (PB Ports and Marine, 2003).

Table 3. Cargo tonnage (million tons) and vessel trips through the Vancouver-The Dalles Reach of the Columbia River: 1980 – 2000 (data from PB Ports and Marine, 2003)

Upriver tonnage	**1980**	**1985**	**1990**	**1995**	**2000**
Total tons	3.5	2.1	2.1	3.3	3.2
Downriver tonnage					
Total tons	7.2	6.2	7.6	8.3	7.4
Vessel trips					
Upriver	7498	5754	5234	2555	1980
Downriver	7307	5754	5174	2556	1907
Avg. Daily	41	32	28	14	10

Barged cargo moving downriver is predominantly grain but also includes wood chips, chemicals, pulp and paper products, aggregate, and manufactured equipment and goods. Grain is loaded from elevators located between The Dalles and Lewiston. Wood chips move out of shallow draft facilities at Boardman and Lewiston. Empty petroleum barges move downstream after unloading at Umatilla, Clarkston, Pasco , and Lewiston while full container barges return to Portland after loading in Boardman, Umatilla, Pasco, and Lewiston. Gravel and aggregate barges are loaded at The Dalles, Umatilla and Wishram (WA.EFSEC, 1998).

The historical distribution and recent movement of native species illustrates how infrastructural in the river and commercial shipping are associated with upstream dispersal of organisms in the river. *Corophium salmonis* and *Corophium spinicorne* are estuarine-amphipod species that are native to the lower Columbia River. *C. salmonis* and *C. spinicorne* are currently found in reservoirs above Bonneville, The Dalles and John Day dams, and in the lower Snake River. Sprague et al. (1995 *in* Nightengale, 1999) suggested that *Corophium spp.* was transported upstream through the transfer of ballast water by commercial barges. Although our discussions with local river barge companies indicated that most of the barges operating on the middle reach of the Columbia River do not use ballast water, these species may be moved through the lock system in conjunction with barge and boat traffic either as fouling organisms, in water that is incidentally transported by barges, or through passive movement through the locks.

The invasion of the lower Snake River by *Corophium spp.* most likely occurred during the mid-1970s, following the closure of Lower Granite Dam. Benthic macroinvertebrate studies conducted in Little Goose Reservoir and the pre-impounded Lower Granite Reservoir area in early 1970s did not note the presence of *Corophium spp.* Dorband (1980) listed the presence of *Corophium spp.* upstream of the confluence of the Snake and Clearwater Rivers (Rkm 224), and in Little Goose and Ice Harbor reservoirs. This first occurrence of *Corophium spp.* in lower Snake reservoirs coincided with the beginning of barge traffic up the lower Snake River, supporting the suggestion by Sprague et al. that commercial barges were the mechanism for the upstream movement of *Corophium spp.* (Nightengale, 1999).

Upstream movement of the native, estuarine-mysid shrimp, *Neomysis mercedis*, which is endemic to the Columbia River estuary and in the lower Columbia River below Bonneville Dam, is also tied to shipping and impoundments of the river. In 1982, *N. mercedis* was found in the gut contents of three types of introduced fish (northern pikeminnow, walleye, and channel catfish) in the John Day Reservoir (Gray et al., 1984 *in* Haskell, 2003). In 1994, *N. mercedis* was observed in smolt sampling facilities and in the forebay of John Day Dam. In March, 2003, it was collected from Lower Granite Reservoir; the most upstream impoundment of the lower Snake River, 224 km upstream of John Day Reservoir. These observations strongly suggest that *N. mercedis* currently exists in all mainstem impoundments of the lower Snake and Columbia Rivers. This pattern corresponds with barge traffic on the river; barges can navigate into Lower Granite Reservoir to Lewiston, Idaho on the Snake River, but cannot travel beyond McNary Reservoir on the Columbia River. The historical spread and current distribution infers that mysids are able to move upstream through lock operations or are transported upstream via barge bilge water (Haskell, 2003).

Extensive benthic surveys from 1951-1953, prior to the construction of McNary, The Dalles, and John Day dams revealed evidence of many invertebrates, but no mysids, near the area of present day McNary Dam (Robeck et al., 1954 *in* Haskell, 2003). Rondorf also sampled in McNary extensively in the early 1980s and never saw any *N. mercedis* (Dennis Rondorf, personal communication 18 Feb. 2005). From 1994-1996, *N. mercedis* was abundant in nighttime net-hauls at various sites in John Day Reservoir and also in McNary Reservoir immediately upstream. Thus, *N. mercedis* probably became established in McNary Reservoir in the mid to late 1980s and earlier in John Day Reservoir (Haskell, 2003).

Fisheries and wildlife enhancement

Human beings often bring their favorite food, sport, and ornamental species with them when they colonize new locations (Minns and Cooley 1999). This behavior was particularly evident in fish introductions to the lower Columbia River where the rate of new fish species reported in the literature peaked in the 1950s (Sytsma et al. 2004). This trend was attributed to a decline in intentional fish introductions by individuals and fish and game agencies in the second half of the 20^{th} century. Intentional introductions of game species in the middle Columbia River mirror this trend. Many of the introduced species present in the lower river system such as shad, *Alosa sapidissima,* walleye, *Stizostedion vitreum,* and bass, *Mircopterus spp.,* are currently found throughout much of the Columbia River basin. Other species with more limited ranges, such as the suspected aquarium introduction of Oriental weather loach, *Misgurnus anguillicaudatus,* in the Willamette River have not been reported from the middle Columbia.

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 twenty five species of non-native, popular, game fish have been successfully introduced to the middle Columbia River basin.

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). In addition, 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 although birds, lizards, snakes and bats are also known prey items (Crayon 2002). Bullfrogs have also been implicated globally in the spread of a fungus, *Batrachochytrium dendrobatidis* or chytrid fungus, which is deadly to many amphibians.

Biological Control Organisms

The nonnative fishes grass carp (triploid), *Ctenopharygodon idella*, and mosquito fish, *Gambusia affinis*, are still in use as aquatic biological control organisms in the area and escapees are often found in parts of the Columbia River Basin. Mosquito fish are widespread in the basin. There are restrictions on grass carp stocking but reports of the fish outside stocked waterbodies are common. Loch and Bonar (1999) reported fish in the For example, were reported grass carp moving upstream at Columbia and Snake river dams in 1997, that were possibly escapees from Silver Lake and other waterbodies during flooding in the winter of 1996. They also cited several other reports of grass carp in tributaries to the Columbia river.

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, 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, anglers, etc. Although the practice of dumping left-over live bait has not been explicitly implicated in ANS introductions in the Columbia River, it is a potential vector for ANS introductions or range expansion such as the arrival of the Siberian prawn, *Exopaelemon modestus*, in the lower Snake system. The bait itself may be an ANS, as could be its packing material or other associated "hitchhiking" organisms. The risk of bait as ANS may increase with the availability of exotic bait species available for purchase on the internet (e.g. many crayfish species such as the rusty crayfish, *Orconectes neglectus*, found in the John Day River (pers com. Jeff Adams) are widely available for purchase as live bait).

Aquarium and Water Garden Hobbiests

Numerous aquatic plants, fish, and aquatic invertebrates such as snails have been transported around the world and are bred and sold 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 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 - thath have been repeatedly released into the system, see Farr and Ward 1993) there are several established species that were likely the result of intentional releases. These include the oriental weatherfish, *Misgurnus anguillacaudatus*, the goldfish, *Carassius auratus*, aquarium plants such as *Cabomba caroliniana* and *Egeria densa*, and the Chinese mystery snail *Cipangopaludina chinensis malleatus*. Unintentional introductions may be the result of the flooding or other escape from outdoor ponds, flooding or failure of commercial rearing operations, or improper disposal of species (especially via flow-through drainage system sometimes found in research labs, hatcheries, etc.). Examples of such accidental introductions into the lower Columbia River include carp, *Cyprinus carpio* and the escape of nutria, *Myocaster coypus*, from a fur farm (ODFW 2001).

Literature Review[2]

Major sampling projects conducted by the U.S. Army Corps of Engineers (USACE), the Bonneville Power Administration (BPA), the Washington Public Power Supply System (WPPSS), the U.S. Department of Energy (DOE), the U.S. Geological Survey (USGS), the U.S. Fish and Wildlife Service (USFWS), and the Washington State Department of Ecology (Ecology) on the middle Columbia River have primarily focused on salmonids; accompanying species lists are limited and concentrate on fish and their prey items. These species records are also characterized by low taxonomic resolution of invertebrates and other non-fish organisms. Many smaller studies done consultants or contractors, either independently or in conjunction with some of the larger projects, are difficult to access.

Methods

Technical publications, project reports, collection records, and "gray literature" were reviewed to compile lists of native and non-native species present in the middle Columbia and lower Snake Rivers.

Information searches were conducted using ORBIS (Summit, ORBIS Cascade Alliance- the Pacific Northwest academic libraries online catalog) to search the Pacific Northwest academic libraries including, but not limited to, the University of Washington, University of Idaho, Portland State University, Oregon State University, Southern Oregon University, and Lewis and Clark College. The Interlibrary Loan (ILL) Program at OSU and PSU were used to retrieve books, reports, and theses from a variety of sources including the above mentioned libraries as well as the NWFSC library. Search tools such as BIOSIS and ASFA (Aquatic Sciences and Fisheries Abstracts) were used to conduct searches. Google was also used as a search tool, especially when searching for "gray literature" sources. Interviews were conducted by phone, e-mail, and in person with staff members of USACE, ODFW, USFWS, USGS, USGS-WFRC, NOAA, EPA, ECOLOGY, HMSC, and Grant Co. PUD, and requests for information were sent out to several list-serves such as PNW-Aliens.

The USGS Nonindigenous Aquatic Species Database was accessed at: http://nas.er.usgs.gov/queries/huc6nw.asp . This nationwide database includes ANS by drainage basin (HUC). The middle Columbia HUC# is 17071 and the Lower Snake HUC# is 17061. Until recently, aquatic plant coverage of this database was poor. The ANS species found in the LCRANS HUCs were mostly fish. One mollusk and one amphibian were reported in the middle Columbia and two amphibians and three mollusks were reported in Lower Snake (although it is unclear if one of the amphibians was collected from the mainstem of the river or from a tributary stream).

Washington Department of Ecology (Ecology) online Aquatic Plant Survey database was accessed at: http://www.ecy.wa.gov/programs/eap/lakes/aquaticplants/index.html. Searches for "Columbia River" and for "Snake River" included collection data from 1995-1997.

[2] This section was written as a separate report by Kurt Shultz, a Master's of Marine Resource Management student at Oregon State University, in partial fulfillment of his degree requirements. We have made only minor editorial modifications to his document.

Overview of major studies

Dam related research

Seven of the eight dams on the middle Columbia/Lower Snake River system are controlled by the Corps of Engineers. The eighth, Priest Rapids Dam (at Rkm 639) is owned and operated by the Public Utilities District #2 of Grant County, Washington. Several tests related to dam drawdowns have been conducted and the associated Environmental Impact Statements (EIS) usually contain surveys of biota that may be affected by the drawdowns. The EIS's often focus on threatened, endangered or commercially important species and may or may not contain detailed species lists of other organisms. Dam drawdown tests have been conducted for the Bonneville Dam and Reservoir although these plans have not been reviewed at this time.

In addition, studies of effects of dissolved gas supersaturation have been conducted at several of the dams and reservoirs (Shrank et al., 1997; Toner et al, 1995). These studies often include lists of biota (fish and invertebrates) that may be affected but invertebrate species identification is usually limited, often identified only to the family or order.

Studies have also been conducted to evaluate the environmental impacts of channel dredging and management of dredged materials. Construction of dam systems alters the character and flow of the natural river. One effect of the dam system causes sedimentary materials to be deposited in lower velocity areas of the system, creating problems with aquatic habitat and system management including changes in aquatic biota and interference with navigation and flood control. Changes to reservoirs due to dredging do not necessarily introduce potential nonindigenous species unless dredge spoils are dumped in different reservoirs than those from which they were removed, but could potentially affect the survival or well being of native organisms or species assemblages by altering water quality or habitat attributes. These effects could possibly contribute to the survival and succession of introduced organisms. For example, macroinvertebrates displaced by dredged material removal can aid in recolonizing or supplementing existing populations at the in-water disposal sites. Repeated large volume dredging could deleteriously affect the ecosystem by shifting the river bottom to below the photic zone, thereby reducing primary productivity. Effects could include loss of benthic macroinvertebrate production, and in turn, loss of fish rearing habitat (USACE and EPA, 2002). These changes may result in an environment more favorable to introduced species than to native assemblages. Because of this, dredge sites and dredge spoil sites may be areas to monitor and sample for succession of nonindigenous species.

A Dredged Material Management Plan and Environmental Impact Statement was prepared in 2001-2002 for the McNary reservoir and Lower Snake River reservoirs. Many of the studies resulting from this action, although concentrating on fish, contain useful species lists of benthic invertebrates and aquatic macrophytes as well. Monitoring of the fish and benthic macroinvertebrates began in 1988 and continued through 1994 with ancillary studies conducted through 1997 (USACE and EPA, 2002).

Overview of sampling by taxa and area

Fish

Recent structural alterations to watersheds of the Pacific Northwest have changed the ecological settings for fish assemblages. Dams have acted as physical zoogeographic barriers and may have increased the importance of fish diseases both as zoogeographic barriers and as mechanisms for structuring fish assemblages. The impoundments favor the establishment of exotic, temperate mesotherms and eurytherms from the Midwest. Native fishes differ in susceptibility to diseases because of differential immunity and because the virulence of endemic diseases is temperature-dependent. For example, *Flexibacter columnaris* becomes virulent to salmonids at temperatures above 10° C, but catastomids and cyprinids are relatively unaffected at temperatures below 20°C. The conditions that favor the warmwater fishes have greatly increased the numbers of piscivorous fish and the risk of predation to native fauna in the Columbia River. These conditions have also changed the food-web patterns (Li et al. 1987).

