An Exotic Species Detection Program for the Lower Columbia River Estuary

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The goal of an Exotic Species Detection Program (ESDP) is to detect and identify previously undetected exotic species. This is distinct from the goals of other components of exotic species monitoring—such as monitoring the spread or abundance of known exotics or monitoring the activities that transport exotic organisms—though there may be some elements in common.

An effective ESDP provides both research and management benefits. Research benefits include the opportunity to study successful introductions from their earliest stages and to study introductions that fail; the development of better data on where and under what conditions new arrivals become established; and the development of better data on the numbers, types, source regions, vectors and rates of introduction of exotic species in the ecosystem. Management benefits include the potential to initiate control or to begin mitigating impacts early in an invasion; and an improved understanding of vectors, source regions, rates of introduction, and factors controlling the success or failure of introductions, which should allow for improved designs and better-informed decisions in managing the problem of exotic species.

Scope, Definitions and Assessments

Some fundamental issues of definition, scope and methods of assessment must be addressed in setting up an ESDP.

1. The ESDP should focus on the marine and estuarine organisms that typically occur below the level of normal maximum high water (excluding storm surges, etc.) within the Columbia River Estuary, defined here as the region between the mouth and Skamokawa.
2. The invasion status of organisms should be assessed using a weight of the evidence approach, with the criteria clearly defined. A description of the evidence and how it was assessed should be provided for each organism classified.
3. The population status of organisms should be assessed using a weight of the evidence approach, classifying organisms as Established, Not Established (with subcategories of Failed or Extinct) or Not Known. A description of the evidence and how it was assessed should be provided for each organism classified.

The following additional types of data and assessments also be compiled for each organism included in the ESDP database:

- All early records in the Columbia River Estuary, and a summary of later records sufficient to indicate how its distribution and abundance changed over time.
- An estimate of its date of introduction to the Pacific Coast and to the Columbia River Estuary.
- Its global distribution, native region, and source region(s) for introduction to the Pacific Coast and to the Columbia River Estuary.

- The vector(s) thought to be responsible for introducing it to the Pacific Coast and to the Columbia River Estuary.
- For any organism that appeared in the Columbia River drainage upstream of the Estuary before it appeared in the Estuary, the database should also include its early records, an estimate of the date of introduction, and the source region and vector responsible for its occurrence upstream.

Taxonomic Support

One obstacle to the early detection of new introductions is the difficulty of recognizing when a specimen may represent a new organism for the Estuary. This problem could be ameliorated by funding an "Exotic Species Taxonomic Coordinator" who would be responsible for organizing the identification of specimens of suspected exotics; and by developing appropriate informational tools (available on the internet, if possible), including:

- A list of all organisms that have been collected from the Columbia River Estuary.
- Supplemental information on these organisms, including taxonomic descriptions, species synonymies, taxonomic bibliographies and other references, scientific illustrations and photographic images, and the location of preserved specimens; and information on geographic and habitat range, ecology, morphological variation and similar species.
- Similar types of supplemental information on exotic organisms on the Pacific Coast, including newly-discovered and suspected exotics.
- Collections of representative specimens of (1) exotic organisms established on the Pacific Coast, (2) exotic organisms in other temperate, estuarine waters that are not yet reported on the Pacific Coast, and (3) estuarine organisms in regions that are thought to be common donors of exotic species to the Pacific Coast.
- Readily accessible taxonomic keys.

The ESDP should help establish and support a regional "Exotic Species Taxonomic Coordinator" in collaboration with agencies from other areas; participate in or otherwise contribute to regional efforts to develop informational tools; and develop informational tools specific to the Columbia River Estuary where needed.

Initial Study

The ESDP should complete an Initial Study that assembles the available information on the invasion history and status of the exotic species in the Columbia River Estuary, including information from the scientific literature, unpublished data, collected specimens and collection records, and other sources. The Lower Columbia River Aquatic Nonindigenous Species Survey (LCRANS) has compiled much of this information for the entire Lower Columbia River region (Draheim 2002). Appendix B of this report contains information from LCRANS and from other sources that pertains specifically to the Estuary. An Initial Study for the Estuary could be completed from these two sources with modest additional effort.

Sampling Program

Although there have been occasional surveys of the Columbia River Estuary's fish, shellfish or invertebrates by agencies or academic institutions, including a survey by LCRANS that targeted exotic species in 2002-2003 (Draheim 2002), there have been no ongoing monitoring programs to sample the biota of the Estuary other than the collection of certain species to assess contaminant levels in their tissues. Thus, there is no existing long-term monitoring of biota that could serve as the base for an ESDP. The Lower Columbia River Estuary Program recommended the development of an exotic species sampling program that would be conducted at least every five years and include marsh plants, aquatic macrophytes, zooplankton, benthic macroinvertebrates and fish (LCREP 1998).

ESDP sampling efforts should emphasize habitats where exotic species are likely to be found, such as floating docks, pilings, bridge supports, buoys, seawalls, artificial lagoons, and areas near marinas and aquaculture sites; and should sample across the range of salinities in the Estuary. Sampling should also focus on taxonomic groups that are likely to be introduced into the Estuary and that have received relatively little attention, such as seaweeds, marine invertebrates, marsh insects and spiders, and gobies and blennies; and if appropriate expertise is available, on taxonomically obscure groups like phytoplankton, protozoans, fungi, bacteria and viruses.

If possible, sampling and core taxonomic work should be conducted annually by permanent staff, with additional taxonomic work contracted to specialists as needed. If funding is limited a Rapid Assessment Survey employing a team of specialists, as has been used in other estuaries, could be conducted less frequently (but at least every five years), supplemented by a modest program of sampling using other methods in off years.

When possible, the ESDP should collect and provide specimens from the Estuary for current morphological and genetic taxonomic studies; and should participate in appropriate regional surveys for particular exotic species, such as exotic cordgrasses, eelgrass, green crabs, mitten crabs, etc. A public monitoring or volunteer sampling program may also be useful in monitoring conspicuous and easily identified organisms.

Scope of this Report

This report provides a draft plan for an ESDP for the Lower Columbia River Estuary, and was produced for the Lower Columbia River Estuary Partnership under an agreement with the U.S. Environmental Protection Agency's National Estuary Program. It represents one independent researcher's view of a useful program to improve the detection and identification of previously undetected exotic species, but it is surely not the final word on the subject. It has been reviewed by LCREP and the other participating estuary projects, and may be further reviewed by LCREP's Science Work Group. Organizations involved in implementing this ESDP should take into account the resources that are available, any potential collaborations, any recommendations from further review or related studies (incliuding the Lower Columbia River Aquatic Nonindigenous Species Survey), and other relevant factors, and make appropriate modifications in the ESDP.

Acknowledgments

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What is an Exotic Species Detection Program?

The purpose of an Exotic Species Detection Program (ESDP) is to detect and identify previously undetected exotic species in a defined region or ecosystem. An ESDP's focus is thus distinct from other possible components of exotic species monitoring, such as monitoring the spread or abundance of an exotic species after it has been detected, or monitoring activities that transport exotic organisms to assess their importance or their compliance with regulations. It may, however, complement or share some elements with these other monitoring components.

A necessary precursor to detecting new exotic species is understanding which exotics have already been detected in the ecosystem. Therefore, as the first step in an ESDP this report discusses the development of a baseline list and database of exotic species in the study area, including the work that has been done to date and what additional work would make the baseline more complete and accurate. Ongoing ESDP activities would then augment this list over time, adding exotic species that had been present and established but that had gone undetected, as well as new arrivals. An effective ESDP would eventually produce a comprehensive list of established exotic species, and would detect most new arrivals soon after their establishment. This would have several research and management benefits (Table 1).

Supplemental research can also be conducted in combination with an ESDP to achieve other objectives or address additional questions that are not within the purview of the ESDP itself. For example, supplemental research could:

- Assess the effects of exotic species on the ecosystem. Examples include investigations of interactions between particular exotic and native organisms; and ecological or economic impact/risk assessments.
- Investigate through manipulative experiments how different factors—including characteristics of the environment, characteristics of the introduced organisms, and characteristics of the transport mechanisms—affect the success or failure of introductions.
- Test the effectiveness of different techniques for controlling the population growth or spread of particular exotic species.

The value of an ESDP may thus be enhanced if such research can be encouraged and funded, and developed in co-ordination the ESDP.

The scope of work for this report is to provide a draft plan for an ESDP for the salt and brackish water within the reach of the tides in the Lower Columbia River Estuary. The geographic boundaries for this region have generally been taken to range from the bar at the mouth of the river to Skamokawa, about 56 km upstream, consistent with the estuary as defined by the Lower Columbia River Aquatic Nonindigenous Species Survey (LCRANS) (Draheim 2002; Draheim *et al*. 2003). The report first provides some background information on the physical and habitat structure of the Estuary and on existing monitoring programs that may be relevant to the development of an ESDP. It then describes an ESDP for the Estuary, including the development of a baseline list of exotic species; a process and materials for taxonomic support; and sampling considerations, including both the use of existing monitoring programs and the establishment of supplemental sampling programs.

Table 1. Benefits of an Effective ESDP
<u>Examples of Research Benefits</u> • Opportunities to study introductions from their earliest stages, contributing to a better understanding of their dynamics and impacts. • Opportunities to study introductions that ultimately fail as well as those that succeed, contributing to a better understanding of what controls the success or failure of introductions.[1] • Better data on where and under what conditions new arrivals become established, contributing to a better understanding of what environmental conditions affect the success or failure of introductions. • Better data on the numbers and types of exotic species in the system, and their source regions, vectors and rates of introduction. This would facilitate comparisons between systems, which may produce insights into the factors that control introductions.
<u>Examples of Management Benefits</u> • Opportunities to implement control at an earlier stage, before an exotic organism has become abundant or widespread. Where control is feasible, rapid detection and rapid response will generally reduce the cost of control, produce fewer environmental and social side-effects, and increase the chance of success.[2] (Unfortunately, control may not be feasible for many exotic estuarine organisms even if detected at a relatively early stage.) • Earlier warning of potential impacts from an introduction will provide greater opportunities to avoid or mitigate those impacts when direct control is not feasible. • More complete data on vectors and source regions will allow more effective management of vectors and prevention of future introductions. • More complete data on vectors and rates of introduction will help in assessing whether measures implemented to prevent introductions are effective. • A better understanding of the factors that control the success or failure of introductions might suggest strategies for preventing exotic species from becoming established, and would improve invasion risk assessments, which are used both to assess proposals for importing, culturing or releasing exotic species and to assess the urgency and value of efforts to prevent unintentional introductions.
1 Simberloff (*e.g.* 1986), Cohen (2002) and others have pointed out the need for data on both failed and successful invasions in order to analyze invasion patterns and to test hypotheses about the influence of propagule size, invader characteristics, environmental similarity, biotic resistance, disturbance effects, etc. 2 The few cases of successful eradication of exotic organisms in estuarine or marine waters all occurred when the organism had been detected at an early stage in its invasion. These include the eradication of the mussel *Mytilopsis* from Darwin Harbor, Australia and the eradication of a sabellid worm *Terebrasabella heterouncinata* from a cove in southern California (Culver and Kuris 2000). A possible exception is the removal of exotic cordgrasses and other vascular plants from tidal marshes, where they may be susceptible to approaches used to control terrestrial weeds (*e.g.* various combinations of mowing, pulling, burying and herbicide application). In some cases these plants have been eradicated, at least locally, decades after arriving.

Definitions

In the scientific and management literature, there is no agreement about what to call organisms that have been transported and/or established outside of their natural range. Different publications have referred to such organisms as acclimatized, adventive, adventitious, alien, allochthonous, colonizing, ecdemic, escaped, exotic, foreign, immigrant, imported, introduced, invading, invasive, naturalized, neobiotic, neogenic, nonindigenous, non-native, nuisance, pest, quarantine pest, transfaunated, transferred, translocated, transplanted, weed or xenobiotic species; or by acronyms such as AIS ("Aquatic Invasive Species"), ANS ("Aquatic Nuisance Species" or "Aquatic Nonindigenous Species"), IAS ("Invasive Alien Species" or "Invasive Aquatic Species"), NIS ("Non-Indigenous Species"), NAS ("Nonindigenous Aquatic Species"), NEMO ("Nonindigenous Estuarine and Marine Species") and so on. Recently, the trend has been to use the term "invasive" (Carlton 2002). This has been variously defined in different publications as non-native species that:

- escape from cultivation and reproduce in the wild; or
- spread from their initial site; or
- are weedy species that may or may not impact native communities; or
- cause changes in natural or semi-natural environments; or
- threaten native biodiversity; or
- have a large and "usually undesirable" impact on the environment; or
- have detrimental economic impacts on native populations; or
- cause or are likely to cause harm to the environment, to human health or to the economy.

"Invasive" is used sometimes to refer to organisms that are established in a region; sometimes to organisms that are merely present in the region, and sometimes to include organisms that have the potential to be introduced into the region. Finally, "invasive" is also sometimes applied to *native* species that spread aggressively or that have an undesirable impact. Its recent popularity may be due to the negative connotations and rhetorical power of the terms invader, invasion and invasive, bolstered by films and other entertainments that feature horrific creatures from outer space. However, the term's persistent ambiguity makes it an unfortunate choice for scientific publications.

This report uses the following terms:

- *Exotic*, to refer to organisms that are not native to the area in question, but rather have arrived there as a result of human activities, without any implication regarding their population status, behavior or impact. "Arriving as a result of human activities" includes intentional or unintentional transport by humans, and passage through links constructed between formerly isolated biotic systems (*e.g*. canals), but does not include range expansions facilitated by other anthropogenic changes in the environment such as environmental changes in the newly colonized area or changes in ocean temperatures or currents resulting from anthropogenic alteration of atmospheric gases.
- *Established exotic*, to refer to an exotic organism that is present in the area and reproducing in the environment in sufficient numbers, over a sufficient area and for a sufficient time that it is unlikely to go extinct due to the stochastic and demographic effects that threaten small populations (called Allee effects).
- *Introduction*, to refer to the anthropogenic transport of an exotic organism into a new area and its release into the environment, including both intentional and unintentional transport or release.
- *Vector*, the mechanism, pathway or activity through which an exotic organism is transported to the new area and/or released into the environment.