Fish species are well documented in the middle Columbia River areas of the study. The U.S. Fish Commission Report “Attempts to Acclimatize Fish and Other Water Animals in the Pacific States” (Smith 1896) documents the transfer and introduction (both successful and non-successful) of fish from eastern states, Hawaii, and Europe into the Columbia and its tributaries in Washington, Oregon, California, Idaho, and Nevada. Studies by Ward et al. (2004), Gadomski and Barfoot (1998), and Barfoot et al. (2002) surveyed fish in the lower three reservoirs (Bonneville, The Dalles, and John Day). McNary Reservoir was the most heavily surveyed, especially in the Hanford area, with extensive sampling starting in the 1940’s. Becker (1990) documents many of the earlier studies in his review and Gray and Dauble (1977), Toner et al. (1995), Schrank et al. (1997), and Benton Co. PUD (2002) also contribute survey data to this report. The lower Snake River Dams were completed between 1961 and 1975. Most papers on fish reviewed for this area concentrated on salmon issues and other fish identified in these papers were generally listed by common names only, so were not included in this paper’s species lists for these reservoirs. In general, the lists included the same fish recognized to be present in the McNary Reservoir.

Invertebrates

The most heavily sampled area for invertebrates is around the Hanford Reach in McNary Reservoir. Sampling to evaluate effects of radioactivity and heated water on aquatic organisms began in the 1940’s and although concentrated in the Hanford area, several of these studies also sampled as far downstream as Bonneville Dam. Nine sources were found with information on invertebrate sampling in this area. Few sources were found for invertebrate information from the Bonneville Reservoir, although a USACE report on potential dam drawdown exists which is purported to contain species lists for most aquatic organism which would potentially be affected by a drawdown, but this document has not yet been accessed (as of May 2005). Prahl et al. (1998) conducted a study which sampled a few zooplankton in Bonneville and The Dalles Reservoirs and Gilbreath et al. (2000), Haskell et al. (2001), and Haskell (2003) conducted fairly extensive samplings for both benthic invertebrates and zooplankton in the John Day Reservoirs. In the lower Snake River, theses by Dorband (1980) and Nightengale (1999) contain fairly extensive invertebrate listings for the Ice Harbor, Lower Monumental, and Little Goose Reservoirs. Invertebrate information for the Lower Granite Reservoir, although not included in this part of the study, are also included in these theses. Two other studies containing invertebrate surveys for the Lower Granite Reservoir (Pool and Ledgerwood 1997; Ledgerwood et al. 2000) have also been obtained for future reference.

Aquatic Macrophytes

Data regarding macrophytes are rare in many areas (mainstem of the river, for example) in this study. The Washington Department of Ecology (DOE), as part of its Aquatic Plants Technical Assistance Program (APTAP), conducted spot surveys of several sites on the Columbia and Snake Rivers from 1995 to 1997. The APTAP did not conduct a comprehensive survey of macrophytes in the reservoirs, but performed a series of spot surveys at 13 sites in the Lower Snake River (three in Ice Harbor, five in Lower Monumental, two in Little Goose, and three in Lower Granite reservoirs) and two sites in the Columbia River (one in the Bonneville and one in The Dalles reservoir). The survey concentrated on nonindigenous species but native "nuisance" species are also included in this survey site which can be accessed at: http://www.ecy.wa.gov/programs/eap/lakes/aquaticplants/index.html. Ecology's APTAP also has a Freshwater Aquatic Weed Management Program whose objectives are to provide advice on aquatic plant identification, biology, and management to government agencies and the public, and to document aquatic plant distribution throughout the state.

As mentioned earlier, the U.S. Geological Survey (USGS) in conjunction with the Western Fisheries Research Center (WFRC) has done some side scan sonar mapping of aquatic macrophytes in the Bonneville Reservoir, mostly focusing on the ANS Eurasian water-milfoil, *Myriophyllum spicatum.*

A study was conducted in 1974 on aquatic macrophytes of the Columbia and Snake River drainages (Falter et al. 1974). Although most of the sampling was conducted in the Palouse River drainage, six stations, encompassing 26 sites in the Lower Snake river were sampled during this study.

Review of Major Sampling Efforts in the Middle Columbia and Lower Snake Rivers

One of the earliest reviews of introductions of species to the Columbia River system is a Bulletin of the United States Fish Commission (Smith 1896). This article details the history of the introductions, both successful and unsuccessful, of 34 species of fish and aquatic invertebrates to the Pacific states in the 1800s. It includes descriptions and accounts of rail transportation successes and failures, and locations and amounts of releases to the western rivers. Also included in this account are descriptions of economic importance, food values, "injurious qualities" of fish released, and distribution in the western states. This report constitutes a good general beginning to the study. Many reports and studies have been compiled along these rivers, but up until now, there has not been a major study focused solely on nonindigenous species and species introductions. Many, such as Ebel et al.'s study focusing on a holistic understanding of the Columbia River, give good general overviews of the river's morphometry, hydrology, mainstream flow regimes, and water quality (Ebel et al. 1989). This report also include data on fish and zooplankton assemblages, but, like many others, this report does not include a detailed or useful distinction as to the sites at which the species detailed in the study were collected. Robeck et al., (1954) conducted water quality studies from 1951 to 1953 on the Columbia River and its tributaries, mostly taking place between Priest Rapids and the McNary Dam which was put into operation in 1953. Limited studies were also undertaken in the Bonneville Reservoir. The principal objectives of the study were to determine water quality characteristics of the stream prior to impoundment and effects of radioactivity on the physical, chemical, and biological characteristics of the study area. The General Electric Laboratories were used to identify the specimens collected. According to the book, phytoplankton were identified to genus and a few of the invertebrates were identified to species (although most only to family or order) but the publication only identifies most animals to family or order, plants to genus, and fish to common names, so this publication is not very useful to this study.

Other reports and some databases focus on certain species or types of organisms and may cover many sections of the study area. information useful to this survey must be extracted from many of these nonspecific reports. For example, Frest and Johannes report on interior Columbia Basin mollusk species of special concern (Frest and Johannes 1995) contains overviews of freshwater mollusks, collection and preservation techniques, references to collections, and distributions of mollusks over the entire Columbia River basin. Databases compiled by the Washington Department of Ecology (Ecology) and the U.S. Geological Survey (USGS) for example, can be searched by site for many species of non-native and nuisance plants or nonindigenous aquatic species respectively (Ecology 1997, USGS 2005). Falter et al. (1974), in a report to the U.S. Army Corps of Engineers (USACE), summarizes and analyzes results from a survey that encompasses 723 site visits from the Columbia and Snake River Drainages. This survey includes sites in the Lower Granite, Little Goose, Ice Harbor, and Lower Monumental Reservoirs on the Lower Snake River, but no sites on the main stem of the Columbia River. The report includes a moderately comprehensive list of the Northwest's aquatic macrophytes, and a guide to heavy occurrences of certain taxa with an overview of the sets of environmental parameters associated with heavy aquatic plant growths. Another example is the 2002-2003 Annual report to the DOE and Bonneville Power Administration (BPA) on white sturgeon mitigation and restoration in the Columbia and Snake Rivers (Ward et al. 2004). This report includes species lists and number of fish caught with bottom trawls from the Bonneville, The Dalles, and John Day reservoirs during fall sampling in 2002.

Basin by Basin Summary Columbia River Reservoir Studies

Bonneville Reservoir

The Bonneville Dam was the first major dam installed in the middle Columbia River, coming into service in 1938. A paper by Gadomski and Barfoot (1998) examined diel and distributional abundance patterns of fish larvae and embryos collected in 1993. Six thousand five hundred sixty-five embryos and larvae representing 14 taxa were collected from 235 tows. Approximately 86% of the samples collected from the main channel were native taxa, with two introduced species comprising about 13% of the samples. In contrast, in tows from Columbia River backwaters, approximately 84% of the fish collected represented introduced species. This paper examines diel and area differences and explores possible reasons for this difference.

A study by Prahl et al. (1998) examining biogeochemical gradients in the lower 350 kilometers of the Columbia River, sampled at 45 sites, including Bonneville and The Dalles reservoirs. Copepods and other zooplankton were identified to species level. Sampling was conducted in 1992 during a period of anomalously dry weather conditions and low river flow. Only a few species were identified as coming from specific river locations, but a couple of these were mentioned as having not been found in earlier sampling studies conducted from 1964-1968, and so may be introduced species.

Gadomski and Barfoot (1998) sampled for fish embryos and larvae during summer 1993 at four main-stem Columbia River locations. Icthyoplankton samples were collected in main-channel habitats of the lower Dalles Reservoir, the upper Dalles Reservoir, and the upper John Day Reservoir, as well as a backwater of the upper John Day Reservoir (Plymouth Slough). Substrate in the Dalles reservoir (Rkm 309-348) consisted of sand, rock, and bedrock, while substrate composition of the John Day Reservoir (Rkm 348-470) was mud, sand, gravel, and cobble. Banks of the Dalles reservoir and lower regions of the John Day Reservoir were relatively steep-sided and confined as the river passed through the Columbia River Gorge. The approximate one-third of the John Day Reservoir was relatively wide and shallow and contained numerous embayments and extensive areas of shallow backwater and side channel habitats. Water velocities at all sampling sites were moderate and ranged from 0.3 to 0.8 m/sec (Gadomski and Barfoot 1998).

The 2002-2003 Annual Report to the Bonneville Power Administration and DOE on white sturgeon mitigation and restoration upstream from Bonneville Dam contains species lists of all fish caught during data collection for this project between 1999 and 2002 (Ward et al., 2004). Sampling was conducted using a 6.2m high-rise bottom trawl. The sampling program called for conducting a total of 66 tows at 11 sites in the Bonneville Reservoir (six replicates per site), 24 tows at 12 sites in the Dalles reservoir (two replicates per site), and 39 tows at 19 sites in the John Day Reservoir (two replicates per site). Sample sites were designated with a code indicating statute river mile and relative position across the river channel. Trawling was conducted in an upstream direction, each tow was typically 10 minutes in duration, and maintained a speed-over-ground of approximately three km/hr during each tow. Northern pikeminnow (*Ptychocheilus oregonensis*) were also collected by angling and prickly sculpins (*Cottus asper*) were also collected using baited minnow traps. Additional sampling during 2002 was conducted by the Oregon Dept. of Fish and Wildlife (ODFW). ODFW sampled 12 locations with gillnets and made 36 overnight sets in The Dalles Reservoir and made 40 gillnet sets in the John Day Reservoir (Ward et al. 2004). This report is the latest available. Earlier reports are available at the BPA website at: http://www.efw.bpa.gov/searchpublications.aspx

At this time, not much information has been found on invertebrate sampling in the Bonneville Reservoir, although documents related to the Bonneville Dam drawdown (USACE Reports) should contain some information and species lists for potentially affected species.

Prahl et al.'s (1998) paper on biogeochemical gradients in the lower Columbia River includes samples taken for biota between June 14th and 22nd, 1992 at 45 mid-channel sites along a downstream gradient in the lower 350 km of the Columbia River drainage, six of which appear to have zooplankton data for Columbia River sample sites above the Bonneville Dam. The study is limited in that sampling occurred only during a single sampling period during a time of anomalously dry weather conditions and low river flow. The samples were collected in mid-channel from three prescribed depths (near surface, mid-depth, and near bottom) in the Bonneville and The Dalles Reservoirs. Water for zooplankton analysis was collected at each depth in a plastic carboy and filtered through an 80μm screen (Prahl et al. 1998).

Skamania County Washington's Integrated Aquatic Vegetation Management Plan's (Pfauth and Sytsma 2004) goal is to control noxious aquatic vegetation in three waterbodies confluent with the Columbia River mainstem (Rock Cove, the mouth of Wind River, and Drano Lake) where Eurasian water milfoil has become established. Rock Cove is a shallow cove (max depth 14 to 20 ft), the mouth of the Wind River has a maximum depth of 10 feet, and Drano Lake has a small littoral area comprising a narrow strip of shallow water (5 to 15 ft depth) around the perimeter of the lake and a maximum depth of 30 feet. All areas of the water bodies were sampled in August and September of 2003. Sampling was done by tossing a plant rake from a boat, retrieving the rake and identifying the plants brought up in the rake. Sample points in Rock Cove and the Wind River were located at 30m intervals along transects spaced 30m apart and sampling points in Drano Lake were spaced 50m apart (Pfauth and Sytsma 2004).

The USGS began aquatic macrophyte bed mapping to document the extent of Eurasian watermilfoil (*Myriophyllum spicatum*) in Bonneville Reservoir beginning in 2001. Beds were sampled using a modified-rake sampler to collect specimens at each macrophyte bed. Using a boat, the USGS collected samples and surveyed the Oregon and Washington shoreline from Bonneville Dam's forebay boat restricted zone (BRZ) at Rkm 235.1 to The Dalles dam tailrace BRZ at Rkm 307.8. Locations and boundaries of macrophyte beds were recorded using a GPS and downloaded to Arcview GIS software. The USGS is in the process of modeling the probability of occurrence of aquatic macrophyte beds in the Columbia River based on habitat conditions in the reservoir. Seven aquatic macrophytes were identified during their surveys in the reservoir and, based on their observations; Eurasian watermilfoil (*Myriophyllum spicatum)* was far and away the most abundant macrophyte species in the reservoir (USGS-WFRC 2005; Counihan, personal communication 2005).

The Skamania County Integrated Aquatic Vegetation Management Plan (Pfauth and Sytsma, 2004) studied noxious aquatic vegetation, both native and nonindigenous, in three waterbodies located in the Bonneville Pool; Rock Cove (Rm 147), the Wind River mouth (Rm 155), and Drano Lake (Rm 163). All three waterbodies are drowned river mouths and have only been in existence since the mid 1930's. The two ANS detailed in this survey/study are Eurasian watermilfoil (*Myriophyllum spicatum*) and curlyleaf pondweed (*Potamogeton crispus*). *Myriophyllum* was found at all three sites but *Potamogeton* was not found at the Wind River site. The goals of this study are to help control noxious aquatic vegetation in order that human recreational and aesthetic use of these waterbodies is facilitated, acceptable water quality conditions are maintained, and natural functioning of aquatic systems is not impaired. Locations and densities of native and ANS macrophytes are detailed in this study.

The Washington State Aquatic Plant Survey visited one site on the Columbia River at Bingen in 1995 and identified two species of nuisance plants (Ecology1995).

The Dalles Reservoir (Lake Celilo)

The Dalles Reservoir is the shortest of the reservoirs in the study area and has the least available information. Frest and Johannes (1995), Prahl et al. (1998), and Ecology (1995) are the only three sources located so far that contain species information for this reservoir. Frest and Johannes identify mollusk species of special concern and Prahl et al., although concentrating in the Bonneville Reservoir, also identifies several copepods and other zooplankton to species in The Dalles Reservoir.

John Day Reservoir (Lake Umatilla)

Barfoot et al. (2002) conducted a study on resident fish assemblages in 1995 which replicated another study conducted from 1984-1985. These studies sampled fish from shallow shorelines of the impoundment with the objective of studying the temporal and spatial composition of the shoreline fish assemblages at six locations in the John Day reservoir. The same taxa were found in all years except that no goldfish (*Carassius auratus)* were found in the 1985 study, and no speckled dace (*Rhinicthys osculus*) were found in 1995. It is interesting to note that in the 1984-1985 study, the assemblages were dominated by four native taxa (>90%) and introduced taxa comprised only approximately 1.3% of the taxa found. In the 1995 study, the four dominant native taxa from the first study now comprised only 37.7% of the sample and introduced species comprised 61% of the sample.

Gilbreath et al. (2000) conducted limnological investigations in the John Day Reservoir from April 1994 to September 1995 to provide baseline sampling prior to a scheduled dam drawdown. The sampling was anticipated for a drawdown to the minimum operating pool and the samples were concentrated at the upper reservoir pool, in selected upper reservoir habitats. Five years of sampling was scheduled but drawdown did not occur and the study funding was withdrawn after one year. The biological attributes studied included chlorophyll-a, zooplankton, benthic macroinvertebrates, and fish. Invertebrate samples were preserved and zooplankton samples were identified by a contracted laboratory. Larger numbers of both cladoceran and rotifer species were found in upper reservoir stations than were found in either lower or middle reservoir stations. All the cladocerans that appeared in the lower reservoir stations also appeared in the upper reservoir stations. For rotifers, the most abundant at lower and mid-reservoir sites were also the most dominant at upper reservoir sites, but most taxa were rare, appearing infrequently and at low densities.

McNary Reservoir and the Hanford Reach (Lake Walulla)

One of the most comprehensively studied sections of the Columbia River is the Hanford Reach in Washington, between the Priest Rapids Dam and the Columbia's confluence with the Snake River. Extensive tests have been conducted, beginning in the 1940's, by the Atomic Energy Commission. In 1965 the governmental research laboratory at the Hanford Site was separated from Hanford Operations and Battelle Memorial Institute assumed responsibility for the management of the Hanford Site laboratories. Pacific Northwest Laboratory officially became a national laboratory in 1985 and the name was changed to Pacific Northwest National Laboratory in 1994. The research at the lab focuses on the DOE's science, energy, environmental quality and national security missions. The testing conducted focused on the effects of radiation, gas bubbles and heat on the biota of the Hanford Reach and occasionally as far downstream as the mouth of the Columbia. Declassified technical reports are available on the Hanford Site's Technical Reports Base at: http://www2.hanford.gov/ddrs//search/advanced.cfm .

Studies were undertaken from 1948-1950 (Davis and Cooper, 1951) that included radiological surveys of the fish and benthic and planktonic invertebrate fauna that inhabited the Columbia River within the confines of the Hanford Works downstream to the site of the McNary Dam. Other studies tested bottom algae (algal mats and filamentous green algae), bacillariophycae, plankton, invertebrates, and "principal crustacea" of the same sections of the river (Coopey, 1948, 1953). Several studies on fish were conducted in the Hanford area (Davis and Cooper, 1951, Gray and Dauble, 1977 and 2001). Another study of zooplankton was undertaken with sampling taking place at three stations in the Reach between 1973 and 1980 (Neitzel et al., 1982). Fifty-three zooplankton were identified in this study, 16 to species, 21 to genus, and 16 others only to order or family.

Several overviews of Hanford Site sampling have been compiled. Aquatic Bioenvironmental Studies: The Hanford Experience 1944-84 (Becker, 1990) gives a good review of bioenvironmental studies undertaken in the Hanford Reach from 1944-1984. Fish, invertebrates, and plants are included in the review, but only the fish and a few plants are identified to species. Another compilation of macroinvertebrate biodiversity studies has been compiled in a literature review format (Newell, 2003) and encompass 11 studies undertaken between 1948 and 2002, including information from the author's unpublished research and personal communications from other researchers. The author's study in 1988 found 11 species of Ephemeroptera (mayflies) previously unreported from the river.

Davis and Cooper (1951) documented a study that was carried out during the period of October 1948 to February 1950 on the effect of Hanford pile effluent upon aquatic invertebrates in the Columbia River in the confines of the Hanford Works and downstream to the site of McNary Dam. The study was designed to test the accumulation by and effects of radioactivity on the fauna of the river. Sampling for macroscopic bottom dwelling invertebrates were taken every two weeks except when disrupted during spring freshets. Originally, sample stations consisted of one upstream control and one below each of the then existing pile areas. These were changed to select for fast water, cobble stone bottom areas, which were favored by large populations of a maximum number of faunal forms. A river fish study was also conducted in the fall of 1948.

Coopey (1948, 1953) conducted studies on the accumulation of radioactivity in organisms in the vicinity of the Hanford works beginning in 1947. His first study, from November 1947 to April 1948, concentrated mostly on fish and "bottom algae". The study also included filamentous green algae, bacillariophycaea, benthic invertebrates (found both on rocks and in algal mats), and river plankton. The second study concentrated on the principle crustacea (crayfish, cladocerans, and copepods). Eight stations were sampled in this 14 month study, starting ½ mile upstream of the Hanford site, down to just above the McNary Dam.

Weekly zooplankton samples were taken between June 1973 and March 1980 at the Hanford site to determine identification, relative abundance and seasonal distribution of Columbia River zooplankton (Neitzel et al. 1982). Samples were taken from depths at three stations at Rkm 611 between June 1973 and June 1974. Samples were also taken at Rkm 566 between 1974 and 1980; once in 1974, six times in 1975, quarterly in 1976, and monthly from 1977 through 1980. Fifty-three taxa of zooplankters were identified, 16 to species, two to genus, and 14 to order or family.

Gray and Dauble (1977) published a checklist and relative abundance of fish species sampled from two locations within the Hanford Reach (Rkm 550-629) from 1973-1975. It is the first complete list of fish species published for the Hanford Reach and includes a short list of fish species collected earlier at the site. Another study (Gray and Dauble, 2001) describes the biology and life history characteristics of cyprinids in the Hanford Reach, but this publication uses the same species list as the 1973-1975 study.

Two studies evaluated the effects of dissolved gas supersaturation on fish and invertebrates downstream of the Ice Harbor and Priest Rapids Dams in 1994 and 1995 (Schrank et al., 1997; Toner et al., 1995). The study by Schrank et al. investigates gas bubble disease (GBD) in fish and invertebrates and the paper includes descriptions of sampling techniques and locations. Samples were collected from the surface, from depths of two to three meters, and from four meters. The Schrank paper identifies fish and a few invertebrates to species from samples collected in 1995 below the Priest Rapids Dam and below the Ice Harbor (and Bonneville) Dams although the study is mostly concentrated in the Priest Rapids Reservoir. In this study, 84 salmonids, 7272 non-salmonids, and 1303 invertebrates were examined for symptoms of GBD upon capture and after holding for four days in net pens. All fish were identified to species and some of the invertebrates were identified to genus, but most were only identified to family or order. Downstream of Ice Harbor Dam, a total of 499 invertebrates encompassing 16 types were collected but only *Argulus* was identified to genus.

The 1994 study was conducted by essentially the same research group. In the 1994 study, 750 salmonids and one non-salmonid were collected downstream of Priest Rapids Dam, and out of 203 invertebrates collected, only two were identified to species (*Corbicula fluminea* and *Pacifasticus leniusculus).* None of these specimens showed signs of GBD and this paper does not include a species list.

A study of the Columbia River and its tributaries, mostly taking place between Priest Rapids and the McNary Dam, which was placed into operation in 1953, was undertaken from spring 1951 to spring 1953 (Robeck et al. 1954). The principal objectives were to determine water quality characteristics of the stream prior to impoundment and to determine the effects of radioactivity on the physical, chemical and biological characteristics of surface waters. The General Electric Laboratories identified the specimens, but this publication is not too useful because only a few invertebrates are identified to species (most to family or order), phytoplankton are identified to genus, and fish only to common names.

A review of environmental studies related to the Hanford reach was compiled by Becker (1990). Material for the review was drawn from publications and periodic reports issued by government, industrial, and institutional scientists along with gray literature form contractors and information published in open-literature journals and symposia. It contains a short species list of fish, invertebrates and aquatic plants.

Another literature review, this one concentrating on the biodiversity of aquatic macroinvertebrates of the Hanford Reach, compares taxonomic findings of studies conducted between 1948 and 2002 (Newell 2003). In the 11 studies discussed, many techniques and methods are reviewed and compared. The identification scheme often differs among studies, some identifying to species and others only to genus or order. This, along with major taxa revisions in the mollusks, often makes comparisons difficult.

Becker's (2000) review of aquatic bioenvironmental studies related to the Hanford Reach of the Columbia River on the Hanford Site form 1944 to 1984 contains lists of fish collected in these studies but little information is available in this book regarding sample collection areas except in very general terms. It appears most non salmonid fish collected for study were collected by hook and line but this report does not contain much specific information as to areas or methods of collection for most fish other than listing locations as "upstream" or "downstream" of the Hanford Site.

Gray and Dauble (1977) conducted sampling for the first known complete species list for the Hanford Reach of the Columbia River. Forty-three species of fish representing 13 families have been collected between 1943 and 1977 in this area. From April 1973 to June 1974, fish were sampled weekly between Rkm 605 and 613. In September 1974, sampling began between Rkm 557 and 566 and continued at intervals of about three weeks. Thirty-seven species representing 12 families were collected in this study.

Several types of sampling gear were used to suit various areas and to compensate for gear selectivity. Methods included: gill nets, trammel nets, beach seines, hoop nets, minnow traps, trotlines, electroshocker, various types of trawls and hook and line. Gill nets were set from shore into the river or offshore perpendicular to the current in deeper waters, and were rotated among various locations at each study area. Nets were about 2m deep and were composed of panels of different mesh size ranging, in 1.25cm increments, from 1.25-10cm square mesh. Nets varied in length from 7.5-37.5m. Gill nets were set in the afternoon and retrieved the next morning about 19 hours later. Hoop nets were usually set for one week periods, checked every 24-72 hours, and rotated among various locations. Hoop nets were composed of two 61cm diameter tunnels, each 3m long and set in pairs so the mouths faced each other and the mouths were connected by a lead 61cm high and 6m long. Mesh size of the throats, netting surrounding the hoops, and connecting lead was 1.25cm square mesh.

Shrank et al. (1997) evaluated the effects of dissolved gas supersaturation on fish and invertebrates in the McNary Reservoir downstream from the Ice Harbor Dam. Sampling was conducted weekly from 14 April to 15 August 1995 between Snake Rkm 13.7 and Rkm 1.6. An earlier study by Toner et al. (1995) sampled in the same Snake River locations and also sampled in the Columbia River downstream of the Priest Rapids Dam in the Hanford Reach (Rkm 650.5 to Rkm 592.9) at least once each week from 10 May to 14 June, 1994. In some areas of the reservoir, fish were sampled by electrofishing from a boat equipped with a pair of adjustable booms and fitted with umbrella node arrays. Sampling in some shallow areas was conducted using 7.5m 2-stick seine with 12.7mm webbing and along shorelines with steep gradients, a 3.4m deep, 50m variable-mesh beach seine was used, with mesh size varying from 9.5mm to 19mm along different sections of the net. Benthic and epibenthic invertebrates were collected weekly at several locations from depths up to 0.6m. Samples were collected with 0.5mm mesh plankton nets, an epibenthic pump, and a Ponar bottom sampler. Samples of epifauna that encrusted aquatic vegetation were also collected. A total of 16 species of fish and 18 invertebrate taxa were collected from this area, although most of the invertebrates collected were identified only to order and so the invertebrate information will not be useful for this study.

Entrix Inc. (2002) conducted a study to assess the potential impacts to fisheries and fish habitat from the proposed Black Rock Reservoir Project. As envisioned, Columbia River water would be withdrawn from one of several proposed alignments upstream or downstream of the Priest Rapids Dam. A total of 44 resident fish species are known, or are thought to occur in the mid-Columbia reach in the vicinity of the proposed intake site. A table listing these fish, along with status and relative abundance is found in Section 4.1 of this paper. Most of the fish listed in this table were collected in a 1999 descriptive survey, but collection details are not included in this publication.

Coopey's (1948) study on the accumulation of radioactivity collected bottom-living organisms from nine stations on the vicinity of the Hanford Works from November 1947 to April 1948. This study concentrated on algal samples, but several invertebrates samples were collected as well. Most invertebrates were collected from the undersides of stones or were hidden beneath them. Many of the insect larvae were found buried in the algal coating on the tops of rocks. Fourteen zooplankters are described to genus and several more insect larvae are described to order. Another study by Coopey (1953) concentrated on the principal crustacea of the Columbia River. Samples were collected from ten stations over a 14 month period in 1949 and 1950. Seven of the stations were in the Hanford area, with one other at Richland, WA, one five miles above Pasco, and one above the McNary Dam site. Occasional samples of crayfish were also taken from Bonneville Dam. Crayfish and copepod samples were taken from river current, riffle, and eddy habitats. Bottom cladoceran samples were taken from slack water environments of eddies or sloughs along the river margin.

Field studies by Davis and Cooper (1951) were made upon bottom-dwelling invertebrate fauna collected from October 1948 through February 1950. The stations were the same as described in the Coopey (1953) study above. Samples were collected every two weeks with additional samples collected occasionally from slack water areas at the Hanford site. Samples were obtained from stones or other substrata picked up by hand from shallow waters or by using gravel forks with the tines bent 90 degrees for deeper water samples. Most specimens were identified to species except for Dipteran larvae (midges) which were grouped only into subfamilies.