- *Native*, to refer to organisms whose presence in the area in question is not due to arrival via human activities, as described above. These include both organisms that were present in the area prior to human occupation, and organisms that have since spread there "naturally."
- *Cryptogenic*, to refer to species for which the evidence of native or exotic status is unclear.

The Lower Columbia River Estuary

The Columbia River runs for 1,984 km from its headwaters on the western slope of the Rocky Mountains in British Columbia southward into Washington, then westward to form the border between Washington and Oregon before entering the ocean at about 46.5°N latitude. Its largest tributary, the Snake River, enters at 523 km above the Columbia's mouth. The entire watershed covers 660,500 km^2 and extends into seven states and Canada (Simenstad *et al*. 1990; Prahl *et al*. 1998; USACE 1999). Mean annual discharge is about 7,300-7,800 m^3/s, ranging from summer lows of around 2,000-3,000 m^3/s to spring highs over 15,000 m^3/s (Jones & Bottom 1984; Hamilton 1990; Prahl *et al*. 1998; NOAA 1998; USACE 1999; though Simenstad *et al*. 1990 report mean annual discharge of about 5,100 m^3/s). In June 1948, peak daily mean flow reached 26,000 m^3/s (Fuhrer *et al*. 1996). Discharge is highest in late spring, corresponding to peak snowmelt in the Cascade Mountains, and lowest in late summer to early fall (Fuhrer *et al*. 1996; Prahl *et al*. 1998; Draheim 2002). There are over 250 dams and reservoirs and 150 hydroelectric projects in the watershed, including 18 main-stem dams on the Columbia and Snake rivers (USACE 2001a). Extensive hydroelectric development has turned the United States portion of the main stem Columbia River into a series of slow-moving reservoirs punctuated by 11 large dams, the lowest of which is Bonneville Dam (Sherwood *et al*. 1990; Prahl *et al*. 1998; USACE 1999).

The influence of the tides extends 235 km from the river's mouth to Bonneville Dam on the main stem and 207 km from the mouth to Willamette Falls on the Willamette River. Within this region, generally defined as the Lower Columbia River, the water covers a surface area of about 625 km^2 with a mean depth of about 5 m at mid-tide, and drains an area of about 46,000 km^2 (Simensted *et al*. 1990; Hamilton 1990; NOAA 1998; USACE 1999; Draheim 2002). The main tributaries on the Lower Columbia are the Willamette River, entering from Oregon, and the Lewis and Cowlitz rivers, entering from Washington. Table 2 provides some water temperature data for this area. Sea surface temperatures off the mouth of the river are typically around 9-10°C in the winter and 14-15°C in the summer (Sverdrup *et al*. 1942; NOAA 1999), while temperatures within the Lower Columbia typically run colder in the winter (around 3-7°C) and warmer in the summer (around 20-22°C) (University of Washington 2001).There are five major ports on the Lower Columbia, at Portland, Vancouver, Kalama, Longview/Kelso and Astoria.

The estuarine portion of the Lower Columbia River has two main channels connected to a network of smaller channels and four large peripheral bays—Grays, Baker, Youngs and Cathlamet—with extensive sandbanks, tidal flats and marshes. Downstream of Skamokawa at about 56 km from the mouth, the river forms a relatively wide coastal plain estuary, while upstream to Longview it consists of a single channel contained within steep valley walls (Draheim 2002; Draheim *et al*. 2003). Vertical stratification varies from fully mixed to salt wedge conditions (Hamilton 1990). Jones and Bottom (1984) report that the upper edge of the

Table 2. Some Water Temperature Data for the Lower Columbia River

Location, with distance upstream from the mouth	Period	Mean	Range of Measures	References
Bonneville Dam Forebay, at 235 km	Jan 1990	–	6.7-7.0°C	University of Washington 2001
	Feb 1990	–	5.0-5.6°C	
	Mar 1990	–	5.0-7.8°C	
	Aug 1990	–	21.1-21.7°C	
Longview, at 100 km	Jan 1967-68	–	3-6°C	University of Washington 2001
	Feb 1967-68	–	4-6°C	
	Mar 1967-68	–	7-9°C	
	Aug 1967-68	–	20-22°C	
At 45 sites at ≈25-350 km	Jun 1992	–	17-18°C	Prahl *et al*. 1998
At 21 km, at 9 m depth	Apr 1980	–	9°C	Bottom & Jones 1990
	Jun-Aug 1980	–	13-16°C	
	Oct 1980	–	13°C	
Sea surface off the mouth	Jan 1999	9.2°C	–	NOAA 1999
	Feb	9-10°C	–	Sverdrup *et al*. 1942
	Jul 1999	14.4°C	–	NOAA 1999
	Aug	14-15°C	–	Sverdrup *et al*. 1942

salt wedge fluctuates from around 13 km from the mouth in spring to around 32 km from the mouth in summer, while Hamilton (1990) reports that salinity intrusion typically extends to around 50 km from the mouth, though largely confined to the two main channels.

Jones and Bottom (1984) considered the estuary as extending to around 37 km from the mouth, dividing this into marine, estuarine mixing and freshwater zones. The Columbia River Estuary Data Development Program (CREDDP) defined the estuary as extending to the eastern tip of Puget Island at about 75 km from the mouth, and covering 412 km^2 including 59 km^2 of marsh and 39 km^2 of tidal flats (Simenstad *et al*. 1990; Draheim 2002). The Lower Columbia River Aquatic Nonindigenous Species Survey (LCRANS) defined the estuary as extending to Skamokawa at 56 km from the mouth, but noted that the estuary's boundaries fluctuate over several time scales (Draheim 2002; Draheim *et al*. 2003).

Biological Monitoring Programs in the Lower Columbia River Estuary

For the purposes of this report, ecological monitoring is defined as a program that consistently samples some physical, chemical or biological component of an ecosystem over the long term in order to characterize the condition of that ecosystem over time. This is distinguished from ecological research, which is generally short-term and primarily oriented toward hypothesis-testing in order to arrive at general ecological truths, rather than local ecosystem characterization. There are no hard and fast boundaries, however. Some research is certainly useful for characterizing the state of particular ecosystems and, more rarely, some research involves consistent, long-term sampling of ecosystem components. Long-term in this context may be taken to mean a decade or longer.

Relevant Existing Monitoring Programs in the Lower Columbia River Estuary

Monitoring programs that could usefully be included in an ESDP are primarily those that sample some of the biota, especially where the objective is to assess species composition and where the work includes the production of a species list. In such programs, the collecting of the organisms is not necessarily the most costly or time-consuming component. Sorting, labeling, identifying, fixing, preserving and curating specimens and recording, entering, organizing, summarizing and reporting data may in some cases involve considerably more time, effort and expense than the actual sampling. Whether an existing program that samples biota would be useful to include in an ESDP depends on the relationship between the additional costs and the knowledge that is expected to be gained.

In 1998 the Lower Columbia River Estuary Program (LCREP) summarized the existing data collection and monitoring activities in the Columbia River basin (LCREP 1998, pages A-6 to A-8, A-47). These included various ambient and effluent monitoring programs measuring conventional pollutants, toxic contaminants, dissolved gases, temperature or other chemical or physical water quality parameters; sediment characteristics or contaminants; and contaminants in fish. However, other than programs monitoring contaminant levels in selected species, LCREP listed no programs that sample the biota.

LCREP did recommend the development of a sampling program for exotic species to include sampling at least every five years for exotic terrestrial and wetland plants, aquatic macrophytes, zooplankton, benthic macroinvertebrates, fish, amphibians and reptiles, but provided no further details. Exotic amphibians and reptiles are unlikely to occur in the salt or brackish tidal waters of the Estuary, but the other sampling components, if developed, would be relevant to this ESDP. (See Appendix A for further information on the exotic species monitoring component of the Lower Columbia River Estuary Plan.)

Exotic Species Database: Data Categories, Assessments and Baseline Data

The first step in an ESDP is creating a database on the exotic species that have already been collected in or reported from the ecosystem. This is done through an "Initial Study" that reviews the published and gray literature, collection records, species lists, etc. for the Estuary; interviews regional taxonomists and ecologists; re-examines specimens deposited in museum or private collections; and, where appropriate, conducts targeted field work to check whether reported species are still present or to examine particular habitats. The evidence compiled is then used to assess which organisms reported from the ecosystem are exotic, which ones are established, etc. In this assessment, *all* species reported from the region should be considered, both those that are suspected to be exotic as well as those that are generally believed to be native. The literature review and related work currently underway by the Lower Columbia River Aquatic Nonindigenous Species Survey (LCRANS) (Draheim 2002; Draheim *et al*. 2003) will assemble much of this information for the entire Lower Columbia River region; while Appendix B below contains information on exotic species from LCRANS and other sources that is specific to the Estuary. With these two resources, it should be possible to complete an Initial Study for the Estuary with a modest additional effort.

Information on the invasion status (whether or not exotic) and the population status (whether or not established) of species reported from the region is fundamental to an ESDP. Additionally, there are some other types of information, such as native range, global distribution, etc., which are generally useful to include in the ESDP's database. For many Pacific Coast exotic species, a good deal of data on distribution records, native range, history of introductions and association with different vectors has now been developed and compiled by other studies or databases and can be easily obtained.

Over time, the ESDP would add to, correct and fill in the database as new collections are made and new data becomes available, and as old collections and data are further analyzed. To assemble this database, several issues must be decided regarding definitions, boundaries and how various assessments will be made. A number of studies that have developed lists or databases of exotic aquatic species for different regions have grappled with these questions. Their various solutions, and recommended approaches, are discussed below.

Spatial Boundaries

The spatial boundaries of the study area must be clearly defined in order to determine in a consistent manner whether or not a particular species is present or established within the covered area. For marine and estuarine studies, boundaries need to be defined for both the seaward margin and, usually more critically, the upstream freshwater limit of the study area. Boundaries also need to be defined for the landward limits of the study area relative to the reach of the tides. In addition to defining these spatial limits, a study should define what kind of occurrence a species needs to have within the limits to be considered present in the study area. For example, if a study defines its landward limit as the high tide mark, is a species to be included if it is primarily terrestrial but is occasionally found within the intertidal zone? Examples might include:

- animals that are typically terrestrial but occasionally forage in the intertidal zone, including starlings, pigeons, rats, mice, opossums, hares, foxes, cats and dogs (feral and domestic), pigs, horses (wild and domestic), cattle and other livestock;
- fleas, lice and other external and internal parasites of the above animals;
- coastal insects that are blown into the intertidal zone;
- insects or spiders that are typically found on terrestrial plants but are sometimes found on the vegetation in tidal salt or brackish marshes;
- plants, crustaceans and insects that typically occur just landward of the high tide mark (*e.g.* plants of ocean beaches, supralittoral isopods and amphipods, etc.), but occasionally occur just below it.

- insects, sowbugs, slugs, snails or plants that are typically found on moist ground but are sometimes found in the upper reaches of tidal marshes during times of the year when these are freshened by rain or runoff;
- plants, insects, spiders, mites, sowbugs, rodents and birds that are typically terrestrial but are sometimes found in the upper reaches of tidal marshes, especially in parts of marshes with restricted circulation, when they are dry for a substantial period of time.

Cohen and Carlton (1995), in a study of in the San Francisco Estuary, did not include the above types of organisms (with a few exceptions) in their primary list of exotic species that are characteristically found in the estuarine and aquatic habitats within the normal range of the tides, but did include them in supplemental lists consisting of exotic terrestrial species reported from the estuary and exotic species occurring in areas adjacent to the estuary (including the supralittoral zone, the riparian zone alongside tidal freshwater reaches, and freshwater tributaries above the reach of the tides). Ruiz *et al*. (2001), in a review of exotic algae and invertebrates on North American coasts below the mean monthly limit of spring tides, included some species commonly found in salt marshes and beach strand-lines, but excluded some "boundary species" that primarily occurred in terrestrial habitats but were occasionally or rarely found within the study boundaries. Orensanz *et al*. (2002), in a study of exotic marine benthic/littoral organisms in Uruguay and Argentina, excluded anadromous salmonids and species present only on the freshwater end of estuaries. Wonham and Carlton (2003), in a review of exotic organisms in marine and estuarine waters between Cape Mendocino and the Queen Charlotte Islands, included vascular plants in salt-water flooded habitats, but excluded terrestrial plants that occur along the edges of salt marshes, dunes, beach cliffs and bluffs, terrestrial animals that venture into the intertidal to feed, fish that do not reproduce in brackish waters, and freshwater species that may occasionally occur as adults in waters contiguous with tidal brackish waters.

Recommended approach: Define the study's focus as the marine and estuarine organisms that typically occur below the level of normal maximum high water (excluding storm surges, etc.) between the mouth of the Columbia River and Skamokawa, 56 km upriver, including all bays and inlets between. This would include anadromous or catadromous organisms that typically spend part of their life cycle in salt or brackish water. It would not include boundary species of the estuary-land ecotone that are more typical of terrestrial than aquatic habitats (such as those described in the bullets above), or boundary species at the fresh water-salt water ecotone that are more typical of fresh water. Such boundary species would, however, be noted in supplemental lists.

Invasion Status

In the first major regional assessment of exotic marine species, Carlton (1979) classified organisms into three categories of Clearly Introduced, Probably Introduced and Native. In 1996 Carlton formally defined the term "cryptogenic" as "a species that is not demonstrably native or introduced," and Carlton & Cohen (1995) provided the first list of cryptogenic species in a regional study. Nearly all regional studies of exotic marine or estuarine species since then have used this three-part classification of Exotic (or some equivalent term)/Cryptogenic/Native, although the various studies' definitions of these terms are not completely equivalent (Table 3).