Zooplankton samples were collected at two sites on the Columbia River (Rkm 611 and Rkn 566) from June 1973 through March 1980 (Neitzel et al., 1982). Samples were collected at Rkm 611 from June 1973 through June 1974 and at Rkm 566 from December 1974 through March 1980 for the WPPS' Columbia River aquatic ecological studies. Weekly zooplankton samples were taken at Rkm 611 from depths at three stations across the river. Samples were collected with a Clarke-Bumpus plankton sampler equipped with a number 10 plankton net. At Rkm 566, samples were taken once in 1974, six times in 1975, quarterly in 1976, and once each month from 1977 through March 1980. A 153µm net with a 30cm diameter mouth was used to collect samples at Rkm 566. Duplicate stepped-oblique zooplankton tows were taken. This sampling method integrated the sample over depth. Vertical stratification was not examined in this study because the weekly samples taken at Rkm 611 indicated mid-Columbia zooplankton are not vertically stratified. The crustacean-zooplankton community sampled at Rkm 611 consisted of 12 species. Other invertebrates observed included insect larvae, aquatic arachnids, annelids, rotifers, nematodes, Tardigrades, and Hydras. Fifty-eight zooplankton taxon were observed in samples collected at Rkm 566**.**

Studies conducted in support for the Final License Application for the Priest Rapids Hydroelectric Project in 1999 concentrate in the Priest Rapids Reservoir but include one sampling site downstream of the dam in the Priest Rapids Tailrace (Grant PUD 2003). The benthic macroinvertebrate communities were evaluated using three sampling strategies. First, three replicate Peterson dredge samples were collected at five cross-channel sample points. Second, if the mean substrate particle size was >6.25mm, artificial substrate samplers were placed in august for one-month incubation periods. Third, the littoral habitats were intensively sampled for mollusks in September. The benthic macroinvertebrate community is dominated by oligochaetes and chironomids. The mollusk community composition was unremarkable and the forms found were representative of taxa previously identified above and below the Priest Rapids Project reach. The dominant fauna throughout the Project is the ANS *Corbicula fluminea*, attaining densities of 784 organisms/m^2. This paper contains species lists for zooplankton and phytoplankton densities for the "Below Priest Rapids Dam" sampling station.

Newell's report to the Nature Conservancy of Washington (Newell 2003) reviews literature of aquatic macroinvertebrate studies of the Hanford Site and compares taxonomic findings of studies conducted between 1948 and 2002. It includes a summary list of all benthic invertebrate taxa reported by major benthic studies on the Hanford Reach 1949-1998, and includes immature organisms as well as adults.

Snake River Reservoir Studies

Lower Snake River Reservoirs: Ice Harbor Reservoir (Lake Sacagawea), Lower Monumental Reservoir (Lake West), Little Goose Reservoir (Lake Bryan) and Lower Granite Reservoir

Falter et al. (1974) in a report to the USACE, put together a summary and analysis of a survey of the aquatic vascular flora of the Columbia and Snake River drainage basins and the coastal drainages of Washington. It is a moderately comprehensive list encompassing 723 site visits (although no samples were taken in the mainstem of the Columbia) of Northwest aquatic macrophytes and a guide to heavy occurrences of certain taxa with an overview of the sets of environmental parameters associated with heavy aquatic plant growths. The Snake River sites included in this survey relevant to this project include Ice Harbor Reservoir, Lower Monumental Reservoir, Little Goose Reservoir, and Lower Granite Reservoir.

Benthic macroinvertebrate communities in the Lower Snake River reservoir system were studied and sampled for a University of Idaho Ph.D. thesis (Dorband 1980). The study describes a post-impoundment limnological evaluation of the Lower Granite reservoir (completed 1975) and uses as a baseline (and builds on) a pre-impoundment study (Falter et al. 1974) for the Lower Granite Reservoir. The study also includes the impoundments behind the Little Goose and Lower Monumental Dams. The objective was to describe quantitative and qualitative aspects of the benthic communities present in the Lower Snake Reservoir System. Population dynamics and successional status of these communities and relationships between environmental variables and assemblages of organisms are also investigated. Lower Monumental Reservoir was not included in the sampling because of the influence of two major tributaries (the Palouse River and the Tucannon River). This reference contains extensive species lists with most organisms (except oligochaetes) identified to species. It also mentions that *Corbicula fluminea* (identified as *Corbicula manilensis* in the paper) populations were much more prominent in Little Goose Reservoir, especially in 1976. In 1977 there was a significant increase in the population in Lower Granite Reservoir and Ice Harbor Reservoir, which indicates that the 1977 specimens were all members of the first year class. For this study, two sites were sampled in Ice Harbor Reservoir, three in Little Goose Reservoir, and two in the Lower Granite Reservoir. Pool and Ledgerwood (1997) collected and identified benthic invertebrates at three soft substrate sampling area in the Lower Granite Reservoir as part of a study on the effects of experimental reservoir drawdown.

A 1994 report (Bennett and Nightengale 1994) on a study designed to develop a baseline of the benthic macro-invertebrate community including species composition, relative abundance, density, and standing crop in Lower Monumental, Little Goose, and Lower Granite Reservoirs was brought about by a 1992 drawdown of Lower Granite and Little Goose Reservoirs that subjected extensive areas of the substrate to desiccation. The paper describes the study areas and sampling methods but most organisms are separated only to order and occasionally down to genus, so this report is of limited use to the project.

Sampling Plan

Limited resources and the relatively large study area required that we identify sampling locations of interest such as sites closely associated with probable vectors for ANS introduction such as barge terminals, and boat ramps, habitats with previously reported ANS and cryptogenic species, and areas that have been understudied previously. The literature review was integral to the development of a stratified and adaptive sampling plan. The MCRANS 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. If sampling a specific site was restricted by access and weather we either arranged to return to those stations at a later date or we attempted to sample as near to those locations as possible.

Sampling sites in prior studies

Snake River study sites

Two primary Snake River management issues have prompted aquatic species surveys within the survey area: navigation channel dredging and disposal (USACE 2002) and experimental reservoir drawdown (USACE 1993). Two of the studies identified many of the collected benthic invertebrates to species. Dorband (1980) surveyed benthic organisms at nine sites in the lower Snake River survey area (Figure 3). Pool and Ledgerwood (1997) collected and identified benthic invertebrates at three soft substrate sampling area in the Lower Granite Reservoir as part of a study on the effects of experimental reservoir drawdown. Other studies have focused on benthic communities (Bennett and Shrier1987, Bennett et al. 1988, Bennett et al. 1990, Bennett et al. 1991, Bennett et al. 1993a, Bennett et al. 1993b, Bennett et al. 1994, Bennett and Nightengale 1996, Nightingale 1999), however the taxonomic specificity of these studies was not as detailed as Dorband (1980) and Pool and Ledgerwood (1997).

Macrophyte (Falter et al. 1974, Washington DOE) and zooplankton (Normandeau and Associates et al. 1999, Funk et al. 1985, Ledgerwood et al. 2000) surveys have also been conducted. Falter et al. (1974) surveyed macrophytes to species at five sites within the lower Snake River survey area and the Washington DOE surveyed macrophytes to species at 13 sites.

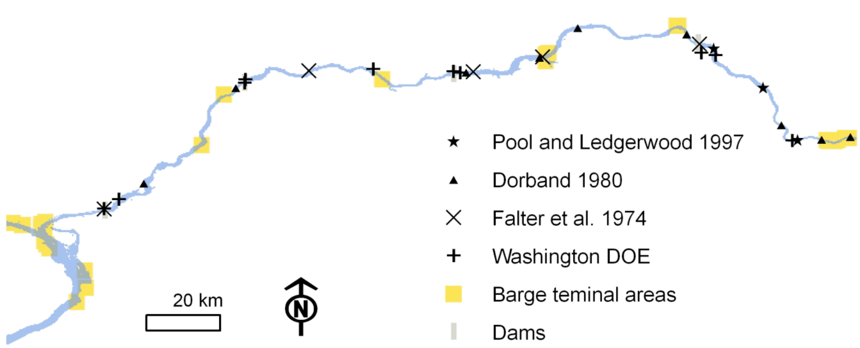

Figure 3. Prior Lower Snake River studies benthic invertebrate (Pool and Ledgerwood 1997, Dorband 1980) and macrophyte (Falter et al. 1974, Washington DOE) survey sites.

Columbia River reservoirs study sites

Several studies have been conducted in the middle Columbia Reservoirs in which at least some of the benthic invertebrates and zooplankton were identified to species. Two of the studies established benthic sampling stations within the middle-Columbia reservoirs (Figure 4). Sprague et al. (1992) surveyed benthic invertebrates at seven sites in the Dalles Pool as part of a study on white sturgeon feeding behavior. Gilbreath et al. (2000) surveyed benthic invertebrates at six sites and zooplankton at nine sites in the upper John Day Reservoir. A subset of the established benthic invertebrate survey sites were revisited for the MCRANS survey. Benthic invertebrate survey sites established for other studies (e.g. Toner et al. 1995, Shrank et al. 1997) were not considered when selecting MCRANS survey sites as identifications were not specific.

Other studies have identified zooplankton to species at many sites in the survey area (Haskell et al. 2001, Haskell 2003) and zooplankton and benthic invertebrates to species in fish guts (Muir and Emmett 1988, Rondorf et al. 1990). However, these sites were not considered when selecting MCRANS survey sites because both fish and zooplankton are mobile relative to a single sampling site.

Few macrophyte surveys have been conducted on the Middle Columbia River although seven species have been noted in the Bonneville pool including extensive beds of the ANS *Myriophyllum spicatum* (T. Counihan, unpublished data).

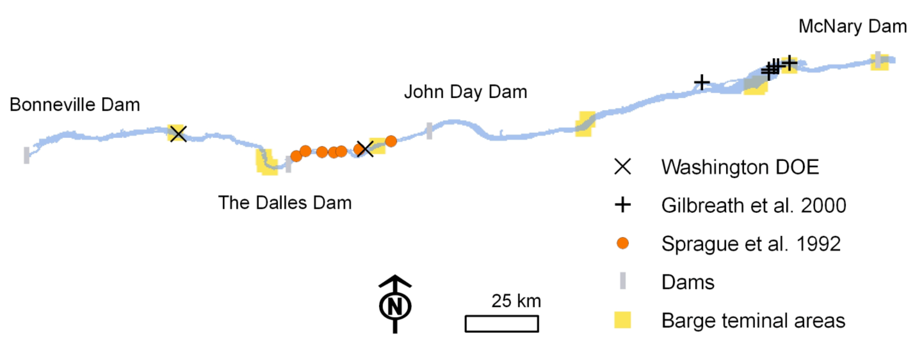

Figure 4. Prior benthic invertebrate (Gilbreath et al. 2000, Sprague et al. 1992) and macrophyte (Washington DOE) study sites on the Middle-Columbia River from Bonneville Dam to McNary Dam.

Hanford Reach study sites

The large volume of benthic invertebrate research carried out within the Hanford Reach has been summarized by Newell (2003). The majority of research has dealt with the effects of heat and radioactivity on biota, and the use of biota to track the dispersal of radioactivity through the river. The most comprehensive and detailed benthic surveys were conducted by Davis and Cooper (1951) and Coopey (1953). The surveys collected and identified benthic invertebrates to species at seven Hanford Reach sites and two McNary Pool sites during the period of 1948 to 1950 (Figure 5). Recently, the Priest Rapids Dam Hydroelectric Project relicensing procedure has spurred surveys of zooplankton and macrophytes directly below the dam (Normandeau and Associates et al. 2000) as well as research on the effects of daily fluctuating water levels on benthic invertebrates (Stark 2001). No macrophytes were found below the dam, however, 14 species were observed in the upstream reservoirs (Normandeau and Associates et al. 2000).

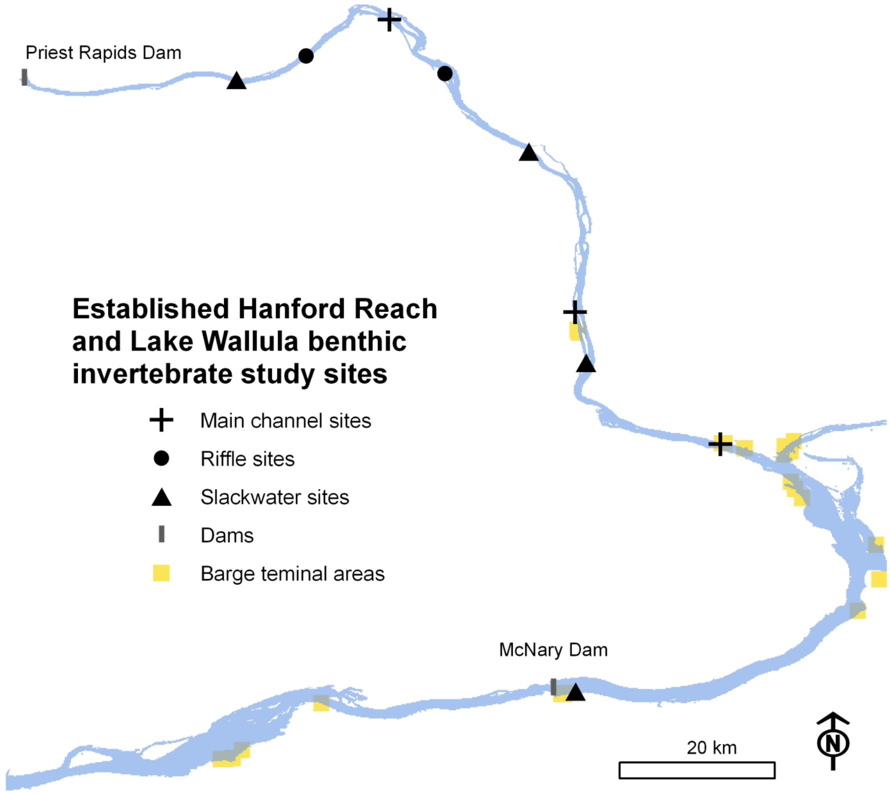

Figure 5. Prior Hanford Reach and Lake Wallula benthic invertebrate study sites visited by Davis and Cooper (1951), and Coopey (1953).

Port facilities on the middle Columbia and lower Snake

Many potential vectors deliver ANS to the middle reach of the Columbia River (Kolar and Lodge 2000). While the association between some vectors and introduced ANS is clear for some species, e.g., walleye and smallmouth bass were intentional and well-documented introductions by fish and game agencies (Ebel et al. 1989), vectors associated with other ANS in the Columbia River, such as the Asian clam and Siberian prawn, are not well-defined. Commercial shipping is an important vector for introduction of ANS into the lower Columbia River (Sytsma et al, 2004) and, as noted above, has been implicated in transport of species from the lower to the middle reaches of the Columbia and lower Snake. Over 1000 round-trip barge trips per year occur through the middle Columbia and lower Snake River (see Table 2). The barges primarily transport grain, wood products, petroleum products, and shipping containers between 49 shallow draft terminals on the reservoirs (Table 4).

Table 4. Barge terminals on the middle Columbia and lower Snake Rivers (from USACE 1995).