Table 3. Invasion Status Definitions Used by Different Studies

Native	A species that is believed to have originated in the broad region in question (Carlton 1979). Species that were aboriginally present (Cohen & Carlton 1995). "Populations occurring within their natural range without aid of human activities" (T N & Associates 2002). "Aboriginal species, including pre-historical invasions" (Fairey *et al.* 2002).
Introduced, Nonindigenous or Exotic	A species that has been transported by man into a region where it did not formerly exist in historical times, and which has become established through maintaining naturally reproducing populations (Carlton 1979). Species that successfully colonize and establish populations outside of their historic or native geographic ranges, mediated by human activities (Grigorovich *et al.* 2002). "Reproductive populations of species or subspecies established by human activities outside of their previous natural range" (T N & Associates 2002). A species that "colonizes a new area that is geographically discontinuous from its native area; whose range extension is linked, directly or indirectly, to human activity; and which is established" (Fairey *et al.* 2002). Species "that have been transported by human activities - intentionally or unintentionally - into a region in which they did not occur in historic time and in which they are now reproducing" (Ashe 2002).
Cryptogenic	Organisms that are neither demonstrably native nor introduced (Cohen & Carlton 1995). Possible introductions; no definitive evidence of either native or introduced status (Ruiz *et al.* 2001). A species whose origin cannot be readily determined with available data (Wasson *et al.* 2001). This study employed an "operational definition" of cryptogenic, but noted that the term usually denotes a species that cannot be proven to be either introduced or indigenous (Paulay *et al.* 2002). Possible introduction; no reliable historical data are available to discern whether the species is indigenous or introduced (Grigorovich *at al.* 2002) Reasonable candidates for the status of invasive exotics (Orensanz *et al.* 2002). "A species that is not demonstrably native or introduced...A catchall category for species with insufficiently documented life histories to allow characterization as either native or introduced" (Fairey *et al.* 2002). Species "that appear to be widespread in bays, ports and estuaries of the world and cannot be identified as definitely native or exotic" (Boyd *et al.* 2002). Species for which evidence of native or exotic status is mixed or otherwise unclear (T N & Associates 2002; Draheim *et al.* 2003). Species of uncertain origin (Lee *et al.* 2003).

Some studies define introduced or exotic species as being introduced during historic times, implicitly (Cohen & Carlton 1995; Grigorovich *et al.* 2002; Ashe 2002) or explicitly (Fairey *et al.* 2002) accepting any species introduced by aboriginal populations as now being native; others avoid the question by referring only to "natural" ranges; and yet others seem to be trying to have it both ways (*e.g*. Carlton (1979) defining native species as having "originated"—presumably in an evolutionary sense—in the general region, while defining introduced species as having been transported into the region during historic times). Another difference is that a few studies define or refer to cryptogenic species as being probably exotic (*e.g*. Orensanz *et al*. 2002), while most studies define the term in a neutral sense, as species whose invasion status cannot be determined one way or the other with the available evidence.

A study of aquatic invertebrates in the Ponto-Caspian region employed four categories instead of the usual three, using Native and Cryptogenic categories but also distinguishing Definite Introductions, wherein the species is directly transported by human activities, from Probable Introductions, wherein the spread of the species is "an indirect byproduct of human activities including alteration of hydrological regimes or canal and reservoir construction" (Grigorovich *et al*. 2000). A review of exotic organisms in California coastal waters introduced the term NativeX for species native to one part of the state that had recently expanded their range to another part of the state, with or without the benefit of human transport (Fairey *et al*. 2002; Ashe 2002). A few recent classifications have directly addressed organisms whose identification is poorly resolved. Ashe (2002) considered taxa identified to the species level as Distinct and capable of being further classified as Native, Cryptogenic or Introduced, and all taxa that were not unambiguously identified to the species level as Non-Distinct and not suitable for assessment of their invasion status. Fairey *et al*. (2002) defined taxa identified to species as Known (and appropriate for classifying by invasion status), taxa identified to genus as Unknown, and taxa not identified beyond family as Not Assignable. Lee *et al*. (2003), in an analysis of San Francisco Bay benthos, and Cohen *et al*. (2003), in a survey of southern California bays and harbors, more flexibly distinguished Determinate taxa, defined as those identified to a sufficiently low taxon to classify as native, cryptogenic or exotic, from Indeterminate taxa, which are not.

Aside from the variation in classification systems, there are the thornier questions of what approach to take in determining which invasion status category an organism falls into and what criteria or types of evidence should be used to make that determination, as well as the question of how to present or explain the assessment. The approaches used can be sorted into four general types: Received Wisdom, Scoring System, Correspondence with Criteria, and Weight of the Evidence. These are discussed below, and the use of these approaches by various studies is summarized in Table 5.

<u>Received Wisdom</u>: In this, the quickest and easiest approach, one simply uses the determinations made by previous workers. This approach was used in part by Wasson *et al*. (2001) in a study of Elkhorn Slough, T N & Associates (2002) in a classification of Pacific Coast benthic sampling data, probably Orensanz *et al*. (2002), who state only that their introduced category consists of species "whose 'exotic' status is well documented," and Lee *et al*. 2003. Despite its obvious appeal, this approach has several obvious drawbacks and some less obvious pitfalls. Some drawbacks are that there may not be determinations made for all the species you need to deal with; previous workers may have used a different classification system, or different definitions for some of the classes, from the system and definitions you want to work with; if you mix determinations made by different workers, or another worker's determinations with some of your own, they may be inconsistent; and some of the determinations that you rely on could be in error (drawing inappropriate conclusions from the available data) or outdated (superseded by

newly available information). A less obvious issue is that determinations of invasion status are made with regard to a *particular place*; so that a species may be confidently classified as exotic in one part of the coast, but should be considered cryptogenic or even native elsewhere on the coast. Thus, simply lifting the invasions status determinations from another study, without fully understanding the methods and limitations of that study, may produce erroneous assessments.

In terms of explaining the assessments, all that is necessary is a citation to the study whose determinations are being used.

Scoring System: In this approach a species is tested against a list of criteria, a categorical response (such as positive/negative or yes/no/no data) is determined for each criterion, and the responses are totaled up by a predefined system to unambiguously categorize the species' invasion status. Scoring systems were used in part by Wasson *et al*. (2001) in a study of Elkhorn Slough, and by Paulay *et al*. (2002) and Lambert (2002) in a study of exotic marine species in Guam (Table 4). This type of approach has been described as "more objective" than other methods (Paulay *et al*. 2002), and this is true in the sense that different users of one of these systems are likely to produce the same or similar results in any particular case, because of the limited, categorical responses permitted for each criterion and the inflexible rules for tallying them up. On the other hand, the approach is not necessarily any more accurate than other methods, and to the extent that it does not make use of all available information it is likely to be less accurate. Information that is excluded includes the strength of the response to each criterion; the precision, clarity and reliability of the evidence supporting the responses; the relative value of each criterion, and their degree of interdependence, which could vary from case to case; and any relevant evidence that doesn't fit any of the criteria.

An explanation of the assessments requires only a clear description of the criteria, the allowable responses, and the method of tallying them; and a list or table providing the response to the criteria for each organism.

Correspondence with Criteria: This approach was developed in three papers that assessed the invasion status of a few peracaridean crustaceans (Chapman 1988; Chapman & Carlton 1991, 1994), and used in a slightly modified version by several later studies. As in the previous approach, categorical responses are determined for a set of criteria (usually phrased so that a positive response indicates a likelihood of being exotic, and a negative response indicates a likelihood of being native), but there is no unambiguous method for tallying these up to determine invasion status, that is, none of the studies state that a certain number of positive responses means that a species is exotic. Rather, the "overall correspondence" of the responses to the criteria determined for each species to the positive responses expected for exotic species "can be assessed and probability values can be calculated for the overall results" (Chapman & Carlton 1991). In essence, this means that in each individual case the researcher applies his or her judgment as to whether the mix of positive, negative and unknown responses warrants classifying the organism as native, cryptogenic or exotic. Presumably, part of that judgment involves weighing the relative value of the different criteria, their interdependencies and the strength and reliability of the determined responses.

Table 4. Scoring Systems for Assessing Invasion Status

Wasson *et al.* (2001)	
Exotic species:	• Have very disjunct global distributions; • Were not previously reported from the study area; and • Were described originally from distant localities.
Cryptogenic species:	• Have somewhat disjunct global distributions; or • Have cosmopolitan distributions.
Paulay *et al.* (2002)	
Introduced species:	Positive for at least 1 primary indicator or at least 2 secondary indicators
Cryptogenic Species:	Positive for 1 secondary indicator, or at least 2 tertiary indicators
Primary Indicators:	• Documented purposeful introduction. • Appeared first with and on dry docks towed to Guam. • Clear association with purposefully introduced nonindigenous species.
Secondary Indicators:	• Restriction to artificial substrata. • Extra-Indo-West Pacific, disjunct distribution. • Intra-Indo-West Pacific, disjunct distribution.
Tertiary Indicators:	• Likely association with purposefully introduced nonindigenous species. • Extra-Indo-West Pacific distribution. • At range boundary and restricted to Apra Harbor. • Frequent but not exclusive association with artificial substrata. • Opinion of specialist.
Lambert (2002)	
Introduced species:	Meets Criteria 1 and 2
Cryptogenic species:	Meets Criteria 1, 2 or 3
Criteria:	1 Restricted to artificial surfaces 2 Extra-Indo-West Pacific distribution 3 Predominantly on artificial surfaces; only a few small specimens collected in natural areas

In the first three studies, probabilities were calculated for the set of responses for each case considered (Chapman & Carlton 1991, 1994) and for all cases together (Chapman 1988) using a Chi-square test of likelihood. These calculations yielded significantly low probabilities for the observed strong association of positive responses with each of the organisms tested, implying that there is a high likelihood that these species are exotic. However, the assumptions implicit in these statistical tests (*i.e*. about the independence of the criteria, and the underlying probability of positive and negative responses) are invalid, and so the statistical analyses appear to be invalid as well. Later studies that used this approach did not report and apparently did not calculate probabilities for the sets of responses (T N & Associates 2002, Toft *et al*. 2002 and Draheim *et al*. 2003). Without the probability analysis, this approach begins to resemble the Weight of the Evidence approach (and indeed, both approaches have used similar lists of criteria), with the main advantage being that the determined responses can be succinctly presented in a list or table. However, a full explanation of the assessment also requires a detailed, narrative description of the researcher's judgment of the value, interdependence, strength and reliability of the criteria and responses (thus essentially qualifying the responses so they are no longer categorical), and how the responses were combined to produce the determination of invasion status.

Weight of the Evidence: In this approach, the researcher simply applies his or her considered judgment to all the available evidence (often organized into different types of evidence or criteria) and comes up with a determination of the species' invasion status. While it doesn't sound very scientific when described this way, if done thoughtfully, carefully and consistently, this approach may in the end produce more accurate assessments, since all the evidence can be considered on its own appropriate merit, without forcing it into predetermined categories or simplified response determinations, and without applying a numerical gloss to the proceedings. It is essential, however, that a full, narrative description be provided of the available evidence and how it was weighed and combined to produce the assessment, so that consistency can be maintained and checked and other researchers can review how the assessments were made. This is probably the most common method used in regional assessments of exotic aquatic organisms (Table 5), and is certainly the most common approach in assessments of individual organisms.

Correspondence with Criteria and Weight of the Evidence approaches both usually refer to a set of criteria (sometimes presented as "types of evidence") when assessing invasion status, and the sets of criteria used have been modified over time and reworked by different researchers (Table 6). While there is general consensus on the types of criteria or evidence that are relevant, researchers are not in complete agreement about the validity or value of every criterion that has been proposed, or on how restrictively each criterion should be stated. As additional studies are done and invasion status assessments are discussed and debated, there is likely to be further development of these concepts.

Recommended Approach: Use the following categories to classify the invasion status of organisms:

- Determinate taxa
  - Exotic taxa
  - Cryptogenic taxa
  - Native taxa
- Indeterminate taxa

with exotic, cryptogenic and native as defined above in the Definitions section. Determinate taxa are those identified to a sufficiently low taxon to classify as native, cryptogenic or exotic, while indeterminate taxa are not. In most cases determinate taxa will be identified to species, but in a few cases higher taxon identification will allow an assessment of invasion status (for example, identification to genus when the genus is known only from other ocean regions, and therefore is exotic; or when all known species in the genus are native to the study region, and therefore is native).

Use a weight of the evidence approach to assess invasion status in order to make use of all available evidence. Assessments done by previous studies of the organisms in question should be reviewed and considered, but the ESDP should strive to apply its selected criteria to the most complete and up-to-date evidence in a consistent manner, taking into account any evidence specific to the Lower Columbia River Estuary. Given the unsettled state and the continuing evolution of researchers' views on the validity and value of different criteria, no particular set of criteria is recommended at this time. Whatever criteria are used should be clearly defined; and for each organism classified, a description of the evidence considered (with citations) and a full and complete explanation of the assessment of its invasion status should be included in the database.