Barge Shipping Terminal	River	Pool	River mile	Use
SDS Lumber Co. Dock	Columbia	Bonneville	170.5	Wood
Mountain Fir Lumber Co. The Dalles Div.	Columbia	Bonneville	187.1	Wood
Cargill The Dalles Grain Elevator Dock	Columbia	Bonneville	188.7	Grain
Port of The Dalles Dock	Columbia	Bonneville	189.6	Grain
Mid Columbia Grain Growers	Columbia	The Dalles	207.5	Grain
Cargill Arlington Grain Elevator Dock	Columbia	John Day	241.6	Grain
Farmers Warehouse and Commission	Columbia	John Day	243.5	Grain
Idaho Overseas Log Ramp	Columbia	John Day	269.9	Wood
Longview Fiber Co	Columbia	John Day	270.2	Wood
Port of Morrow West Beach	Columbia	John Day	270.6	General cargo
SK Terminal Dock	Columbia	John Day	271.6	Grain
Morrow County Grain Growers	Columbia	John Day	278.2	Grain
Port of Umatilla Commercial Dock	Columbia	McNary	292.5	Containers, wood, heavy lift
Pendleton Grain Growers	Columbia	McNary	292.7	Grain
Tidewater Barge Lines Umatilla	Columbia	McNary	292.8	Petrol. Prod., fertilizer
Walla Walla Grain Growers 2	Columbia	McNary	311.6	Grain
Walla Walla Grain Growers	Columbia	McNary	314.5	Grain
Boise Cascade Wallula Plant	Columbia	McNary	316.5	Wood pulp
Phillips Pacific Chemical Company	Columbia	McNary	321.6	Fertilizer
Chevron Chemical Co.	Columbia	McNary	322.6	Not used
Unocal Chemicals	Columbia	McNary	323.3	Chemicals
Port of Pasco Container Terminal	Columbia	McNary	326.8	Containers, heavy lift
Port of Pasco Barge Slip RO/RO Dock	Columbia	McNary	326.9	General cargo, roll on / roll off
Northern Pacific Grain Growers	Columbia	McNary	328.0	Grain
Port of Pasco Marine Terminal	Columbia	McNary	328.2	Grain, petrol. prod.
Port of Benton	Columbia	McNary	342.7	General cargo
Port of Benton Barge Slip	Columbia	McNary	343.1	General cargo
Port of Walla Walla Dock	Snake	McNary	1.7	Not used
Connell Grain Growers	Snake	McNary	1.8	Grain
Cargill Burbank Grain Elevator Dock	Snake	McNary	2.0	Grain
Chevron Pipeline Co. East Pasco Terminal	Snake	McNary	2.2	Petrol. prod.
Tidewater Pasco Terminal	Snake	McNary	2.9	Petrol. prod., molasses, fertilizer
Walla Walla Grain Growers, Sheffler Dock	Snake	Ice Harbor	29.0	Grain
Louis Dreyfus Windust Station Dock	Snake	Ice Harbor	38.5	Grain
Columbia Cnty Grain Growers, Lyons Ferry	Snake	Lower Mon.	61.1	Grain
Pomeroy Grain Growers Dock	Snake	Little Goose	83.0	Grain
Columbia County Grain Growers	Snake	Little Goose	83.5	Grain
Central Ferry Terminal	Snake	Little Goose	83.7	Grain
McGregor Terminal	Snake	Little Goose	84.0	Ammonia
Almota Elevator Co. Dock	Snake	Little Goose	103.6	Grain
Port of Almota Dock, S&R Grain	Snake	Little Goose	103.7	Grain, fertilizer
Tidewater Wilma Terminal	Snake	Lower Granite	135.5	Containers, petrol., fertilizer, salt
Port of Whitman County, Site H Dock	Snake	Lower Granite	135.6	Wood, general cargo
Potlach Corp. Dock	Snake	Lower Granite	135.7	Wood
Mountain Fir Lumber Co. Wilma Dock	Snake	Lower Granite	136.0	Wood
Stegner Grain Terminal Dock	Snake	Lower Granite	136.5	Grain
Port of Whitman County Docks	Snake	Lower Granite	137.0	Wood, general cargo
Port of Clarkston Dock	Snake	Lower Granite	137.8	Containers, wood, heavy lift
Clarkston Grain Terminal Dock	Snake	Lower Granite	138.4	Grain

Sampling locations

The final list of 27 potential locations we used to guide our sampling (Table 5) was based on the considerations proximity to potential shipping and ballast water influence, historical sampling sites, and habitat type. Final site selection was made in the field and often dependent on weather conditions and access. In addition, extra sampling sites were chosen in the Bonneville and Hanford reaches for a comparison between impounded and free-flowing reaches. Additional sampling sites were chosen to reflect additional habitat types and flow regimes.

Table 5. MCRANS sampling sites identified during literature review.

MCRANS target sampling sites	River km	Prior detailed surveys in vicinity	Distance downstream from barge terminal (km)
Bonneville pool at Stevenson	241	-	30
Bonneville pool at Bingen	275	a	0
Bonneville pool at The Dalles	306	-	0
The Dalles pool at Horsethief	313	b	20
The Dalles pool below Maryhill	332	b	4
The Dalles pool above Maryhill	339	a, b	50
John Day pool at Arlington	391	-	0
John Day pool at Crow Butte	424	c	13
John Day pool at Petersen Slough	449	c	0
McNary pool above McNary Dam	472	d	0
McNary pool at Pasco	529	d	0
McNary pool at Richland	549	d	4
Ice Harbor pool at Charbonneau	16	a, f	28
Ice Harbor pool at Levey	21	e	24
Ice Harbor pool at Windust	62	-	0
Lower Monumental pool at Devil's Bench	68	a	30
Lower Monumental pool at Ayer	82	f	16
Lower Monumental pool at Lyon's Ferry	95	a	3
Little Goose pool at Little Goose Landing	114	a, f, e	20
Little Goose pool at Central Ferry	134	e, f	0
Little Goose pool at Boyer Park	170	e	47
Lower Granite pool at Offield Landing	174	a, f, g	43
Lower Granite pool at Chief Timothy	212	a, g	6
Lower Granite pool at Wilma	217	e	0
Mouth of Snake River Tidewater Terminal	5	-	0
Hanford Reach above 100B backwater	576	d	upstream
Hanford Reach at old Hanford townsite backwater	618	d	upstream
Other Hanford Reach backwater sites	-	-	upstream

a = Washington DOE; b = Sprague et al. 1992; c = Gilbreath et al. 2000; d = Davis and Cooper 1953; e = Dorband 1980; f = Falter et al. 1974; g = Pool and Ledgerwood 1997

Sampling methods

Samples were collected between July 1 and August 31, 2006, to avoid salmonid spawning and incubation periods (Adams 2004). Multiple locations were sampled at each site. Sampling locations within each site were selected haphazardly; access was a major constraint on sampling location. Sampling gear was limited to types that would not collect fish. Incidental catch of fish was minimal and all fish collected were immediately returned to the water. Caution was taken within the Hanford Reach to avoid salmon and steelhead redds and adult fish.

Macrophytes and associated organisms were collected with a double-sided thatch rake, placed in plastic bags, and stored on ice until sorting. Epiphytic and benthic organisms associated with the macrophytes were separated from the samples by vigorously agitating the macrophytes in tubs of wash water. The wash water was decanted through a 250-µm mesh sieve to retain organisms. Organisms were placed in sample bottles and preserved with 80% ethanol. Epiphytic and benthic crustaceans were identified to species by Jeff Cordell. Oligochaetes were preserved in 10% formalin and sent to Wayne Fields for identification. Macrophytes were identified to species in the field when possible and retained for identification by CLR staff when needed. Voucher macrophyte specimens were pressed and archived.

Zooplankton were collected with a 250-µM mesh, 20-cm diameter Wisconsin-style net that was towed from bottom to the surface near the deepest part of the channel at each site. Zooplankton samples were preserved with 80% ethanol and identified to species by Jeff Cordell.

Epibenthos were collected with a 700-µM epibenthic sled. Samples were preserved in 80% ethanol and crustaceans identified to species by Jeff Cordell. Mollusks were identified by CLR staff.

Benthic samples were collected with a 225-cm^2 petit ponar grab sampler. Benthic organisms were sorted by vigorously agitating mud, sand, gravel and rock samples in water to suspend organic material and small invertebrates. The suspensions were decanted through a 250-µM mesh sieve to retain suspended organisms. The washing and decanting procedure was repeated until the majority of organisms in the samples were removed. Bulky samples of aquatic plants, peat, rocks or gravel or other similarly course substrata were washed on a 4-mm or 2-mm mesh sieve in a 20-liter dishpan. Large 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. The procedure was repeated until most invertebrates in a sample were acquired. A priori, sorting the thousands of specimens potentially collected in some of the fouling and benthic samples was deemed 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. An additional 40-60 minutes of sorting was performed under a stereomicroscope to collect rare or inconspicuous species. Live sorting of the samples allowed some identification of species that were unique in behavior or coloration, and that might have been overlooked in fixed samples.

In addition to the regimented sampling methods listed above, we also conducted opportunistic sampling. A variety of sampling methods were employed including collection by hand and scraping vertical substrata. Sorting, preservation, and identification were based on the type of organism encountered.

Results and Discussion

Field Sampling

We sampled at 59 locations in the middle Columbia and lower Snake rivers selected and collected 188 samples (Figure 6). We documented 88 aquatic species (and 30 other distinct organisms (not including insects) that we were unable to identify at the species level[3]). Of the 88 species identified, 17 (19%) were introduced, 46 (52%) were native, and 25 (28%) were cryptogenic or of unknown origin. 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 organisms collected were primarily planktonic crustaceans, followed in descending order by oligochaetes, plants, mollusks and then miscellaneous taxa (including bryozoans, sponges, leeches, and benthic crustaceans). Zooplankton and oligochaetes dominated the cryptogenic species category. *Phragmites australis* was considered indeterminate and labeled cryptogenic. Genetic tests are needed to to determine whether the population is the native or the invasive cultivar.[4]

Twelve of the introduced species collected were new records for the middle Columbia River (see Appendix. Aquatic nonindigenous species in the middle Columbia River from literature review and field survey in 2005-2006). Three of these species were new records for the Columbia Basin (the isopod *Caecidotea laticaudatus,* the amphipod *Crangonyx floridanus* [also present in the San Francisco Bay/Sacramento River system], and the harpacticoid copepod *Hapacticella paradoxa* [also present in Klamath River estuary, CA and the Samish River estuary, WA]). The remaining nine new records may reflect a lack of sampling and poor characterization of the biota in the middle Columbia rather than recent introductions (Cordell et al. 2007).

The nonindigenous copepod *Pseudodiaptomus forbesi* occurred in plankton samples from the first four reservoirs in the Columbia River, where it was often the dominant species. It was present in one sample from the first reservoir in the Snake River but otherwise did not occur there. *Pseudodiaptomus forbesi* also did not occur in samples from the free-flowing part of the Columbia River at Hanford Reach, where native calanoid copepods dominated.

It is interesting that two of the areas sampled had few or no *P. forbesi*. Hanford reach, a free-flowing course of the lower Columbia River was the only area where native fresh water copepods (family Diaptomidae) dominated, and the reservoirs on the Snake River were dominated by native cladocerans and cyclopoid copepods. *Pseudodiaptomus forbesi* occurred in only one sample from the Snake river in very low numbers. These findings suggest that either *P. forbesi* is still expanding within the system, and has not yet become abundant in these areas, or that it has experienced biological and/or physical factors limiting its spread.

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[3] All organisms not identified to species were considered “other”, even those genera considered endemic or native to the Columbia River Basin in order to ensure that the same identification and origin standards were applied to all taxa.

[4] Researchers at Portland State University’s Center for Lakes and Reservoirs have collected additional samples and will send in specimen to the Cornell University Phragmites Laboratory for further testing.

Two other invasive species that were found in earlier surveys of the lower Columbia River, the cyclopoid copepod *Limnoithona tetraspina* and the calanoid copepod *Sinocalanus doerrii*, were not found during this study. This is especially notable for *L. tetraspina*, which makes up ~95% of copepod numbers in the low salinity region of the San Francisco estuary (Bouley and Kimmerer, 2006).

ANS found in literature review and field sampling

The literature review and field surveys identified 212 species[5] in the Middle Columbia and Lower Snake rivers. At least 50 of the 212 distinct species were not native to the Middle Columbia and Lower Snake (Appendix I). Two fishes, *Piaractus brachypomus* (NAS 2007) and *Pogonichthys macrolepidotus* (Smith 1897) were probably unsuccessful introductions. *Piaractus spp*., however, may be able to breed and overwinter in thermally influenced areas, such as those near Stevenson, Washington, where several specimen displaying breeding colors were captured (Pam Meacham, pers com. 2007). The majority of the nonnative species were fish (54%), aquatic plants (14%), and crustaceans (12%). The remaining species (24%) were mollusks, bryozoans, hydrozoans, annelids, one amphibian and one aquatic mammal (Figure 6). There was no clear effect of location on the total abundance of ANS in samples (Figure 7).

[5] This number does not include 155 insects, protozoans and rotifers reported in the literature review due to lack of information in the literature on the species or failure of the species to meet the criteria established for classification as nonnative in this study..

Table 6. MCRANS sampling sites.

Station ID	Sampling Date	River	Reach	Latitude	Longitude	Distance from mouth of Columbia (km)	Distance to nearest barge terminal (km)	Distance to nearest boat launch (km)
1.01	13-Jul-06	Columbia	Lake Celilo	45.68931	-120.76753	342	6.4	1.7
1.02	13-Jul-06	Columbia	Lake Celilo	45.68747	-120.77235	342	6.0	2.1
1.03	13-Jul-06	Columbia	Lake Celilo	45.68702	-120.78161	341	5.3	2.8
1.04	13-Jul-06	Columbia	Lake Celilo	45.68463	-120.78212	341	5.2	2.9
1.05	13-Jul-06	Columbia	Lake Celilo	45.66974	-120.84212	336	0.2	2.2
1.06	13-Jul-06	Columbia	Lake Celilo	45.6829	-120.82059	338	2.4	0.0
1.07	13-Jul-06	Columbia	Lake Celilo	45.63865	-121.10383	312	7.0	0.2
1.08	13-Jul-06	Columbia	Lake Celilo	45.63862	-121.10405	312	7.0	0.2
2.01	07-Aug-06	Snake	Lower Granite L.	46.42682	-117.02766	747	2.1	1.1
2.02	07-Aug-06	Snake	Lower Granite L.	46.42981	-117.04243	746	1.0	0.9
2.03	07-Aug-06	Snake	Lower Granite L.	46.42601	-117.04412	746	0.8	0.6
3.01	08-Aug-06	Snake	Lower Granite L.	46.41629	-117.20733	732	7.7	1.6
3.02	08-Aug-06	Snake	Lower Granite L.	46.65115	-117.39706	697	8.0	1.6
3.03	08-Aug-06	Snake	Lower Granite L.	46.65187	-117.41793	696	6.9	0.0
3.04	08-Aug-06	Snake	Lake Bryan	46.70077	-117.46955	689	0.2	0.4
3.045	08-Aug-06	Snake	Lake Bryan	46.70208	-117.46825	689	0.2	0.6
3.05	08-Aug-06	Snake	Lake Bryan	46.61334	-117.7883	656	0.6	0.7
3.055	08-Aug-06	Snake	Lake Bryan	46.61952	-117.79588	656	0.4	0.5
4.01	09-Aug-06	Snake	Lake Bryan	46.58832	-118.00338	637	14.7	0.3
4.015	09-Aug-06	Snake	Lake Bryan	46.58559	-118.00322	637	14.7	0.0
4.02	09-Aug-06	Snake	L. Herbert G West	46.5775	-118.08781	630	8.1	0.2
4.025	09-Aug-06	Snake	L. Herbert G West	46.5775	-118.08781	630	8.1	0.2
4.02C	09-Aug-06	Snake	L. Herbert G West	46.57604	-118.09102	630	7.9	0.1
4.03	09-Aug-06	Snake	L. Herbert G West	46.59355	-118.21593	617	3.1	0.1
4.03C	09-Aug-06	Snake	L. Herbert G West	46.59026	-118.22206	617	3.1	0.5
4.04	09-Aug-06	Snake	L. Herbert G West	46.57365	-118.52772	590	6.1	1.0
4.05	09-Aug-06	Snake	L. Sacagawea	46.53194	-118.57977	584	0.2	0.2
5.01	10-Aug-06	Snake	L. Sacagawea	46.31354	-118.77662	551	15.2	1.0
5.02	10-Aug-06	Snake	L. Sacagawea	46.26523	-118.85203	541	13.6	1.1
5.03	10-Aug-06	Snake	Lake Wallula	46.22458	-119.00713	527	0.8	1.5
5.035	10-Aug-06	Snake	Lake Wallula	46.21232	-119.01891	525	0.2	0.2
5.03C	10-Aug-06	Columbia	Lake Wallula	46.22126	-119.00965	527	0.5	1.1
5.04	10-Aug-06	Columbia	Lake Wallula	46.14828	-118.9435	515	5.0	1.5
5.05	10-Aug-06	Walla Walla	Lake Wallula	46.06684	-118.92021	507	0.7	1.4
5.055	10-Aug-06	Walla Walla	Lake Wallula	46.06526	-118.91635	507	0.5	1.1
6.01	14-Aug-06	Columbia	Hanford Reach	46.59077	-119.3831	583	28.1	1.4
6.02	14-Aug-06	Columbia	Hanford Reach	46.56567	-119.3253	578	24.4	4.3
6.03	14-Aug-06	Columbia	Hanford Reach	46.53133	-119.2737	571	20.0	3.1
6.04	14-Aug-06	Columbia	Hanford Reach	46.5051	-119.25808	570	17.1	0.2
6.05	14-Aug-06	Columbia	Hanford Reach	46.49188	-119.25808	568	15.6	1.4
6.06	14-Aug-06	Columbia	Hanford Reach	46.46603	-119.25789	565	12.8	4.3
7.01	15-Aug-06	Columbia	Hanford Reach	46.6398	-119.7429	624	48.7	0.8
7.02	15-Aug-06	Columbia	Hanford Reach	46.72149	-119.53213	604	45.9	8.0
7.03	15-Aug-06	Columbia	Hanford Reach	46.72021	-119.49881	600	44.7	6.1
7.04	15-Aug-06	Columbia	Hanford Reach	46.69652	-119.44864	595	40.8	2.5
7.05	15-Aug-06	Columbia	Hanford Reach	46.6744	-119.4573	594	38.8	0.3
7.06	15-Aug-06	Columbia	Hanford Reach	46.67614	-119.46025	594	39.1	0.5
8.01	16-Aug-06	Columbia	Lake Wallula	46.12741	-118.96675	513	4.4	4.1
8.015	16-Aug-06	Columbia	Lake Wallula	46.13151	-118.95672	513	4.4	3.4
8.02	16-Aug-06	Columbia	Lake Wallula	46.16792	-119.01512	520	0.2	2.3
8.03	16-Aug-06	Columbia	Lake Wallula	46.19066	-119.02599	521	1.8	0.9
8.04	16-Aug-06	Columbia	Lake Wallula	46.20796	-119.06565	525	0.8	2.3

Table 6. continued.

Station ID	Sampling Date	River	Reach	Latitude	Longitude	Distance from mouth of Columbia (km)	Distance to nearest barge terminal (km)	Distance to nearest boat launch (km)
8.045	16-Aug-06	Columbia	Lake Wallula	46.21828	-119.1113	529	0.9	0.1
8.05	16-Aug-06	Columbia	Lake Wallula	46.24867	-119.2577	541	11.1	1.7
8.055	16-Aug-06	Columbia	Lake Wallula	46.25421	-119.2577	541	10.5	1.2
9.01	30-Aug-06	Columbia	Lake Umatilla	45.90291	-119.47934	455	6.8	1.0
9.02	30-Aug-06	Columbia	Lake Umatilla	45.92495	-119.36272	465	6.0	0.9
9.025	30-Aug-06	Columbia	Lake Umatilla	45.92999	-119.35223	467	5.1	0.1
10.01	31-Aug-06	Columbia	Lake Umatilla	45.73639	-120.21034	391	1.4	1.2
10.01C	31-Aug-06	Columbia	Lake Umatilla	45.73191	-120.2079	391	0.9	1.0
10.015	31-Aug-06	Columbia	Lake Umatilla	45.73718	-120.21255	391	1.5	1.1
10.02	31-Aug-06	Columbia	Lake Umatilla	45.93691	-119.15396	483	9.9	2.7
10.03	31-Aug-06	Columbia	Lake Wallula	45.94419	-119.28994	472	1.7	0.7
10.04	31-Aug-06	Columbia	Lake Umatilla	45.85686	-119.8551	423	13.6	0.4
11.01	01-Sep-06	Columbia	Lake Umatilla	45.72311	-120.69475	349	13.1	0.3
11.02	01-Sep-06	Columbia	Lake Celilo	45.6829	-120.82059	338	2.4	0.0
11.03	01-Sep-06	Columbia	Lake Celilo	45.65871	-120.95845	326	8.9	1.2
11.035	01-Sep-06	Columbia	Lake Celilo	45.6501	-120.96408	325	9.5	0.2
12.01	06-Sep-06	Columbia	Bonneville	45.7201	-121.51891	271	3.6	1.5
12.02	06-Sep-06	Columbia	Bonneville	45.68964	-121.39615	282	6.6	2.6
12.03	06-Sep-06	Columbia	Bonneville	45.7048	-121.46745	275	0.9	0.9
12.04	06-Sep-06	Columbia	Bonneville	45.68816	-121.86008	243	30.1	1.5
12.05	06-Sep-06	Columbia	Bonneville	45.70852	-121.7887	249	24.5	1.0
12.055	06-Sep-06	Columbia	Bonneville	45.71626	-121.79129	249	24.7	0.2
13.01	07-Sep-06	Columbia	Bonneville	45.67388	-121.27338	293	7.1	0.7
13.02	07-Sep-06	Columbia	Bonneville	45.66734	-121.22111	297	3.8	3.4
13.02C	07-Sep-06	Columbia	Bonneville	45.66734	-121.22111	297	3.8	3.4
13.03	07-Sep-06	Columbia	Bonneville	45.69894	-121.30113	290	10.5	1.3
13.04	07-Sep-06	Columbia	Bonneville	45.69583	-121.29203	290	9.7	0.6
MCR01	16-Jun-05	Columbia	Bonneville	45.67882	-121.28648	291	8.2	1.3
MCR02	16-Jun-05	Snake	Lower Granite L.	46.67843	-117.45213	692	3.0	0.7
MCR03	17-Jun-05	Columbia	Lake Wallula	46.05912	-118.9083	507	0.8	0.5
MCR04	17-Jun-05	Columbia	Lake Umatilla	45.7294	-120.6509	352	16.4	0.0
MCR05	21-Jul-05	Columbia	Lake Wallula	45.9176	-119.1742	481	8.4	0.0
MCR06	22-Jul-05	Snake	L. Sacagawea	46.2466	-118.8775	538	10.6	0.5
MCR07	22-Jul-05	Columbia	Lake Umatilla	45.9011	-119.492	455	5.9	0.0
MCR08	22-Jul-05	Columbia	Lake Umatilla	45.8427	-119.7126	434	2.7	0.1

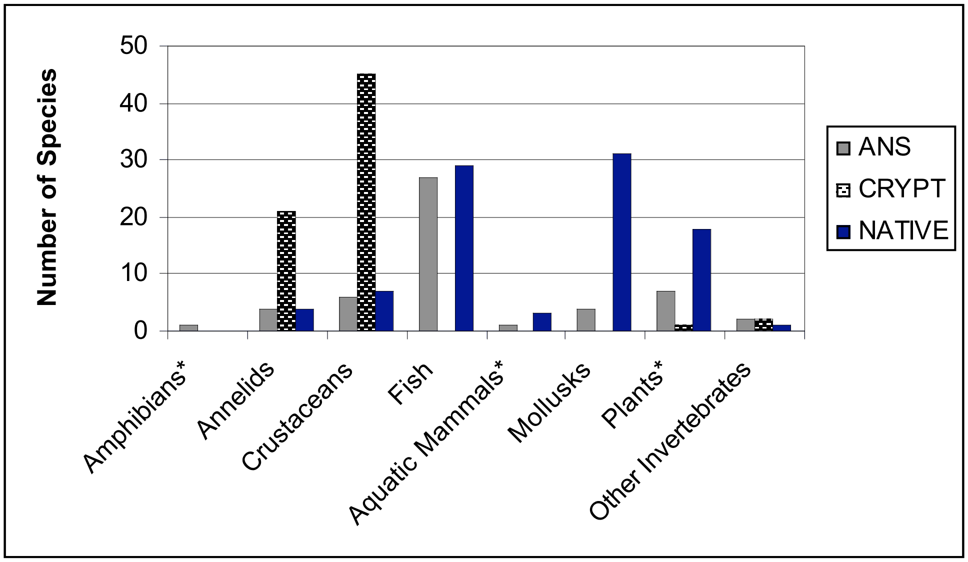

Figure 6. Species composition and invasion status from MCRANS survey and literature review. Taxa marked with an * were not fully surveyed for native species.

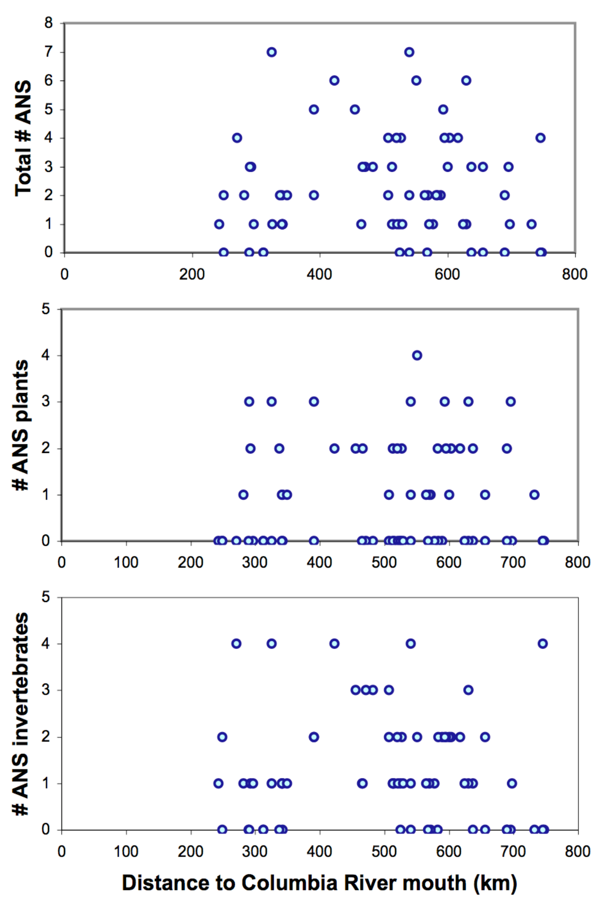

Figure 7. Effect of the distance from the mouth of the Columbia River on the number of total, plant, and invertebrate ANS in samples.

Vectors and Pathways

Vector determination for established ANS is often difficult to ascertain and many species have multiple potential vectors. In most cases, evidence of vector association with a particular species introduction is based on circumstantial, not direct, evidence. Because vector association is typically unknown, multiple possible vectors are often possible.

Intentional releases by agencies or individuals for the purpose of enhancing wildlife or game fish resources accounted for the largest number of introductions to the Middle Columbia and Lower Snake (Figure 8). Wildlife stocking conducted or approved by state and federal agencies were a possible mechanism of introduction for 83% of all nonnative fishes, and the American bullfrog *Rana catsebiana*. Intentional release by an individual to establish a population (as opposed to disposal), which was not sanctioned by an agency, was a potential vector for eight fish, aquatic plant and invertebrate species (Figure 8, Appendix I).