Table 5. Approaches Used in Different Studies to Assess Invasion Status
Received Wisdom
Wasson *et al*. 2001 (in part) – regional study of exotic invertebrates in Elkhorn Slough
Orensanz *et al*. (probably) – regional study of exotic benthic/littoral organisms along the coast of Uruguay and Argentina
T N & Associates 2002 (in part) – assessment of the invasion status of organisms collecting in benthic sampling of the smaller estuaries of Washington, Oregon and California
Lee *et al*. 2003 - analysis of benthos in the San Francisco Estuary
Scoring System
Wasson *et al*. 2001 (in part) – regional study of exotic invertebrates in Elkhorn Slough
Paulay *et al*. 2002 – regional study of exotic marine organisms in Guam
Lambert 2002 – regional study of exotic tunicates in Guam
Correspondence with Criteria
Chapman 1988 (strong version) – assessment of the invasion status of 4 gammarid amphipods in the northeastern Pacific
Chapman & Carlton 1991, 1994 (strong version) – assessment of the invasion status of the isopod *Synidotea laevidorsalis* in 4 regions around the world
T N & Associates 2002 (in part) – assessment of the invasion status of organisms collecting in benthic sampling of the smaller estuaries of Washington, Oregon and California
Toft *et al*. 2002 – assessment of the invasion status of 1 amphipod and 2 isopods in the Sacramento-San Joaquin Delta
Draheim *et al*. 2003 – regional study of exotic organisms in the Lower Columbia River
Weight of the Evidence
Carlton 1979 – regional study of exotic invertebrates and protozoans in Pacific Coast marine and estuarine waters
Cohen & Carlton 1995 – regional study of exotic organisms in the San Francisco Estuary
Cohen *et al*. 1998; Mills *et al*. 2000 – regional study of exotic organisms in Puget Sound
Cohen *et al*. 2001 – regional study of exotic organisms in 3 Washington bays
Ruiz *et al*. 2001 - review of exotic marine organisms
Grigorovich *et al*. 2002 – regional study of exotic aquatic invertebrates in the Ponto-Caspian Region
Fairey *et al*. 2002 – regional study of exotic aquatic organisms in California coastal waters, excluding San Francisco Bay
Cohen *et al*. 2003 – regional study of exotic organisms in southern California bays and harbors
Wonham & Carlton 2003 – regional study of exotic organisms in marine and brackish estuarine waters between Cape Mendocino and the Queen Charlotte Islands

Table 6. Criteria Used in Different Studies to Assess Invasion Status

Criteria	Carlton 1979	Chapman 1988	Chapman & Carlton 1991, 1994	Cohen & Carlton 1995	Toft *et al.* 2002	Cohen *et al.* 2003	T N & Assoc. 2002; Draheim *et al.* 2003
Local absence							
• Previously unknown in the region (absent from the recent fossil and archaeological records, and early biological studies that likely would have collected and identified it).	X	X	X	X	X	X	X
Vector							
• The act of introduction is observed or recorded.	X	X	X	X	X	X	X
• A synanthropic dispersal mechanism exists that is appropriate in space and time.	X	–	–	X	X	–	X
• The organism is associated with a synanthropic dispersal mechanism.	–	X	X	–	–	X	X
Local distribution & population dynamics							
• Has a restricted or discontinuous distribution in the region relative to native species.	X	X	X	X	X	X	X
• Has rapidly increased in abundance in the region.	X	–	–	X	–	–	–
• Has rapidly expanded its range in the region.	X	X	X	X	X	X	X
Local associations							
• Relationship to other exotics in the region:	Solely occurs with or depends on	Commonly occurs with	Commonly occurs with or depends on	Commonly occurs with or depends on	Commonly occurs with	Solely or near-solely depends on	Commonly occurs with or solely depends on
• Relationship to new, artificial or altered environments in the region:	–	Restricted to	Common on	–	Common on	–	Restricted to

Global distribution							
• Has a disjunct global distribution (*i.e.* is present in other bioregions).	X	X	X	X	X	X	X
• The organism's natural dispersal abilities do not account for its observed distribution.	X	X	X	X	X	X	X
Taxonomic associations							
• Evolutionary origins are exotic (*e.g.* it belongs to an exotic taxonomic group).	X	X	X	X	X	X	X
Life history traits							
• Tolerates temperatures or other environmental factors that don't exist in the region.	–	–	–	–	–	–	X
• Vulnerable to exotic parasites to which native species are not.	–	–	–	–	–	–	X

Population Status

Carlton (1979) categorized exotic organisms as Established, Questionably Established or Not Established. Cohen & Carlton (1995) provided separate lists of organisms that were established, that did not become established, that became established but went extinct, and for which there was inadequate evidence to determine whether or not they were established. Ruiz *et al.* (2001) more succinctly proposed categories of Established, Unknown and Not Established, the latter with subcategories of Failed and Extinct. Establishment has been variously defined (Table 7), the main disagreement being whether unassisted reproduction in the environment is a sufficient condition, or if some evidence of stability and persistence of the population is required. Most studies apparently use a weight of the evidence approach and say little or nothing about the assessment. Cohen & Carlton (1995) listed the following types of evidence as relevant:

- Population size.
- Persistence of the population over time.
- Distribution (broad or restricted) of the population, and trends in distribution.
- For species dependent on sexual reproduction, the presence of both males and females, and the presence of ovigerous females.
- The age structure of the population as an indicator of successful reproduction.

Ruiz *et al.* (2001) described criteria that sound in part like a scoring system:

- Established: Documented as reproducing in the last 30 years, with multiple records; for species detected in the last 10 years, recorded in at least two locations or two consecutive years.

Table 7. Definitions of "Established" Used in Different Studies

"Maintaining naturally reproducing populations" (Carlton 1979).
"Organisms present and reproducing 'in the wild' whose numbers, distribution and persistence over time suggest that, barring unforeseen catastrophic events or successful eradication efforts, they will continue to be present in the future. 'In the wild' implies reproduction and persistence of the population without direct human intervention or assistance (such as reproductive assistance via hatcheries or periodic renewal of the population through the importation of spat), but may include dependence on human-altered or created habitats, such as water bodies warmed by the cooling-water effluent from power plants, pilings, floating docks, and salt ponds or other manipulated, semi-enclosed lagoons" (Cohen & Carlton 1995).
A species that "has a population which is present and reproducing in the environment without direct and deliberate human intervention (*e.g*. aquacultural rearing or deliberate re-introductions), and which persists over time in the absence of unforeseen catastrophic events or successful eradication efforts" (Forrest *et al*. 1997).
"Documented as present and reproducing within the last 30 years" (Ruiz *et al*. 2001).
Species that successfully colonize (Grigorovich *et al*. 2002).
Species that "have established self-maintaining populations" (Wonham & Carlton 2003).

- Unknown: No records in the last 20-30 years; if recently introduced, then with too few records to be classified as Established.
- Not Established (Failed): Were reported, but no evidence of establishment.
- Not Established (Extinct): Survived and reproduced for many years before disappearing.

As with scoring systems for assessing invasion status, such a system does not consider all the available evidence, and is more likely to classify some organisms incorrectly.

Recommended Approach: Use the following categories to classify the population status of organisms:

- Established: Refers to an organism that is reproducing in the environment in sufficient numbers, over a sufficient area and for a sufficient time that it is unlikely to go extinct due to the stochastic and demographic effects that threaten small populations (called Allee effects).
- Not Established: Refers to an organism that has not been collected for a sufficiently long time since its last record that it is unlikely to be present, taking into account the frequency, intensity and quality of the sampling that has been done. Also refers to an organism that has been collected at an abundance and frequency that is consistent with continuous reintroduction considering the vectors that are operating, and which is not reproducing in the environment.
    - Failed: Refers to an organism that currently qualifies as Not Established and never qualified as Established.
    - Extinct: Refers to an organism that currently qualifies as Not Established, but which qualified as Established at some point in the past.

- Not Known: Refers to an organism for which there is insufficient evidence to qualify it as Established, and insufficient (in duration, frequency, intensity or quality) unsuccessful sampling to qualify it as Not Established. Also refers to an organism that has been collected at an abundance and frequency that is consistent with continuous reintroduction considering the vectors that are operating, and for which there either is some evidence of reproduction in the environment or there is insufficient evidence to determine that it is not reproducing in the environment.

Use a weight of the evidence approach to assess population status, and for each species classified, provide a description of the evidence considered (with citations) and a full and complete explanation of the assessment.

Other Data and Assessments

Several types of data are useful for assessing invasion status and population status, or for otherwise understanding the status of exotic species in the ecosystem. It is recommended that the following types of data and assessments be included in the database:

Collection Records in the Columbia River. Collections records within the Estuary, and in some cases records from upstream as well, are useful in assessing the population status and potential impact of exotic organisms, and the earliest records are sometimes useful for determining probable vectors. For each organism included, the database should include all early records in the Estuary and a summary of later records (if available) sufficient to indicate how its distribution and abundance changed over time; as well as upstream records where these are relevant. The records should include collection location, date, citation (including storage location and accession number or other identifying information for specimens) and any other relevant information associated with the record. The record listings at the beginning of the species accounts in Carlton (1979) provide an example of an appropriate format and level of detail.

Dates of Introduction: For non-intentional introductions, the earliest collection record is a starting point for estimating the date or period of introduction to the Columbia River and to the Estuary. If the earliest record is a publication or a preserved specimen that does not provide the date of collection, and the collector is known, information on when the collector was working in the River can help to estimate the date of collection. Information on earlier surveys or studies that did not collect the organism but that were of sufficient extent to probably collect it if it had been present, can help to narrow the period when the organism was likely introduced. These estimates, along with an estimate of the date or period of introduction to the Pacific Coast, should be included in the database, with an explanation of the basis for the estimates.

Global Distribution, Native and Source Regions: Several of the databases and studies list or analyze the distribution or native regions of exotic organisms by broad regional categories (such as the Northwest Atlantic, Asia, etc.). It is recommended that the database record an organism's global distribution with greater geographic specificity, at the country level or finer, and include citations for the records. The database should also include fields for the organism's native region, the immediate source region for the earliest introduction to the Pacific Coast, and the immediate source region for the earliest introduction to the Columbia River. If these regions can be determined they should be recorded with as much geographic specificity as possible, along with an explanation of the basis for the determinations. These geographically-specific records can always be classified into broader geographic categories for analysis.

Vectors: Different studies have assessed and recorded the vectors introducing exotic organisms with different systems of vector categories (Table 8). Table 9 provides a set of vector categories intended to cover both anthropogenic transport to the Pacific Coast and anthropogenic transport between sites along the Pacific Coast. Whatever system of vector categories is used to organize the information, the database should record as specific an assessment as possible of just how the organism was transported and released, along with an explanation of the basis for that assessment. In many cases, the available data will fit more than one vector category, and more than one vector may be listed as possibilities. In other cases, a species may have been introduced on more than one occasion by different vectors, so that one vector or set of possible vectors may be listed for the initial introduction, and a different vector or set of vectors for a later introduction. Finally, in rare cases an introduction may fit none of the vector categories, and be listed as unknown (for example, see the discussion of *Guilfordia yoka* in Carlton 1979, p. 353).

Table 8. Vector Categories Used in Different Studies	
Carlton 1979	I. Shipping A. Ship Fouling and Boring Communities B. Ship Ballast (1) Dry and Shingle Ballast (2) Water Ballast (3) Seawater Systems (including fire mains, pipes and condenser intakes) II. Commercial Oysters III. Other Mechanisms A. Algae Shipped with Lobsters and Bait Worms B. Water Associated with Fish and Lobster Introductions C. Lobster (*Homarus americanus*) Importations D. Oil Drilling Platforms E. Private Introductions
Cohen & Carlton 1995	• Solid Ballast (in solid ballast) • Ship Fouling (in ship fouling or boring) • Ballast Water (in ballast water or in a ship's seawater system) • Atlantic Oysters (in shipments of Atlantic oysters) • Japanese Oysters (in shipments of Japanese oysters) • Fish Stocking (fish or shellfish stocked by a government agency) • Marsh Restoration (planted for marsh restoration or erosion control) • Biological Control (released by government agency or with government approval) • Government/Accidental (accidental release with fish stocking or marsh restoration program) • Research Release (intentional or accidental release resulting from research activities) • Individual Release (intentional or accidental release by an individual) • Seaweed (in seaweed packing for live New England baitworms or lobsters) • Gradual Spread (from eastern North America) • Unknown
Cohen *et al.* 1998; Mills *et al.* 2000	• Atlantic Oysters (with shipments of Atlantic oysters) • Pacific Oysters (with shipments of Pacific oysters) • Ship Fouling (in ship fouling or boring) • Solid Ballast (in solid ballast) • Ballast Water (in ship ballast water or seawater system) • Marsh Restoration (planted for marsh restoration or erosion control) • Unknown
Cohen *et al.* 2001	• Ship Fouling (in ships' hull fouling or boring) • Solid Ballast (in solid ballast) • Ballast Water (in ships' ballast water or seawater system) • Packing Material (as packing material for shipped goods) • Atlantic Oysters (with shipments of Atlantic oysters) • Pacific Oysters (with shipments of Pacific oysters) • Plants (with shipments of aquatic plants)

Ruiz *et al.* 2001	• Shipping (in hull fouling, ballast water, dry ballast, in or on cargo, on deck, anchors, etc.) • Fisheries (both intentional and unintentional release; includes aquaculture; includes species associated with the target species) • Biocontrol • Ornamental Escape (includes species associated with the target species) • Agricultural Escape • Research Escape • Canals (created by humans, as a corridor for dispersal) • Multiple
Grigorovich *et al.* 2002	• Deliberate Releases (cultivation on fishery farms and stocking) • Accidental Releases (including from aquaria, escape from cultivation, and releases of nontarget species with aquaculture) • Shipping Activities (including solid and liquid ballast and hull fouling) • Hydrotechnical Development (river damming, construction of canals and reservoirs) • Multiple Vectors • Unknown/Uncertain
T N & Associates 2002	• Hull Fouling • Aquaculture • Ballast Water • Aquatic Plants • Seafood • Bait • Solid Ballast
Cohen *et al.* 2003	• Ship Fouling (in ships' hull fouling or boring) • Ballast Water (in ships' ballast water or seawater system) • Atlantic Oysters (with shipments of Atlantic oysters) • Japanese Oysters (with shipments of Japanese oysters) • Unknown
Ashe 2002	• Ballast Water • Ship/Hull Fouling • Aquaculture • Intentional Releases (by a government agency to enhance a fishery or for biocontrol) • Other (includes aquarium releases, fish market dumping, escape from cultivation, accidental introduction with ornamental plants or game fish, and solid ballast) • Unknown
Wonham & Carlton 2003	• Ballast Water (in ballast water, or in sediments in ballast tanks) • Dry Ballast (in solid ballast of rocks and sand) • Ship Fouling (attached to ships, or boring into wooden ships) • Commercial Oyster Industry > Atlantic Oyster Industry (with introductions of Atlantic oysters) > Pacific Oyster Industry (with introductions of Pacific oysters) • Commerce (accidentally release from transport of fisheries, soil, plants, etc.) • Intentional Plantings (for various purposes including marsh restoration, erosion control, cattle forage and gardens; excludes introductions in Commerce category) • Multiple (two or more of Ballast Water, Ship Fouling or Commercial Oyster Industry) • Unknown (pathway could not be assigned with confidence)

Table 9. Proposed Vector Categories

- Hull and Equipment Fouling (includes commercial, military, recreational and fishing vessels; semi-submersible drilling platforms; barges and other towed vessels; anchor fouling; fouling of nets and other fishing gear, dive gear, marine construction equipment, and so on; fouling of boat trailers; etc.)
- Solid Ballast
- Vessel Ballast Water (includes transport in water or sediments in ballast tanks or in sumps (sea chests), pumps or pipes associated with ballast water systems, in cargo ships or other vessels including semi-submersible drilling platforms, floating drydocks, etc.)
- Incidental Vessel Water (includes transport in other water systems, such as fire-fighting systems, bait wells, engine cooling water, bilge water, etc., on vessels traveling over water or transported overland)
- Marine Aquaculture and Fisheries Stock Enhancement (includes both intentionally and unintentionally transported species, and intentionally and unintentionally released species, through all phases including transport, holding, breeding, rearing and outplanting)
- Biocontrol Releases (includes both intentionally and unintentionally transported and released species, through all phases including transport, holding, breeding, rearing and outplanting)
- Escapes or Releases Associated with Research or Educational Activities (includes both intentionally and unintentionally transported and released species, including transport, holding, breeding and rearing activities and field work)
- Escapes or Releases of Ornamental Species (includes both intentionally and unintentionally transported species, including release from the commercial sector (including transport, holding, breeding, rearing and marketing facilities and activities), the exhibition sector (public or private commercial aquaria, ponds or other facilities holding and exhibiting ornamental species), and the private sector (escapes or releases from private aquaria or ponds))
- Bait Trade (includes fish, worms, clams, snails, squid, shrimp, crabs and other species transported and used or sold for bait, including any species unintentionally transported with them, including both intentionally and unintentionally released species, through all phases including transport, holding, breeding, rearing and use as bait or chum, in all sectors including both the commercial bait trade itself and the use of bait by commercial fishing and non-commercial fishing)
- Live Seafood Trade (includes both intentionally and unintentionally transported species, through all phases including transport, holding and marketing, including releases by or escapes from both the commercial sector and the purchaser)
- Transport with Other Cargo (includes escapes or releases of organisms unintentionally transported with types of cargo not covered above, including transport in the packing for such cargo)
- Unknown (does not fit any of the above vector categories)

Work to date in the Lower Columbia River Estuary

The Lower Columbia River Aquatic Nonindigenous Species Survey (LCRANS) reviewed the scientific literature on the Lower Columbia River and concluded that the biota was poorly studied (Draheim 2002). The most substantial biotic surveys were conducted by the Columbia River Estuary Data Development Program (CREDDP) in the early 1980s, by the Bi-State Water Quality Program (BSWQP) in the late 1980s, and by the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) in 2000-2002 (Table 10). LCRANS conducted its own survey, targeting exotic species, in 2002-2003 (Draheim 2002).

Table 10. Surveys of Biota in Salt or Brackish Waters of the Lower Columbia River

Sampling Period	Organisms Targeted	Sites	Collection Methods	Agency or Program (References)
1963-65	fish, benthic invertebrates, zooplankton	7 sites on the main stem up to Harrington Point, 32 km from mouth	trawls, plankton nets	(Haertel & Osterberg 1967)
1973	fish, benthic invertebrates, zooplankton			NMFS & USACE (McConnell *et al*. 1973; Durkin 1973; Durkin & McConnell 1973; McConnell *et al*. 1973; Misitano 1973; Sanborn 1973)
1973-75	fish, benthic infauna	42 sites in Youngs Bay and its freshwater tributaries		OSU (Higley & Holton 1975; CREDDP 1980a,b)
1975?-77?		Alder Creek in Youngs Bay		NMFS (Durkin *et al*. 1977)
1975?-77?		Alder Creek in Youngs Bay		(Montagne & Assoc. 1977, in CREDDP 1980a)
1975?-78?		lower estuary		OSU (Higley *et al*. 1976; Higley & Holton 1978; CREDDP 1980a)
1978-80?	tidal marsh plants	CREDDP estuary		CREDDP (MacDonald & Winfield 1984)
1978-80?	epibenthic organisms			CREDDP (Simenstad 1984)
1979-81	birds		line and point censuses	CREDDP (Hazel *et al*. 1984)
1980-81	zooplankton & larval fish			CREDDP, UW (Jones & Bottom 1984)
1980-81	fish	49 sites primarily in the main stem of the CREDDP estuary	bottom trawls, beach seines, purse seines	CREDDP, ODFW & NMFS (Bottom *et al*. 1984)
1980-81	benthic infauna	estuary, with focused studies in Baker Bay, Grays Bay and Desdemona Sands	benthic cores	CREDDP (Holton *et al*. 1984)
1980-81	macrobenthic invertebrates	11 sites along a tidal gradient in Baker Bay		(Furota & Emmett 1993)
early 1980s?	epibenthic invertebrates		beach seine, bottom trawl, epibenthic sled, suction pump	CREDDP (Simenstad 1984)
early 1980s	terrestrial and aquatic mammals		transect searches, traplines	CREDDP (Dunn *et al*. 1984)

early 1980s	marine mammals			CREDDP (Jeffries *et al*. 1984)
early 1980s	benthic invertebrates	Cathlamet Bay		NMFS & USFWS (Emmett *et al*. 1986; Durkin *et al*. 1982)
1990-92?	benthic invertebrates	54 sites up to Bonneville		BSWQP (Ellis & DeGasperi 1994)
1995	fish, benthic invertebrates	Trestle Bay		USACE (Hinton & Emmett 2000)
1999-2000		25 non-mainstem sites in 1999, 50 mainstem sites in 2000, up to Bonneville Dam		EMAP, WDE & ODEQ
2002	aquatic macrophytes and macroinvertebrate s	63 sites total in 2002	epibenthic sled, zooplankton tows, scrapers, grab samplers	LCRANS (Draheim *et al*. 2003)

LCRANS' literature and field surveys should provide a good start on an exotic species database for the Lower Columbia River Estuary, and some additional information may be available from a database that has been developed on exotic marine and brackish species between Cape Mendocino and the Queen Charlotte Islands (M. Wonham & J.T. Carlton, unpublished data). Appendix B provides a preliminary listing of exotic and cryptogenic species reported from the Lower Columbia River Estuary, drawing on LCRANS' reports and a few other sources.

Taxonomic Support

> *"The nonindigenous status of a species occurring in an area, such as the Columbia River or the northeast Pacific, may not be apparent until the organism is discovered, described, and published as indigenous in other regions, or until the synonymies of the local species with populations in other parts of the world are resolved (a time consuming undertaking that is outside the scope of most parochial biological surveys)."* — Draheim *et al*. (2003)

> *"The quality of data that result from surveys depends greatly upon taxonomic identification and knowledge. Taxonomic expertise is clearly critical to the correct identification of species, as many organisms may go undetected by the untrained observer. Such under-detection can occur even for those with good working knowledge of a local biota who may be unaware of species from other regions that are similar in appearance."* — Ruiz & Hewitt (2002)

One obstacle to the early detection of new introductions—especially among small or taxonomically obscure organisms, which includes many types of invertebrates, protozoans, microalgae and macroalgae—is the difficulty of recognizing when a specimen may represent a new organism for the Estuary. Exotic marine and estuarine organisms collected on the Pacific Coast have often been initially misidentified as native Pacific Coast species (see, for example, "Examples of introduced species initially reported as native taxa," Table 2 in Carlton 1979). This error commonly arises from using regional taxonomic keys without making use of supplemental information. The frequency of failures to recognize novel species in sampled material and to take the steps needed to correctly identify them can be reduced by providing:

- Appropriate informational tools to aid in recognizing when a specimen should be considered a "suspect exotic."
- An efficient process for identifying these suspects.

Taxonomic Information Tools

Regional keys, when properly designed, are based on a selected set of morphological characteristics that are sufficient to distinguish among the organisms known from the region in question. However, such keys may be of little help in distinguishing, and typically are of no help in identifying, organisms that have not been previously recognized in the region and are therefore not covered by the key. Thus, a specimen of a novel exotic organism may key out in a completely proper and satisfactory manner in such a key, to be identified confidently and incorrectly as a particular native species, simply because characteristics that could have distinguished it were not included in the key—since they were not necessary or useful for distinguishing among the organisms known from the region that the key was intended to cover.

Nevertheless, taxonomists who have done substantial work in the Estuary will generally recognize when something new comes before them, at least in the taxonomic groups that they are most familiar with. However, because there are many highly-diverse and speciose invertebrate groups and few invertebrate taxonomists, taxonomists sometimes end up working on groups of organisms that they don't know all that well, and taxonomists may also be employed who lack substantial prior experience with the Estuary's biota. In either of these cases the taxonomist may not recognize when a specimen represents a new organism in the ecosystem, if no obvious difficulty arises in keying it out. Certain types of informational tools could be developed that would substitute, to some extent, for the expert knowledge that comes from long familiarity with a regional biota, or that would supplement that knowledge.

One noteworthy attempt to deal with this problem within the context of an invertebrate key for a Pacific Coast estuary is a book on a family of polychaete worms, the Spionidae (Light 1978), which was published by the California Academy of Science as the first volume in an ambitious but never-completed series on the invertebrates of San Francisco Bay.[1] These volumes were to consist of detailed, annotated keys plus supplemental information and references, each volume to cover "a group of convenient size, ranging from family to phylum," with the series ultimately covering all of the invertebrates recorded in San Francisco Bay.

The Spionidae volume included keys in three different formats (pictorial dichotomous keys, verbal dichotomous keys, and tabular keys) at both the genus and species level, which covered all genera recorded from California; descriptions of every species recorded from the Bay along with the synonymy for each species; world distribution records; comments on and figures of morphological variations; notes on ecology; notes on preparation, dissection and handling of

1 A volume on the Acmaeidae, a family of gastropod mollusks, was the only other volume published in the series.

specimens; and a complete, illustrated glossary of terms. It described the taxonomic problem relative to the potential occurrence of exotic species, and the approach it took to address this problem, as follows:

> "All species known to occur in San Francisco Bay are included in these keys. In addition, those species not yet recorded from the Bay, but which are likely to occur there and which might be confused with species already known from the Bay, are likewise included...In the event that a species is encountered which almost, but not quite, fits one of those presented in the keys, the user should turn to the remarks section under the account for that species in the systematic section. There he will find detailed comments on every known species in the world which could possibly be confused with the taxon in question...In most cases, these remarks will, in fact, treat every single described species within that genus. In the case of extremely large groups,...species-groups and complexes have been delineated. When a member of such a species complex occurs in San Francisco Bay, it is distinguished from all other known species of that complex...These keys and descriptions have been compiled with the concept of the world fauna constantly in mind" (Light 1978, p. 1-4).

The volume notes that the inclusion of such detailed differential diagnoses "is necessary because many species from various parts of the world have already been introduced into San Francisco Bay, and the likelihood is high that more such exotic species will be discovered" (Light 1978), a statement that we can now make about many of the bays and estuaries on the Pacific Coast. The contents and organization of this volume provide a good example of the type of information which, if it were made readily available to taxonomists working in the Lower Columbia River Estuary for all obscure or difficult taxonomic groups, would significantly facilitate the recognition of suspect exotics and at least the initial steps in their identification.

Unfortunately, completing and updating a full set of such taxonomic references covering the organisms of the Pacific Coast would be a daunting task and is probably too much to be hoped for. A more manageable and still very useful set of informational tools would include the following:

<u>A comprehensive list of the organisms that have been collected from the Lower Columbia River Estuary</u>. If such a list were available, taxonomists could check identifications determined from regional keys or other sources against the list. If the species as determined from the key was not on the list of species previously recorded from the Estuary, this would warn the taxonomist that the identification might not be correct, and that additional information should be sought to check the identification. This list should be made available on the internet and regularly updated.

<u>Ready access to supplemental information on organisms known from the Estuary</u>. Useful supplemental information could include: formal taxonomic descriptions, scientific illustrations, photographic images, information on known geographic and habitat ranges, information on morphological variations, information on other species that the organism in question may be confused with, notes on ecology, references to additional literature, information on dates and sites of collection, species synonymies and taxonomic bibliographies, and data on the existence

and location of preserved specimens (including type specimens). With such information at hand a taxonomist often can quickly determine whether an identification made from a key makes sense, and where to look for help if further work is needed. Much of this information exists, but finding it can be difficult and time-consuming.

This information could be made available over the internet or compiled in a central archive that was organized to provide support (via telephone or email) to the region's taxonomists. A good deal of this sort of information has already been collected at various institutions. Every taxonomic laboratory compiles at least some of the most commonly used information. It would be a boon to both the recognition of suspect introductions and to other taxonomic work in the Estuary if a taxonomist confronted by a difficult specimen could quickly access such information electronically, or could contact a central archive and have the necessary illustration or species description sent back.

Ready access to up-to-date information on exotic organisms on the Pacific Coast, including newly-discovered exotics and suspected exotics. The exotic organisms that are most likely to show up in the Lower Columbia River Estuary are probably those that are already present in other estuaries on the Pacific Coast. Rapid identification of the organism would be aided by ready access (via the internet, or a central archive) to up-to-date information on which exotic species are known or suspected to be established on the Pacific Coast, basic information on identification, and supplemental information as described above. Some information of this type is already available or is being developed (Table 11), but there remain gaps in what's available and a need for regular updating of some of these resources; and it would help if all this information was accessible through one internet platform.

Accessible archives of preserved specimens. There are collections of marine and estuarine organisms at several institutions on the Pacific Coast. However, three specific types of collections would be especially useful if they were housed at an institution that is readily accessible to researchers working in the Estuary:

- Representative specimens of exotic species established on the Pacific Coast. (If feasible, this collection should include representatives of all bay and estuarine species on the Pacific Coast, including exotic, cryptogenic and native.)
- Representative specimens of exotic organisms in other temperate, estuarine waters of the world that have not yet shown up on the Pacific Coast.
- Representative specimens of estuarine organisms from regions that are thought to be common, current donors of exotic species to the Pacific Coast (such as Japan, Korea and China).

In addition, information on what specimens of these types are currently available in collections on the Pacific Coast should be compiled and made available on the internet.