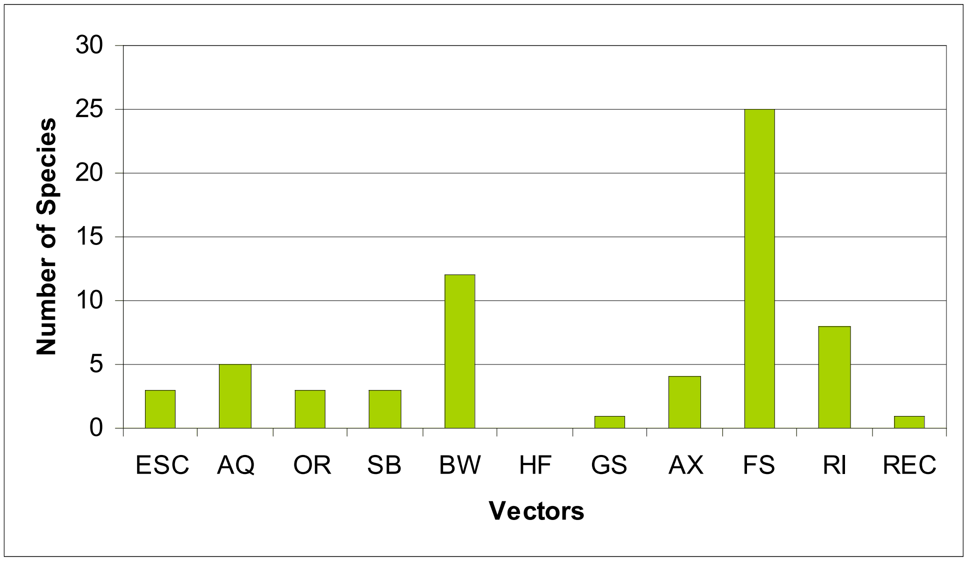

Figure 8. Vectors of ANS introductions into the middle Columbia River Basin. Abbreviations: ESC – escape from commercial cultivation, AQ – aquarium species, OR – ornamental species, SB – ships ballast, BW – ballast water, HF – hull fouling, GS – gradual spread from introduction outside basin, AX – accidental introduction (hitchhiking with an intentional release), FS – fisheries or wildlife enhancement by or approved by an agency, RI – release/stocking by an individual, not sanctioned by an agency, REC – recreational fishing/boating activity.

We found no clear effect of shipping or recreational boating on abundance of ANS in the middle Columbia and lower Snake. Distance from the mouth of the river or the nearest barge terminal, or boat launch were not predictors of total or shipping-related ANS abundance (Figures 9 through 12). Unlike the lower Columbia River where the shipping vector (fouling, solid ballast, and ballast water) accounted for 30 invertebrates and two aquatic plants, shipping vectors were associated with only 12 ANS in the middle Columbia River. Interestingly, four of these shipping-associated species were not found in the lower Columbia River despite the presumably higher risk of shipping related introductions.

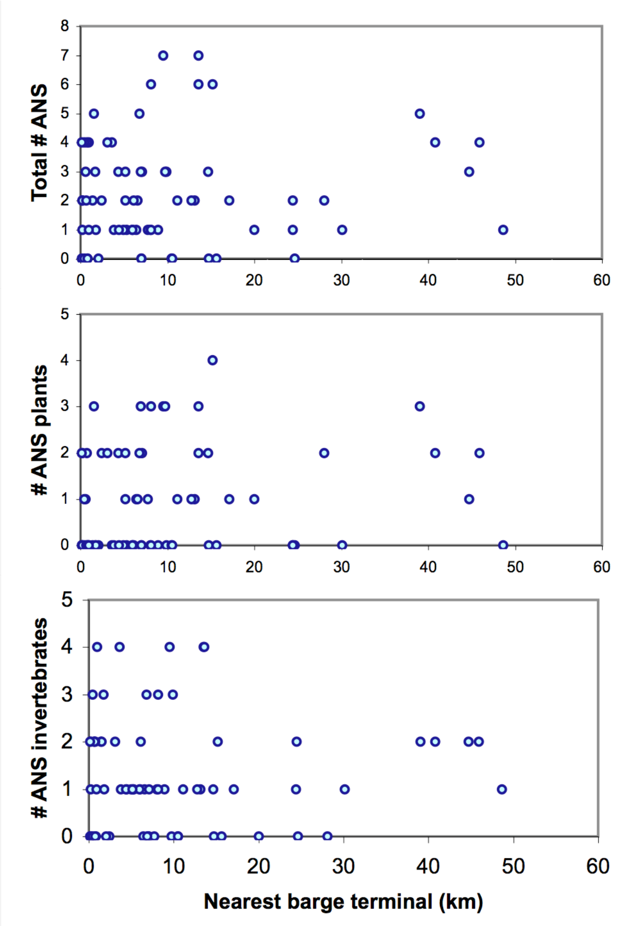

Figure 9. Effect of the distance from the nearest port facility on the number of total, plant, and invertebrate ANS in samples.

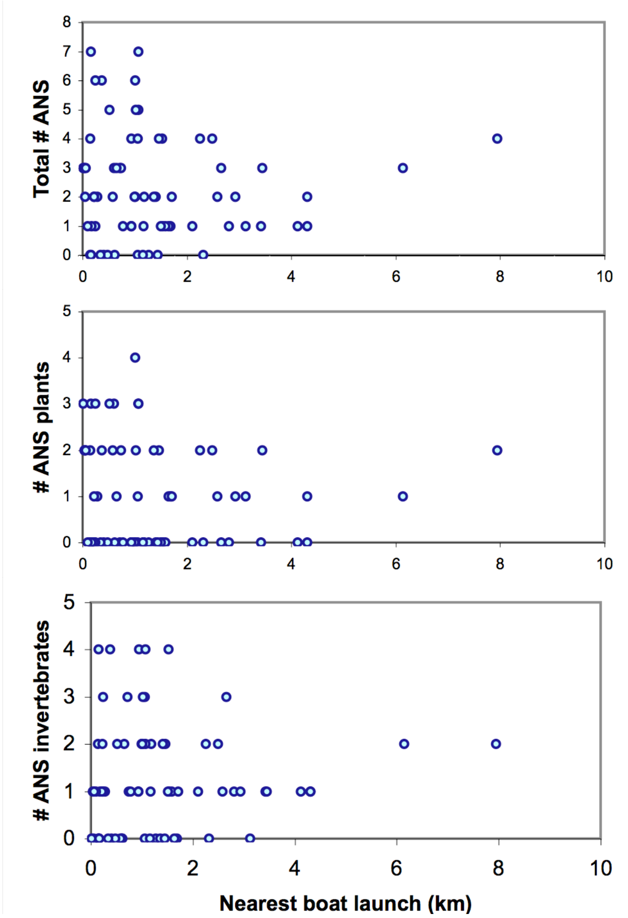

Figure 10. Effect of the distance from the nearest boat launch on the number of total, plant, and invertebrate ANS in samples.

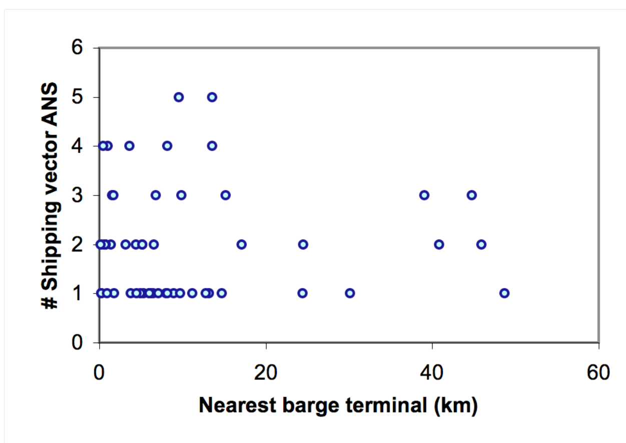

Figure 11. Effect of distance from the nearest barge terminal on the number of ANS with a shipping-related vector.

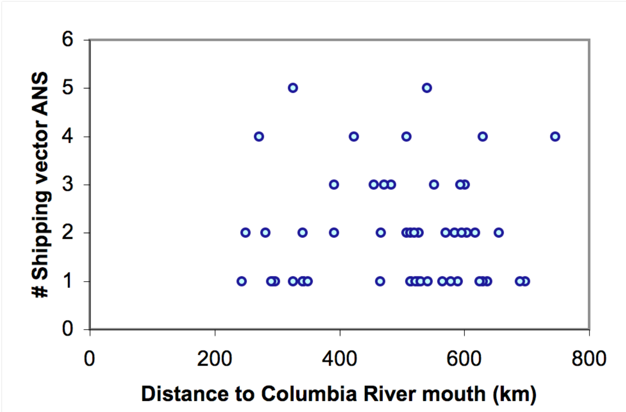

Figure 12. Effect of distance from the river mouth on number of ANS with a shipping-related vector.

Species origins

The majority of introduced species in the middle Columbia are native to North America, east of the Rocky Mountains (Figure 13). Introduced fish accounted for 80% of ANS with North American origins. Unlike the lower Columbia River, shipping-mediated introductions were almost evenly split between Asia, Europe and the Americas.

Facilitation of invasions by reservoirs

The number of ANS in each sample from the Hanford Reach was similar to the number in samples from reservoir sites in the middle Columbia and Snake rivers (Figure 14). Therefore, there was no clear indication of an effect of reservoir construction on ANS invasion. Results are not yet available from the intensive sampling of the Bonneville pool conducted in cooperation with the USGS. When those results become available we will be able to compare the intensive MCRANS sampling of the un-impounded Hanford Reach with Bonneville pool, the oldest reservoir on the river.

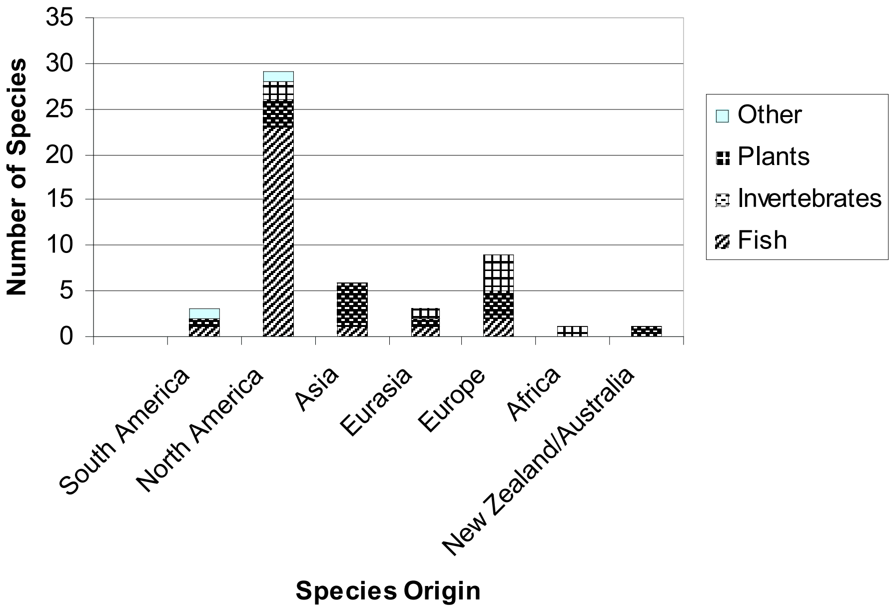

Figure 13. Origins of ANS introductions into the middle Columbia River.

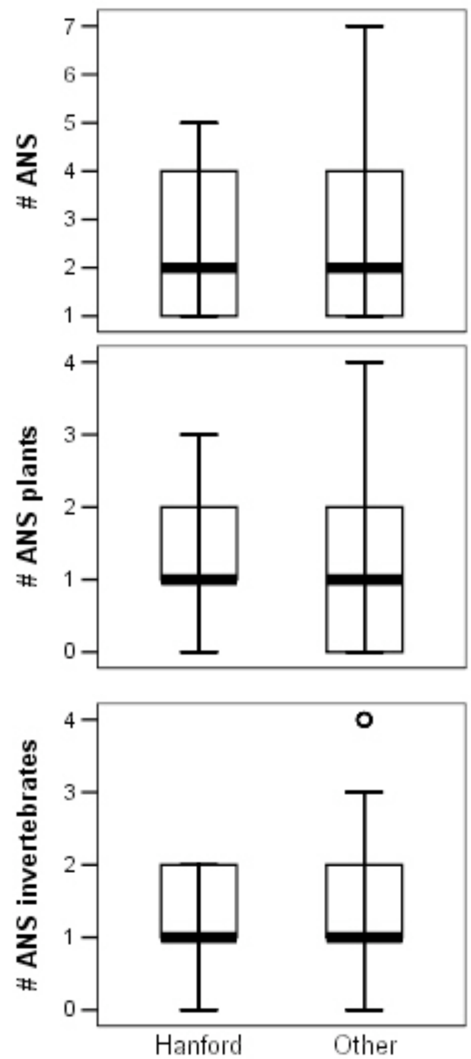

Figure 14. Box and whisker plots of samples from the free-flowing, Hanford Reach and reservoir sites. Horizontal bars are medians, boxes are interquartile ranges, circles are outliers (>1.5 box lengths from the end of boxes), whiskers are ranges of non-outlier

Conclusions and Recommendations

We determined that 50 aquatic species were introduced into the middle Columbia River and lower Snake River since the 1880s. The majority of these species were fish (54%), aquatic plants (14%) and crustacea (12%). The remaining 24% consisted of mollusks, bryozoans, hydrozoans, annelids, one amphibian and one aquatic mammal. These results were likely a conservative estimate of the number of ANS in the river because of spatial and temporal limitations of the survey, inadequate taxonomic resolution in prior studies, and the abundance of unresolved and cryptogenic taxa.

The relative importance of vectors for introduction of ANS has changed over time (OTA 1993; Ruiz et al. 2000; Systma et al. 2004,). Results from the lower Columbia River indicated that shipping-related vectors have increased in importance since 1950 corresponding with a global increase in the volume and speed of shipping. Changes in the Columbia River ecosystem suggest that rates of ANS introduction and establishment may have changed in recent years, however, data to evaluate changes are inadequate. Nine major dams were constructed on the middle Columbia River and the lower Snake between 1938 and 1975, which effectively turned most of the river into a series of reservoirs. Impoundment of the river fundamentally disrupted the hydrology of the system and degraded habitat suitability for native species. Disturbance to the system may have facilitated invasion by ANS and increased the rate of invasion.

The series of reservoirs created by the dams may have served as "stepping stones" for upriver movement of native species and ANS in the lower Columbia River and estuary. Havel et al. (2005) hypothesized that reservoirs are more readily invaded than natural lakes or large, un-impounded river systems because of their physiochemical properties, greater connectivity, and higher levels of disturbance. Dam construction itself may have facilitated introduction of ANS to the middle Columbia River. Construction equipment, movement of soil/dredge materials, and other processes involved in waterway alteration have been implicated in ANS introductions (Kolar and Lodge 2000). Unfortunately, collection records for the aquatic biota in the middle Columbia are uneven over the past 150 years. Reports of fish introductions date back to the late 1800s (Smith 1895), some benthic invertebrate records are available from the 1940s and 1950s (Coopey 1948; Davis and Cooper 1951), and zooplankton species records were reported in the 1950s (Coopey 1953). The bulk of species identifications in the middle Columbia, however, were published after the completion of the dams, which makes makes estimation of historic rates of introduction impossible.