Ready access to taxonomic keys. Despite the limitations of regional keys as noted above, taxonomic keys are nonetheless a fundamental tool for identifying specimens and assessing whether they should be further examined as possible exotics. The Pacific Coast is fortunate to

Table 11. Some Sources of Information on Exotic Marine and Estuarine Species on the Pacific Coast

Area Covered	Type of Information	Source, Format and Availability
Available		
Pacific Coast	collection records, geographic & habitat ranges, ecology notes, references	Carlton (1979). In hard copy from University Microfilms at http://www.umi.com/hp/Products/Dissertations.html.
Pacific Coast	notice of new exotics	PNW-ANS-L discussion list. Subscribe at listserv@freya.cc.pdx.edu.
California, Oregon and Washington	geographic & habitat ranges, extensive taxonomic references and partial synonymy; mention of unresolved taxonomic issues	Database compiled for the EPA by T N & Associates, J.W. Chapman, L.H. Harris and others on exotic species collected by WEMAP.
San Francisco Estuary	summary of collection records, geographic & habitat ranges, ecology notes, references	Cohen & Carlton (1995). In hard copy or download from links at http://www.sfei.org/bioinvasions/index.html.
Southern California	notice of new or suspect exotics; identification information, sometimes with illustrations	SCAMIT (Southern California Association of Marine Invertebrate Taxonomists) Newsletter. Subscribe or download issues since 1998 at http://www.scamit.org.
In Development		
Cape Mendocino to Queen Charlotte Islands	summary of collection records, geographic & habitat ranges, ecology notes, references	M.J. Wonham & J.T. Carlton, unpublished data.
Central California	invertebrate keys to include many exotics on the Pacific Coast	New edition of Light's Manual (J.T. Carlton, ed.). In hard copy from University of California Press (but individual keys might be available electronically?).
San Francisco Bay	identification information, photographs, geographic & habitat ranges, ecology notes, references	*Internet Field Guide to Exotic Species*, a San Francisco Estuary Institute project funded by NOAA and the San Francisco Estuary Project. Initially to cover San Francisco Bay, but expect to eventually cover all Pacific Coast species.
Southern California	summary of collection records, geographic & habitat ranges, ecology notes, references	A.N. Cohen, unpublished data. Lambert & Lambert (1998, 2003) contain information on exotic tunicates.

have two published compilations of keys to the major groups of marine invertebrates, *Light's Manual: Intertidal Invertebrates of the Central California Coast* (Smith & Carlton 1975)[2], and *Marine Invertebrates of the Pacific Northwest* (Kozloff 1987), and the marine algae (Abbot & Hollenberg 1976). However, many other keys to various groups of organisms in this and other regions of the world are scattered through the scientific literature (in older or obscure and hard to obtain journals), in gray literature or as unpublished keys developed by individual taxonomists.

2 An updated and revised edition of *Light's Manual* will include many exotic species that were not in the earlier editions.

If possible, these keys should be assembled and made available over the internet, either by downloadable pdf or in a web-interactive format. In addition, some keys are already available on the internet, and links to these could be provided on a central taxonomic website.

Identification of Suspect Specimens

Even with these information tools available, in many cases it may not be possible for a local taxonomist to identify a specimen that is a suspected exotic. This requires a different set of informational tools and a different type of effort from that which is needed to identify organisms belonging to the known biota of a region. Identifying a new arrival may require global knowledge of the various species in the particular taxonomic group that the organism belongs to, as well as access to the world literature on that group. It may be necessary to obtain specimens for comparison from other parts of the world, or to send specimens off to specialists in that group. Some organizations, including the Western Regional Panel, have developed lists of taxonomists that specialize in various groups.

This level of effort goes beyond what is normally done as part of a sampling or monitoring program. To encourage that this be done more often, it would help if taxonomists working in the Estuary had the option of sending specimens that they suspect are exotic species to an "Exotic Species Taxonomic Coordinator" — an individual who would be responsible for assessing the material, making the identification if possible, and arranging for appropriate specialists to examine the material if necessary. Ideally, a position of that sort would serve a broad region of the Pacific Coast; and while it would be an advantage, other things being equal, to have that individual located near the Columbia River Estuary, there is probably greater benefit in having the position based at a museum like the California Academy of Science or the Natural History Museum of Los Angeles County, in order to take advantage of the specimen collections, global taxonomic literature and range of taxonomic expertise that those institutions offer. The position could be supported by funding from the national Aquatic Nuisance Species Task Force, through the Western Regional Panel, or supported by Pacific Coast state governments.

Sampling

The types of taxonomic support described above would be useful both to increase the recognition, identification and reporting of exotic species by existing monitoring and research programs, and to support additional sampling specifically designed to detect exotic organisms. To maximize the potential for detecting additional exotic species, this additional sampling should focus on either addressing gaps in habitats and taxonomic groups not sampled by existing programs, or target habits or taxonomic groups that are likely to contain unrecognized or recently-arrived exotic species.

General Considerations Regarding Target Taxonomic Groups

Various approaches, or combinations of approaches, may be taken to allocate the exotic species sampling effort among different taxonomic groups. In Table 4, a number of taxonomic groups are scored relative to the following seven approaches for selecting taxonomic groups to sample.

Approach 1: Focus on taxonomic groups that received little attention in previous studies in the study area. This approach would try to "fill in the gaps" left by previous studies. LCRANS' field surveys were intended to focus primarily on taxa that were poorly represented in the scientific literature and not well-studied by previous investigators, and therefore did not actively sample fish (Draheim 2002, p. 7). Within the salt and brackish tidal waters of the Estuary, studies to date have primarily addressed tidal marsh plants, zooplankton, some benthic invertebrate groups, fish and mammals (Table 10, above). The gaps left are substantial, including several large groups of small organisms, many of which are also poorly known taxonomically (including viruses, bacteria, fungi, protozoans and phytoplankton; and flatworms, nematodes, oligochaetes, halacarid mites, kamptozoans and other small invertebrates), as well as some groups of larger invertebrates that are poorly known taxonomically (such as sponges).

Approach 2: Focus on taxonomic groups that seem likely to be introduced into the study area. The many transport mechanisms in operation provide opportunities for representatives of most types of estuarine organisms other than vertebrate animals and vascular plants to be inadvertently moved about the world. For example, most phytoplankton and a few types of invertebrates are planktonic during their entire life cycle; most of the higher taxonomic groups of invertebrates found in estuaries contain many species that are small and planktonic during part of their life cycle; and many types of small benthic organisms in shallow water including benthic microalgae and other microbes may be carried up into the water column by currents, waves or disturbance by passing ships. All of these are thus susceptible to uptake and transport via ships' ballast water to new regions of the world. Once established at one site on a coast, a variety of coastal vectors and natural dispersal by advection in alongshore currents, by rafting or by swimming may distribute these organisms to additional bays and estuaries. Many of the higher taxonomic groups of invertebrates and algae also contain species that are capable of being transported as hull fouling.

In terms of the numbers of established exotic species in various higher taxonomic groups, among organisms other than vertebrate animals and vascular plants these numbers are mostly reflective of how well-known these groups are (few exotics reported in taxonomically difficult and poorly studied groups) and how speciose they are in general (more exotics reported in species rich taxa). For example, the number of exotic species in well-known invertebrate taxa in the San Francisco Estuary generally parallels the estimated number of species in those taxa in the world (Table 12). Notably under-represented taxa are nearly all small, taxonomically difficult or both (*e.g.* nematodes, flatworms, rotifers (which also have few marine species) and sponges). The one exception is echinoderms, a taxonomically well-known and extensively studied group which is nonetheless poorly represented among the exotic species in San Francisco Bay and elsewhere in the world (although one echinoderm introduced to southern Australia, the Japanese seastar *Asterias amurensis*, is considered a high impact species there because of its impact on estuarine clams). This may be because echinoderms generally do poorly in estuarine salinities.

Table 12. Taxonomic Distribution of Exotic Species

Phylum	Estimated number of species in the world (Kozloff 1990)	Exotic species in the San Francisco Estuary (Cohen & Carlton 1995)
Arthropoda	1,000,000	53
Mollusca	> 100,000	30
Nematoda	> 12,000	
Platyhelminthes	11,000	
Annelida	10,000	21
Cnidaria	10,000	17
Echinodermata	6,000	
Porifera	> 5,000	5
Bryozoa	4,000	11
Rotifera	2,000	
Urochordata	1,500	8
Nemertea	800	
Acanthocephala	> 600	
Gastrotricha	500	
Sipuncula	300	
Brachipoda	< 300	
Nematomorpha	250	
Gnathostomulida	100	
Kinorhyncha	100	
Echiura	100	
Entoprocta	< 100	2
Ctenophora	80	
Dicyemida	75	
Chaetognatha	70	
Orthonectida	> 20	
Phoronida	20	
Priapula	15	
Placozoa	1	

Thus, among organisms other than vertebrate animals and vascular plants, there would seem to be little basis for selecting among them on the basis of their likelihood of being introduced and becoming established in the Estuary, except possibly to put less emphasis on sampling echinoderms.

Vascular plants could theoretically be transported across oceans as floating seeds in ballast water, but there doesn't seem to be any evidence that this has occurred. The exotic vascular plants that typically grow in brackish or salt water on the Pacific Coast appear to all have been introduced either through intentional plantings or by vectors that are no longer operating (in solid ballast, or as packing for ships' cargo) or are no longer likely to be effective as transport mechanisms (as seeds or root fragments inadvertently included in oyster shipments, which, given the much reduced volume and frequency of such shipments from the Atlantic or Western Pacific oceans, and the greater care given to transport these oysters free of other organisms, is less likely to occur than in years past) (Cohen & Carlton 1995). Thus, the search effort for exotic vascular plants in the Estuary would most efficiently be focused on looking for the few exotic plants known to occur in other bays and estuaries on the Pacific Coast (primarily cordgrasses, *Spartina* spp.), than on general sampling of estuarine plants.

Among vertebrates, there don't appear to be any vectors likely to unintentionally introduce exotic marine mammals, marine reptiles or seabirds to the Pacific Coast. Among fish, ballast water is the only likely vector for unintentionally introducing temperate estuarine species to the Pacific Coast, and the types of fish whose introductions are most commonly attributed to ballast water are gobies and blennies (71% of established exotic fish attributed to transport in ballast water; Wonham *et al*. 2000), and four species of Asian gobies have become established in other bays and estuaries on the Pacific Coast. So in sampling for exotic fish, it would make sense to emphasize methods and habitats that are likely to produce catches of gobies or blennies.

Approach 3: Focus on taxonomic groups which are likely to have a substantial impact in the study area. While some individual species are generally recognized as having a large impact in some areas where they have been introduced (though often not in all areas where they are known to have been introduced), there does not appear to be any good basis for concluding that certain higher taxonomic groups are more likely to produce significant impacts than others. Examples of exotic estuarine or marine species that have caused substantial harm to the environment, to economic activities, or to public health can be found among the viruses, bacteria, dinoflagellates, macroalgae, vascular plants, cnidarians, ctenophores, annelids, mollusks, crustaceans, echinoderms, tunicates and fish, and several other major groups clearly have the potential to cause harm. In those higher taxonomic groups where there are few or no records of significant impacts from exotic species within the group, there is generally little known about the exotic species in the group.

Approach 4: Focus on taxonomic groups for which there is a good base of information on exotics. This is essentially those groups that are well-represented as exotics in studies elsewhere. The advantage of this approach is that it is more likely that any exotic or cryptogenic organisms that are collected in these groups will be identified, because they are likely to have turned up elsewhere. This approach takes advantage of the global base of knowledge on exotics.

Approach 5: Focus on taxonomic groups which may contain a significant number of exotics, but which we know little about . This is the opposite of Approach 4. As discussed above, in a few groups—such as vertebrates other than fish, and echinoderms—the limited information on exotics is probably due to there really being few exotics in these groups, rather than to poor knowledge of the groups. In others there may be many exotic species, though it will be difficult to recognize them as such because of the poor knowledge base. The advantage of this approach is that any knowledge of exotics gained by focusing on these groups is likely to be a noteworthy contribution to the global knowledge base.

Approach 6: Focus on taxonomic groups for which sufficient taxonomic resources are readily available to identify the sampled organisms. This is similar to Approach 4, and substantiallyoverlaps with it. Taxonomic groups with good taxonomic resources are likely to be well-studied for exotics.

Approach 7: Focus on taxonomic groups that are not periodically sampled or observed by other formal or informal efforts that are likely to recognize new exotic species. If an exotic bird, marine mammal or marine reptile were to become established in the Estuary, it would likely be recognized as something new, and then identified, without any need for an exotic-species focused sampling program. The same is probably true for many (though perhaps not all) groups of fish. There are also periodic surveys for exotic cordgrasses (*Spartina* spp.).

Although a case could be made for any of these approaches, Approach 3 (focusing on high-impact taxonomic groups) doesn't appear likely to offer much help in narrowing the range of groups to be studied, as discussed above. Approach 2 (focusing on taxonomic groups likely to be introduced) and Approach 7 (focusing on taxonomic groups where existing efforts are not likely to detect any exotic species that show up) seem like more useful places to start. These would eliminate marine mammals, birds, marine reptiles, fish other than gobies and blennies, echinoderms, and vascular plants. The remaining approaches, for different reasons, lean toward focusing generally on groups that either are well-known (Approaches 4 and 6), or are poorly known (Approaches 1 and 5). Each has some merit, suggesting that core efforts should focus on the groups that are better known taxonomically, but that the poorly known groups should be looked at when expertise is available. Thus, considering these various approaches, it is recommended that the ESDP's additional sampling efforts should focus on seaweeds, marine invertebrates (other than echinoderms), marsh insects and spiders, and gobies and blennies. In addition, if appropriate expertise can be assembled to identify organisms to species level, studies should be initiated on the protozoans, phytoplankton, fungi, bacteria and viruses in the Estuary, and the data analyzed for the occurrence of exotic species.

Table 13. Selection of Taxonomic Groups for Sampling Based on Different Approaches

	Approach (see text)						
Representative Groups[1]	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Viruses	+	+	?		+		+
Bacteria	+	+	?		+		+
Fungi	+	?	?		+		+
Protozoans	+	+	?		+		+
Phytoplankton	+	+	?		+		+
Macroalgae	?	+	?	+		+	+
Vascular Plants[2]		+[3]	?	+		+	
Invertebrates: Sponges	+	+	?		+		+
Invertebrates: Cnidarians: Hydrozoa	?	+	?		+		+
Invertebrates: Cnidarians: Anthozoa	?	+	?	+		+	+
Invertebrates: Ctenophores	+		?			+	+
Invertebrates: Flatworms	+	+	?		+		+
Invertebrates: Nematode Worms	+	+	?		+		+
Invertebrates: Nemertea	?	+	?		+	+	+
Invertebrates: Annelids: Polychaetes		+	?	+		+	+
Invertebrates: Annelids: Oligochaetes	+	+	?		+		+
Invertebrates: Mollusks		+	?	+		+	+
Invertebrates: Arthropods: Insects & Spiders[4]	?	+	?		+	+	+
Invertebrates: Arthropods: Halacarid mites	+	+	?		+		+
Invertebrates: Arthropods: Barnacles		+	?	+		+	+
Invertebrates: Arthropods: Ostracodes	+	+	?		+		+
Invertebrates: Arthropods: Copepods		+	?	+		+	+
Invertebrates: Arthropods: Isopods		+	?	+		+	+
Invertebrates: Arthropods: Amphipods		+	?	+		+	+
Invertebrates: Arthropods: Decapods		+	?	+		+	+
Invertebrates: Kamptozoans	+	+	?		+	+	+
Invertebrates: Bryozoans	?	+	?	+		+	+
Invertebrates: Echinoderms	?		?		+	+	+
Invertebrates: Tunicates	?	+	?	+		+	+
Vertebrates: Fish		+[5]	?	+		+	?
Vertebrates: Marine Reptiles			?			+	
Vertebrates: Birds			?			+	
Vertebrates: Marine Mammals			?			+	

1	Not all taxonomic groups that may be found in the Estuary are included in this list. The assessments are made relative to those species in these groups that are found in temperate zone estuaries in salt or brackish water within the reach of the tides.
2	Tidal marsh plants and eelgrass.
3	Species of exotic cordgrasses present elsewhere on the Pacific Coast.
4	Primarily in tidal marshes.
5	Gobies and blennies, including four exotic species present elsewhere on the Pacific Coast.

General Considerations Regarding Target Habitats and Communities

LCRANS' 2002 field survey was intended in part to focus on habitats in the Estuary that were poorly represented in the scientific literature, and was designed to "maximize spatial, temporal, taxonomic, and habitat coverage, while focusing our resources on areas thought to be at high risk of invasion as well as locations...with little or no available information" (Draheim 2002, pp. 7, 25). LCRANS also listed seven specific selection criteria (Table 14). The first six of these are relevant to the design of an ESDP, with the first four dealing with sampling where exotic species are likely to be found, the fifth addressing poorly sampled sites, and the sixth focusing on poorly studied taxa, the subject of Approach 1 in the previous section. Later, however, LCRANS reported that the "criteria for sampling sites...were that they were studied previously or were easily accessible or contained broad ranges of habitat types" (Draheim *et al*. 2003, p. 3), which is a somewhat different emphasis.

Table 14. LCRANS Site Selection Criteria for 2002 Field Survey (Draheim 2002, p. 25)
Areas likely to be associated with ballast water discharge.
Ports and sites of sustained disturbance by human activities.
Habitats with previously reported ANS and cryptogenic species.
Marinas, floats, buoys and pilings and accessible fouling communities.
Poorly studied locations.
Locations reported or believed to support poorly studied taxa.
Locations with historical data allowing for the calculation of invasion rates and the establishment of long-term monitoring stations.

For an ESDP, the two main considerations in allocating sampling effort among different environments are (1) sampling in areas or habitats which previous or ongoing studies have not sampled or have sampled poorly, and (2) sampling where exotic species are likely to be found.

1. Areas, habitats and communities not well-sampled by other studies. In general these are likely to be sites that are not easily sampled by boats deploying common types of nets, dredges or bottom samplers, and specialized types of habitat that cover relatively little area. Some typical examples include artificial hard substrates including floating docks, seawalls, and pilings;

artificial lagoons and lagoons with restricted circulation; epibenthic organisms in tidal marshes and very shallow water; crevice and burrow-dwelling fish; and pockets of low salinity water around points of freshwater discharge in primarily marine-influenced bays.

2. Areas and habitats where exotic organisms are likely to be found. These might include the following:

2A. Areas where exotic species are likely to be released. Examples include locations in or near commercial or military ports, small boat marinas and aquaculture sites. It has been suggested, for example, that in the Pacific Northwest exotic copepods, which were probably introduced in ships' ballast water, were found in greater abundance and earlier in their expansion near commercial ports (J. Cordell, pers. comm.), and many other exotic species thought to be introduced to the Pacific Coast in ships' ballast were first collected in bays with major commercial ports (Cohen & Carlton 1995). On the other hand, a recent study in southern California did not find more exotic species in port areas than in non-port areas (Cohen *et al.* 2003). Examples for other vectors include organisms believed to be introduced via aquaculture initially collected in or near beds of imported oysters (*e.g.* Perez *et al.* 1981; Cohen & Carlton 1995), adjacent to sites of seaweed cultivation (Floc'h *et al.* 1991), or adjacent to an abalone farm outfall (Culver & Kuris 2000); a snail believed to be introduced in baitworm packing initially found adjacent to boat ramps and popular fishing sites (Carlton & Cohen 1998); and a seaweed thought to be distributed as hull fouling initially found near commercial ports or in marinas (Fletcher & Manfredi 1995; Silva *et al.* 2002).

2B. Disturbed habitats. Many authors have suggested or concluded that exotic species are more likely to become established in disturbed than in undisturbed habitats (*e.g.* Elton 1958; Mooney & Drake 1989; Hobbs & Huenneke 1992), especially for exotic plants (Luzon & MacIsaac 1997). Although some have questioned whether there is evidence to support this hypothesis (*e.g.* Cohen 2002), exotic organisms may nevertheless be notably abundant in disturbed areas due to an association of transport vectors with disturbance, a greater ability to proliferate in disturbed areas following initial establishment, or other reasons. Disturbance is also defined differently by different investigators, and may refer to either natural or artificial disturbance (Hobbs & Huenneke 1992). Thus naturally disturbed areas in an estuary might include areas with a lot of wave action and frequent resuspension of sediments; areas with substantial daily, seasonal or year-to-year changes in salinity; and areas with a lot of bioturbation. Artificially disturbed areas in an estuary might include areas near sewage outfalls or other pollution sources; dredged areas; areas where dredge spoils are dumped; areas where freshwater inflows or tidal circulation have been changed; areas where sedimentation rates have been increased or decreased due to land-use changes; areas where there is a lot of ship or boat traffic; and areas where many exotic species have become established. Depending on the definition used, many entire estuaries could be considered to be disturbed environments. Thus, the concept of disturbance *per se* may not be particularly useful in selecting sampling sites.

2C. Artificial substrates. Wooden structures including pilings, bridge supports and vessel hulls frequently yield a number of exotic wood-burrowing organisms including molluscs (shipworms) and crustaceans (various isopods and an amphipod). Exotic and cryptogenic species are often common among the organisms fouling artificial floating objects and structures including vessel hulls, buoys and floating docks; on ropes, cables or chains suspended from docks or buoys; and on fixed artificial structures including pilings, seawalls, bridge supports, marker poles, etc.

2D. Areas of low salinity. Areas with salinities that are typically below about 15-20 ppt are uncommon in Pacific Coast estuaries, and often have few resident native biota. Biota adapted to these salinities have evolved in a few parts of the world and are capable of becoming established in such areas on the Pacific Coast. Examples include several hydozoans from the Black Sea and copepods from the margins of the Sea of Japan that have become established in low salinity areas of San Francisco Bay (Cohen & Carlton 1995). Although the number of exotic species may be small, the exotic biota is usually distinct from that found in higher salinity parts of the estuary (*e.g*. see Willapa Bay data in Cohen *et al*. 2001).

2E. Semi-enclosed waters. Cohen *et al*. (1995) noted that several exotic species found in San Francisco Bay were initially collected in semi-enclosed lagoon-type habitats that are hydrologically connected to the bay through pumps, culverts or long, narrow channels. They suggested that these lagoons may act as "invasion incubators," in part because of their ability to retain planktonic larvae in small areas and thereby increase the chance that these organisms will be able to find mates when they mature even though their populations are initially small.

Sampling Recommendations for the Lower Columbia River Estuary

Four general types of sampling are discussed here as components of exotic species detection: making use of existing sampling efforts; establishing new sampling programs; targeted sampling to take advantage of ongoing taxonomic studies; and using volunteer monitoring or sampling.

Existing sampling efforts. Although there don't appear to be a any long-term monitoring programs in place to sample the biota of the Lower Columbia River Estuary (LCREP 1998; R. Draheim, pers. comm.), various agencies have sampled different areas, habitats and taxonomic components of the biota at irregular intervals in the past (Table 10), and will presumably continue to do so in the future. In addition there will likely be occasional sampling conducted by academic institutions for the purposes of focused research or education. Producing and specifically making available to these efforts the types of taxonomic support described earlier (information tools and program for identifying suspect exotics) will in itself encourage the detection of novel exotic organisms in the ecosystem. In addition, some types of sampling efforts that target particular species or groups of organisms may incidentally collect other types of organisms without retaining them for identification. These could be examined for possible exotic organisms, avoiding duplication of the sampling effort.

New sampling programs. New sampling programs should be designed as discussed in the previous sections: to focus primarily on areas and habitats which are otherwise poorly sampled and where exotic species are likely to be found; and to focus on particular taxonomic groups, especially those that are likely to be introduced into the Estuary and that have received less attention in terms of sampling and taxonomic work. Although some workers have argued for standardized, quantitative, spatially-organized sampling methods for general exotic species surveys (*e.g*. Ruiz & Hewitt 2002), this approach is likely to detect fewer novel exotic organisms compared to non-quantitative sampling that tries to maximize the diversity of organisms collected by sampling the full range of biotic assemblages represented by the available substrates and microhabitats (*i.e.* "directed search" techniques), or even compared to randomized sampling of individual organisms (*e.g.* see Gotelli & Colwell (2001) regarding sample-based versus individual-based assessments).

Elements of these new sampling programs should include sampling of artificial hard substrates (floating docks, pilings, bridge supports, buoys, seawalls, etc.), sampling of artificial lagoons and other semi-enclosed water bodies with restricted circulation, and sampling of areas near ports, marinas and aquaculture sites. These types of sites should be sampled wherever they occur across the range of estuarine salinities. Sampling and taxonomic work should primarily focus on seaweeds, marine invertebrates, and marsh insects and spiders. However, if the expertise is available, sampling and identification of phytoplankton, protozoans, fungi, bacteria or viruses, combined with an assessment of the invasion status of these biota, would be a valuable addition to the knowledge base.

If sufficiently funding is available, sampling in each habitat type should be done least annually and possibly in more than one season, with the sampling and much of the core taxonomic work performed by permanent staff, and with other work contracted to specialists as needed. If funding is more limited, a Rapid Assessment Survey employing a team of specialists, as has been done for other estuarine and marine systems (*e.g.* Cohen *et al.* 1998, 2001, 2003; Mills *et al.* 2000), could be conducted in the Estuary less frequently (but at least every five years), supplemented by other types of sampling in off years (benthic grabs, plankton tows, traps, fouling panels, etc.). The sampling program could also include activities that focused on individual species or key groups of related species that are either thought to be especially likely to arrive or are of particular concern, such as visual surveys for exotic cordgrasses (aerial, and by boat or on foot depending on the terrain), trapping for gobies and blennies, trapping for green crabs, and visual surveys (by boat or on foot) for mitten crab burrows.

<u>Targeted sampling for taxonomic studies</u>. Taxonomists will periodically perform morphologic or molecular genetic analyses on a relatively small group of related species (*e.g.* a genus or perhaps a small family), and at that time are often willing to receive and identify specimens within the group from any part of the world. For example, the SCAMIT website currently contains an offer from a biologist to include any pycnogonids (sea spiders) in a molecular, phylogenetic analysis that he is conducting (Appendix C). Pycnogonids are small, cryptic arthropods that live in situations suggesting that they could be transported in hull fouling or oyster shipments, with a couple of exotic or cryptogenic species reported from the Pacific Coast, and molecular genetic analysis of Pacific Coast estuarine pycnogonids could help to clarify the invasion status and native regions of these organisms. The ESDP should collect and send representative specimens from the Estuary whenever such opportunities arise.

<u>Volunteer monitoring or sampling</u>. A public monitoring program may be useful in checking for the arrival and following the subsequent spread of conspicuous and easily identified organisms. Aquaculturists, commercial and recreational harvesters of fish and shellfish, baitshop staff, environmental education programs, and others may be enlisted as additional eyes on the Estuary—to look for, collect or report on unfamiliar organisms or on known, expected invaders

that they encounter in the course of their activities. In San Francisco Bay, several novel exotic organisms were initially collected and brought to the attention of researchers by such individuals: the European green crab *Carcinus maenas* by a baitfish trapper (Cohen *et al*. 1995); the Black Sea jellyfish *Maeotias inexspectata* by a school teacher (Mills & Sommer 1995); the New Zealand seaslug *Philine auriformis* by an environmental education program (Gosliner 1995); the Chinese mitten crab *Eriocheir sinensis* by a commercial shrimp harvester and an environmental education program (Cohen & Carlton 1997); and the Asian clam *Potamocorbula amurensis* by a junior college biology class (Carlton *et al*. 1990). In the 1990s, informal networks using shrimpers, bait trappers and anglers provided information on the spread of green crabs and mitten crabs in San Francisco Bay (Cohen *et al*. 1995; Cohen & Carlton 1997). Informational posters with illustrations of the target organism(s) and a contact number, and internet resources for identifying exotic organisms are often part of such efforts, which additionally help to educate the public about exotic organisms.

In some cases it may also be possible to conduct sampling using volunteers. However, sampling efforts by volunteers are likely to be constrained in some ways that sampling by paid staff is not, *i.e*. constrained by the location, availability, reliability and skills of the volunteers. These types of programs may be most successful when the volunteers are students, their work is overseen by a knowledgeable instructor, and the desire for good grades provides an incentive beyond the intrinsic interest of the work.

Both public monitoring and volunteer sampling programs incur staff costs for planning, recruitment and management, including the essential element of confirming the identification of any reported species. Consideration should be given to these factors in developing an appropriate mix of sampling and monitoring activities by volunteers and paid staff.