We found no clear evidence that barge operations, recreational boating, or impoundment influenced ANS abundance. Clearly, localized effects of vectors would be expected to be short-lived in a system like the Columbia, which although it is impounded over much of its length still has significant current velocity and mixing. Additional data from the Bonneville pool collected by USGS will permit evaluation of reservoir age on ANS abundance, however, given the lack of spatial effects in our data we do not expect to those results to substantially alter our conclusions.

Missing species

There were several species we expected to find but failed to collect or observe, possibly due to constraints on sampling intensity and/or sampling methods. These species included:

Exopalaemon modestus: Siberian prawn. There are several unpublished records of its presence in the middle Columbia as far upriver as Lower Granite Dam on the lower Snake River. However, due to limited sampling gear used (seines and trawls were not used in order to avoid unnecessary take of listed fish species) we failed to collect and document *E. modestus* in the middle reach. We do not believe that our failure to collect this species was because the species was no longer present in this area.

Potamopyrgus antipodarum: New Zealand mudsnail. Much of our sampling area was between the two largest Columbia River Basin populations of mudsnails (the middle Snake River and the Columbia River estuary). Due to passive invertebrate drift as well as the potential for active movement by fish, birds and humans, we expected that new populations of NZMS would be found in the river between these two known populations. To date, however, the only two sightings of NZMS between the middle Snake and the Columbia River Estuary are the lower Deschutes River (Gustafson 2007) and a single snail recorded from the confluence of the Kalama (Systma et al. 2004)[7]. This may be due to a lack of suitable habitat or lack of successful transport.

Myocaster coypus: nutria. In the past 10 – 20 years the nutria population along the Willamette and Columbia Rivers has expanded dramatically in size and geographic range (T. Sheffels, pers com.) Reports of nutria from the middle Columbia River near the Tri-Cities remain anecdotal (P. Meacham pers. com) but, in the light of encroaching, well-documented nutria populations, these sightings are probably reliable.

Species watchlist

Several species are likely invaders of the middle Columbia River because of established populations nearby, presence of likely vectors for introduction, and presumably suitable habitat in the river (Table 7). These species should be considered “species to watch for” in the middle Columbia River.

[7] Follow up sampling in 2005 found no *P. antipodarum* at this site.

Table 7. Middle Columbia River ANS watchlist.

Taxa	*Species Name*	Common Name	Vector*
Fish			
	Esox masquinongy	muskellunge	FS, RI,
	Hypophthalmichthys nobilis, H. molitrix, and Mylopharyngodon piceus	Asian carp	BAIT, REC, RI, AX
	Noturus gyrinus	tadpole madtom	RI, GS
	Pylodictis olivaris	flathead catfish	RI, GS
	Rhinogobius brunneus	Amur goby	AQ, GS
	Salvelinus alpinus	arctic charr	ESC, GS
Invertebrates			
	Dreissena polymorpha, D. bugensis rostriformis	zebra, quagga mussels	REC
	Procambaridae	crayfishes	AQ, BAIT, GS
Plants			
	Hydrilla verticillata	hydrilla	AQ
	Myriophyllum heterophyllum	two-leaf water milfoil	AQ

*See Figure 8 for vector abbreviations

Recommendations

Integration of ANS management and basin planning and activities

Effective ANS prevention and management in the Columbia River Basin requires consideration of the possibility of ANS introduction in all activities that occur in the basin. Operation of the hydropower and lock systems, shipping and port operations, agriculture, recreation, fish and wildlife management, and various hobbyist activities can result in ANS introduction. Restoration and invasive species management activities may result in creation of habitat for colonization by new invaders, and ANS may hitchhike on plants and equipment used in restoration and enhancement activities. The potential introduction of quagga mussels into the basin via fish stocking in Wildhorse Reservoir in the Owyhee system increased awareness of this threat, however, ensuring that ANS are considered in planning and implementation of various activities in the basin is an ongoing challenge. Additional resources for outreach and education on ANS in the Columbia Basin are needed with focused efforts on those agencies and activities that result in importation or transport of biological materials. Hazard Analysis and Critical Control Point training and plan development should be required for all hatchery operations and natural resource activities in the basin.

The multiple regulatory and jurisdictional entities on the Columbia and Snake rivers necessitate a concerted effort to coordinate ANS prevention and management policy. Policy differences between federal and state agencies and even between state agencies within a state limit effectiveness of prevention and management efforts. Better coordination and policy direction is a critical need on the Columbia and Snake rivers, and elsewhere.

Surveys

This survey established a baseline on ANS in middle Columbia River that, with follow-up sampling, can be used to evaluate the effectiveness of ANS prevention programs, such as ballast water management and recreational boater education. Interpretation of the results of this study are limited, however, by fiscal constraints on the number of locations that could be sampled and the number of samples that could be collected. Additional monitoring and sampling is necessary to further characterize the system, detect new invasions, and document invasion rates, impacts and efficacy of management efforts. We recommend a multi-purpose sampling approach to maximize the potential of detecting additional species and new arrivals. Additional sampling should be conducted annually that is targeted on habitats that are likely to receive new invaders, such as in the vicinity of ports and recreational boat launches; a synoptic survey of the middle Columbia River should be conducted every five years; and additional sampling should target data gaps and survey constraints on this effort. Tributaries of the middle Columbia River system, especially those located in urban or developed areas and those that receive heavy recreational pressure, should be included in future surveys.

Research

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 middle Columbia River through dam construction, water impoundment, irrigation withdrawal, etc. have occurred in the last century; and the physical and chemical characteristics of reservoirs change as they age (Gol din et al. 2003, Holz et al. 1997, Popp and Hoagland 1995). Future anthropogenic and reservoir aging effects, as well as climate change, can be anticipated, which will likely impact the relative importance of various vectors and the susceptibility to ANS invasion. Regular monitoring of the biology and physical/chemical characteristics of the reservoirs could aid in understanding the process and consequences of ANS invasions in the Columbia and other large river systems.
- Impacts – While economic and ecological impacts of ANS that are ecological engineers, like zebra mussels and spartina, are readily apparent, impacts of many other ANS are less obvious but may still be ecologically significant consequences. For example, the Asian clam, *Corbicula fluminea*, constitutes a significant portion of benthic biomass in the middle Columbia River, it biomagnifies contaminants such as heavy metals and organochlorides, and may be an important food source for white sturgeon. Nonetheless, we know little about its impact on native bivalves through competition and displacement or how its high biomass and filter-feeding may alter food webs. More generally, we do not have a good understanding of whether the ecological and economic impacts of ANS invaders vary with the trophic level or guild of the invader.
- 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.
- Dispersal of ANS – Movement of ANS in ballast water transferred between domestic ports is a particular threat to the lower Columbia River (Simkanin and Sytsma 2006). While barges operating on the Columbia do not typically discharge ballast water, they

may transport species in water transported incidentally. Barges may be a significant vector for fouling species. Barge movement was likely responsible for some dispersal of zebra mussels from the upper reaches to the lower Mississippi River. The role of hull fouling in transport of organisms in rivers requires additional study.

- Management of ANS – Prevention of new invasions requires interdiction of pathways through regulation of vectors. Research is needed on methods to manage ANS associated with ballast water, hull fouling, live aquatics, ornamental and aquarium escapes.

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Appendix. Aquatic nonindigenous species in the middle Columbia River from literature review and field survey in 2005-2006, ANS in the Lower Columbia River (LCRANS)(Sytsma et. al 2004) and the Sacramento River (Sacto) (Light et al. 2005).

Taxa	*Species Name*	Common Name	Citation	Year	Lit Rev	Sampling	LCRANS	Sacto	Origin	Vector
Mammals										
	Myocaster coypus	nutria	Meacham, pers com 2007	2007	x		x		SAM	ESC
Amphibians										
	Rana catesbiana	bullfrog	NAS Database-HUC# 17061	NA	x		x		NAM	FS
Fish										
	Alosa sapidissima	shad	Smith 1895	1895	x		x		NAM	GS, FS
	Ameiurus catus	white catfish	Smith 1895	1895	x		x		NAM	FS
	Ameiurus melas	black bullhead	Gray and Dauble, 1977	1977	x		x		NAM	FS
	Ameiurus natalis	yellow bullhead	Gray and Dauble, 1977	1977	x		x		NAM	FS
	Ameiurus nebulosus	brown bullhead	Smith 1895	1895	x		x		NAM	FS
	Carassius auratus	goldfish	Barfoot et al., 2002	2002	x		x		ASIA	OR, RI, AQ
	Chaenobryttus gulosus	warmouth	NAS Database-HUC# 17061	NA	x				NAM	FS
	Cyprinus carpio	common carp	Smith 1895	1895	x		x		EURASIA	ESC, FS
	Esox americanus vermiculatus	grass pickerel	NAS Database-HUC# 17061	NA	x				NAM	FS
	Ictalurus punctatus	spotted catfish	Smith 1895	1895	x		x		NAM	FS
	Lepomis gibbosus	pumpkinseed	Gray and Dauble, 1977	1977	x		x		NAM	FS
	Lepomis macrochirus	bluegill	Gray and Dauble, 1977	1977	x		x		NAM	FS
	Micropterus dolomieui	smallmouth bass	Gray and Dauble, 1977	1977	x		x		NAM	FS
	Micropterus salmoides	large-mouth, black bass	Smith 1895	1895	x		x		NAM	FS
	Morone saxitilus	striped bass	NAS Database HUC# 17071	NA	x		x		NAM	FS
	Noturus gyrinus	tadpole madtom	NAS Database HUC# 17071	NA	x				NAM	FS
	*Onchorhynchus aguabonita***	golden trout	NAS Database-HUC# 17061	1973	x				NAM	RI
	Perca flavescens	yellow perch	Gray and Dauble, 1977	1977	x		x		NAM	FS
	*Piaractus brachypomus**	pirpatinga (red-bellied pacu)	NAS Database HUC# 17071	1990	x		x		SAM	AQ
	*Pogonichthys macrolepidotus**	split tails	Smith 1895	1895	x				NAM	FS

Taxa	*Species Name*	Common Name	Citation	Year	Lit Rev	Sampling	LCRANS	Sacto	Origin	Vector
Fish, cont.										
	Pomoxis annularis	white crappie	Gray and Dauble, 1977	1977	x		x		NAM	FS
	Pomoxus nigromaculatus	black crappie	Gray and Dauble, 1977	1977	x		x		NAM	FS
	Pylodictis olivaris	flathead catfish	NAS Database-HUC# 17061	1943	x				NAM	FS, AX
	Salmo trutta	brown trout	NAS Database-HUC# 17061	1942	x		x		EUR	FS
	Salvelinus fontinalis	eastern brook trout	Smith 1895	1895	x				NAM	FS
	Sander vitreus	walleye	Gray and Dauble, 1977	1977	x		x		NAM	FS
	*Thymallus arcticus***	Arctic grayling	NAS Database HUC# 17071	1900	x				NAM	RI
	*Tinca tinca***	tench	Gray and Dauble, 1977	1977	x		x		EUR	FS, RI
Invertebrates										
Annelid-Oligochaete										
	Branchiura sowerbyi			MCRANS		x	x		ASIA	BW, SB
	Chaetogaster diaphanus			MCRANS		x	x		UNK	SB, BW, RI
	Eukerria saltensis			MCRANS		x	x		SAM	BW, AX
Annelid-Polychaete										
	Manayunkia speciosa			MCRANS		x	x	x	NAM	BW, SF
Bryozoa										
	Urnatella gracilis			MCRANS		x		x	NAM	AX
Crustacea-Isopoda										
	Caecidotea laticaudatus			MCRANS		x			EUR	BW
	Caecidotea racovitzai racovitzai			MCRANS		x	x		EUR	BW
Crustacea-Decapoda										
	Exopalaemon modestus	Siberian prawn	Cordell, pers.com. 2006	2005	x		x	x	ASIA	BW, RI
Crustacea-Amphipoda										
	Crangonyx floridanus			MCRANS		x		x	NAM	BW
Crustacea-Copepoda										
	Harpacticella paradoxa			MCRANS		x			ASIA	BW
	Pseudodiaptomus forbesi			MCRANS		x	x	x	ASIA	BW

Taxa	*Species Name*	Common Name	Citation	Year	Lit Rev	Sampling	LCRANS	Sacto	Origin	Vector
Hydrozoa										
	Cordylophora caspia			MCRANS		x		x	EURASIA	SF, BW,
Invertebrates, cont.										
Mollusca-Bivalve										
	Corbicula fluminea	Asian clam	Dorband, 1980	1980	x	x	x		ASIA	RI, BW
Mollusca-Gastropoda										
	Potamopyrgus antipodarum	New Zealand mudsnail	Draheim pers. com. 2005	2005	x		x	x	NZ/AUS	AX, REC
	Radix auricularia	big-ear radix	NAS Database-HUC# 17061	NA	x				EUR	AQ, RI
Plants										
	Lythrum salicaria	purple loosestrife	WA Ecology, 1997	1997	x	x	x	x	EUR	OR, GS, SB
	Mimulus ringens	Allegheny monkey-flower	Caplow and Beck 1997	1997	x	x			NAM	OR
	Myriophyllum spicatum	Eurasian water-milfoil	WA Ecology, 1997	1995	x	x	x	x	EUR, AF	AQ
	Potamogeton crispus	curlyleaf pondweed	Falter et al., 1974	1974	x	x	x	x	EURASIA	AQ
	Rorippa nasturtium-aquaticum	cress	Falter et al., 1974	1974	x			x	EUR	ESC
	Veronica anagallis - aquatica	water speedwell		MCRANS		x		x	EUR	OR
	Phalaris arundinacea	reed canary grass	Caplow and Beck 1997	1997	x		x		NAM	GS, ESC

Abbreviations:

<u>Origins</u> --- NAM – North America, SAM – South America, ASIA – Asia, EURASIA – Eurasia, EUR – Europe, AF – Africa, NZ/AUS – New Zealand/Australia, UNK – unknown
<u>Vectors:</u> --- AQ – Aquaculture, OR – Ornamental, ESC – escape from commercial cultivation, SB – ships ballast, BW – ballast water, HF – hull fouling, GS – gradual spread from introduction outside basin, AX – accidental introduction (hitchhiking with intentional release), FS – fisheries or wildlife enhancement by or approved by an agency, RI – release/stocking by an individual, not sanctioned by an agency, REC – recreational fishing