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Appendix A. Acronyms and Abbreviations Used in this Report

ANS	Aquatic Nuisance Species
BSWQP	Bi-State Water Quality Program
CREDDP	Columbia River Estuary Data Development Program
EMAP	Environmental Monitoring and Assessment Program
ESDP	Exotic Species Detection Program
LCRANS	Lower Columbia River Aquatic Nonindigenous Species Survey
LCREP	Lower Columbia River Estuary Program
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
OSU	Oregon State University
ppt	parts per thousand, a measure of salinity
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
UW	University of Washington
WDE	Washington Department of Ecology

Appendix A. Lower Columbia River Estuary Plan for Exotic Species Monitoring

Table A1. LCREP - Target Groups to be Sampled at Least Once Every 5 Years
(LCREP 1998, page A-32)

- Terrestrial and wetland plants and aquatic macrophytes
- Zooplankton
- Benthic macroinvertebrates (sampled at the same time as sediments sampled for contaminant analysis)
- Fish
- Amphibians
- Reptiles

Table A2. LCREP - Plan Elements Relevant to an ESDP
(LCREP 1998, pages A-33 to A-35, A39 to A-42)

Phase	Task	Cost Estimate
1	• Establish monitoring coordination structure and maintain liaison with monitoring partners. Monitoring partners to assist in developing monitoring strategy. • Develop cooperative agreement with monitoring partners to share data on non-indigenous species and to develop comparable procedures for sampling, quality assurance, data storage and assessment. • Evaluate results of U.S. Coast Guard study and other information to begin developing strategy for exotic species monitoring. Monitoring partners to assist in assessing existing information.	
2	• Maintain monitoring coordination structure and liaison with monitoring partners. • Complete thorough review of existing efforts to sample non-indigenous species and finalize monitoring strategy. • Through contract or interagency agreement, implement a sampling program directed at those species not currently being sampled through other programs.	• $30,000 to conduct review of existing monitoring. • $15,000 to develop and implement sampling program for target exotics (10 sites).
3	• Maintain monitoring coordination structure and liaison with monitoring partners.	
4	• Maintain monitoring coordination structure and liaison with monitoring partners. • Evaluate the results of the 5-year reassessment strategy. • Adjust existing non-indigenous species monitoring efforts based on the findings of the report and develop and implement new strategies as needed.	
Ongoing		• $70,000 for sampling for impacts, extent and new introductions

.Monitoring partners are to include Oregon and Washington Fish and Game Departments, U.S. Fish and Wildlife Service, U.S. Coast Guard, and National Marine Fisheries Service.

Appendix B. Preliminary List of Exotic and Cryptogenic Species in the Lower Columbia River Estuary

The information in these tables on native regions, transport mechanisms and collections outside of the Columbia River is based on Carlton 1979, Cohen & Carlton 1995, Cohen *et al*. 1998 and Mills *et al*. 2000 unless otherwise noted.

Table B1. Brackish or Salt Water Exotic Organisms Established in the Lower Columbia River Estuary

Organism	Records
Anthophyta	
Cotula coronopifolia Linnaeus, 1753	Brass buttons is native to South Africa and probably introduced in solid ballast. First recorded on the Pacific Coast at San Francisco in 1878 and now ranging from southern California to British Columbia. Collected in Baker Bay near Ilwaco (MacDonald & Winfield 1984), and probably present elsewhere.
Zostera japonica Ascherson and Graebner, 1907	Japanese eelgrass is native to the western Pacific and introduced with oyster aquaculture. First recorded on the Pacific Coast in 1957. Collected in Baker Bay in 1980-81 (Furota & Emmett 1993) and at LCRANS Stations 21, 33 and 35 in 2002 (Draheim *et al*. 2003, App. 3).
Cnidaria: Hydrozoa	
Cordylophora caspia (Pallas, 1771)	Native to the Black and Caspian Seas; either an early introduction with ballast water or possibly introduced in hull fouling. First recorded on the Pacific Coast in Puget Sound around 1920. Collected in the Lower Columbia River Estuary at Astoria by 1967 (Carlton 1979: 230), and by LCRANS at Station 16 in 2002 (Draheim *et al*. 2003: 8, App. 3, as *Cordylophora lacustris*).
Annelida: Polychaeta	
Hobsonia florida (Hartman, 1951)	Native to the northwestern Atlantic, and first recorded on the Pacific Coast in Puget Sound in 1940. Collected by CREDDP in Baker Bay in 1980-81, by BSWQP in 1990-1992, by EMAP in 1999-2000, and by LCRANS at Stations 16, 17, 19, 20, 23 and 30 in 2002 (Holton *et al*. 1984; Furota & Emmett 1993; Draheim *et al*. 2003: 10, App. 3). Was the second most dominant benthic species in Baker Bay in terms of biomass in 1980-81 (Holton *et al*. 1984).
Mollusca: Gastropoda	
Potamopyrgus antipodarum	Native to New Zealand. Collected in the Snake River in 1987, then in Youngs Bay near a salmon net pen operation in 1995 and 1996, then at net pens in Cathlamet Bay and at Hammond (Draheim 2002: 12, 20). Collected in the Lower Columbia River by EMAP in 1999-2000 and by LCRANS at Stations 10, 17, 18, 20-24, 29-31 and 45 in 2002 (Draheim *et al*. 2003: 10, App. 3). Though more commonly a freshwater than an estuarine organism, strong freshwater influences may allow it to reproduce in the upper parts of the Columbia River Estuary.
Mollusca: Bivalvia	
Corbicula fluminea Müller, 1774	First reported in the lower Columbia River in 1938 (Britton & Morton 1977). Collected in 1963-65 (Haertel & Osterberg 1967), by CREDDP in 1980-81, by EMAP in 1999-2000, and by LCRANS at Stations 10, 11, 13-16, 27 and 29-31 within the Estuary (Holton *et al*. 1984; Draheim *et al*. 2003). J.R. Cordell (pers. comm. 2003) reports that it is extremely abundant and presumably reproducing in Cathlamet Bay. Mainly a freshwater organism, but with a few records in estuaries. Strong freshwater influences may allow it to reproduce in the upper parts of the Estuary.

Mya arenaria Linnaeus, 1758	The Eastern Softshell clam is native to the northwestern Atlantic and introduced with oyster aquaculture. First recorded on the Pacific Coast in 1874. Collected in the Lower Columbia River by CREDDP in 1978-80, in Baker Bay in 1980-81, by BSWQP in 1990-1992, by EMAP in 1999-2000, and by LCRANS at Stations 19 and 23 in 2002 (Furota & Emmett 1993; Draheim *et al*. 2003: 10).
Arthropoda: Crustacea: Copepoda	
Limnoithona sinensis (Burkhardt, 1912)	Native to China and introduced in ballast water. First collected on the Pacific Coast in 1979 in the San Francisco Bay Estuary in fresh water, but also found downstream in slightly brackish water. Collected in the Lower Columbia River prior to 2002 by LCRANS in 2002 (Draheim *et al*. 2003: 10, App. 3; also see Draheim 2002:70).
Pseudodiaptomus forbesi (Poppe & Richard, 1890)	Native to China and introduced in ballast water. First collected on the Pacific Coast in 1987 in the San Francisco Bay Estuary, where it was the most common copepod in brackish water in 1988-89. Collected in the Lower Columbia River by LCRANS at Stations 14, 17 and 27 in 2002 (Draheim *et al*. 2003: 10, App. 3; also see Draheim 2002:70).
Pseudodiaptomus inopinus (Burckhardt, 1913)	Native to China, Japan and Siberia, and introduced in ballast water, or possibly with oyster aquaculture. Collected in the Lower Columbia River Estuary in the summer of 1990, and by BSWQP 1990-1992 (Cordell *et al*. 1992; Draheim *et al*. 2003, App. 3).
Sinocalanus doerri (Brehm, 1909)	Native to China and introduced in ballast water. First collected on the Pacific Coast in 1978 in the San Francisco Bay Estuary in fresh and brackish water, where it was the most common copepod in fresh water in 1979-1980. Collected in the Lower Columbia River prior to 2002 and by LCRANS at Stations 17 and 27 in 2002 (Draheim *et al*. 2003: 10).
Arthropoda: Crustacea: Cirripedia	
Balanus improvisus Darwin, 1854	Native to the North Atlantic and introduced in hull fouling or with oyster aquaculture. First collected on the Pacific Coast in San Francisco Bay in 1853. Collected in the Lower Columbia River on a crayfish (*Pacifastacus trobridgii*) in Young's Bay by 1965, and by LCRANS at Stations 18, 19 and 31 in 2002 (Miller 1965; Draheim *et al*. 2003: 10, App. 3).
Arthropoda: Crustacea: Cumacea	
Nippoleucon hinumensis (Gamo, 1967)	Native to Japan and introduced in ballast water. First recorded on the Pacific Coast in 1979. Collected in the Lower Columbia River in Trestle Bay in 1995, by EMAP in 1999-2000, and by LCRANS at Stations 17, 20, 21 and 23 in 2002 (Hinton & Emmett 2000; Draheim *et al*. 2003: 10, App. 3). Reported in some earlier literature as *Hemileucon hinumensis*.
Arthropoda: Crustacea: Amphipoda	
Grandidierella japonica Stevenson, 1938	Native to Japan, and introduced by ballast water, oyster aquaculture or hull fouling. First recorded on the Pacific Coast in 1966. Collected in the Lower Columbia River by EMAP in 1999-2000, and by LCRANS at Station 29 in 2002 (Draheim *et al*. 2003: 10, App. 3; also Draheim 2002: 68).
Monocorophium acherusicum Costa, 1857	Native to the northern Atlantic, and introduced by oyster aquaculture or hull fouling. First recorded on the Pacific Coast in 1905. Collected in the Lower Columbia River prior to 2002 (Draheim 2002: 66; Draheim *et al*. 2003, App. 3). Reported in the literature as *Corophium acherusicum* until recently.
Chordata: Pisces	
Alosa sapidissima (Wilson, 1811)	American shad are native to the northwestern Atlantic, and intentionally introduced to the San Francisco Bay watershed in 1871. Collected in the Columbia River in 1876 (Smith 1896), with fry later stocked there in 1906 (Draheim 2002: 11). Collected in the Columbia River in 1963-65 (Haertel & Osterberg 1967), and by NMFS in the estuary in 1980-81 (Bottom *et al*. 1984; Draheim *et al*. 2003). May threaten native fish in the river, including preying on and competing with juvenile salmon; NMFS has recently taken measures to reduce populations in the river (Draheim 2002: 11).

Table B2. Brackish or Salt Water Exotic Organisms Reported but not Known to be Established in the Lower Columbia River Estuary

Organism	Records
Arthropoda: Crustacea: Copepoda	
Acartiella sinensis	Native to subtropical and tropical waters of the China coast, and first reported on the Pacific Coast in 1993 in brackish water in San Francisco Bay, where it is established. Probably introduced in ballast water. Draheim *et al*. (2003, App. 3) report a few specimens collected in the Lower Columbia River, but it is not clear if it is established there.
Limnoithona tetraspina	Three specimens collected in summer 2002 (J.R. Cordell, pers. comm.).
Arthropoda: Crustacea: Cirripedia	
Balanus amphitrite Darwin, 1854	Probably native to the Indian Ocean and introduced in hull fouling. First collected on the Pacific Coast in southern California in 1921 and now established as far north as San Francisco Bay. Has been collected in the Lower Columbia River (Draheim 2002:66).
Arthropoda: Crustacea: Decapoda	
Eriocheir japonicus	Japanese mitten crabs are native to coastal waters in China, Japan and Korea. One specimen collected in the Columbia River near Chinook in July 1997. There were unconfirmed reports of crabs caught by anglers near Portland in 200 and 2001 and near Kalama in 2002, which were presumed to belong to the genus *Eriocheir*.
Chordata: Pisces	
Morone saxatilis (Walbaum, 1792)	Striped bass are native to the northwestern Atlantic, and intentionally introduced to the Pacific Coast in the San Francisco Bay watershed in 1879. Collected in the Lower Columbia River by 2002 (Draheim *et al*. 2003; also Draheim 2002). Reported in earlier literature as *Roccus saxatilis*.

Table B3. Freshwater Exotic Organisms Established in the Columbia River and Sometimes Occurring in the Estuary

Organism	Records
Anthophyta	
Iris pseudacorus Linnaeus	Introduced as a freshwater ornamental pond plant, but collected within the Estuary in Youngs Bay, Cathlamet Bay and Puget Island (MacDonald & Winfield 1984); and at LCRANS Stations 14 and 44 in 2002 (Draheim *et al*. 2003, App. 3)
Lythrum salicaria Linnaeus	Native to Europe and introduced as an ornamental plant. Usually in freshwater, but collected within the Estuary at LCRANS Stations 14 and 44 in 2002 (Draheim *et al*. 2003, App. 3).
Myriophyllum aquaticum	Introduced as a freshwater aquarium/ornamental pond plant, but collected within the Estuary at LCRANS Station 57 in 2002 (Draheim *et al*. 2003, App. 3).
Myriophyllum spicatum	Introduced as a freshwater aquarium/ornamental pond plant, but collected within the Estuary at LCRANS Stations 41, 44 and 55 in 2002 (Draheim *et al*. 2003, App. 3).
Potamogeton crispus	Usually in freshwater, but collected within the Estuary at LCRANS Station 44 in 2002 (Draheim *et al*. 2003, App. 3).
Arthropoda: Crustacea: Isopoda	
Caecidotea racovitzai (Williams, 1970)	Native to the northwestern Atlantic and possibly introduced in ballast water or with aquarium or ornamental pond plants. Primarily occurs in fresh water, but has been collected in brackish water including the Lower Columbia River Estuary by EMAP in 1999-2000 and by LCRANS at Station 14 in 2002 (Toft *et al*. 2002; T N & Associates 2002; Draheim *et al*. 2003: 10, App. 3).
Chordata: Pisces	
Ameiurus natalis (Lesueur, 1819)	Yellow bullhead are native to central and eastern North America and intentionally introduced west of the Rocky Mountains as a food and game fish. Collected in the Columbia River Estuary by NMFS in 1980-81 (Bottom *et al*. 1984).
Ameiurus nebulosus (Lesueur, 1819)	Brown bullhead are native to central and eastern North America and intentionally and widely introduced west of the Rocky Mountains as a food and game fish. Collected in the Columbia River Estuary by NMFS in 1980-81 (Bottom *et al*. 1984).
Cyprinus carpio Linnaeus, 1758	Common carp are native to Eurasia and intentionally introduced widely in North America (starting in 1831) as a food fish. Collected in the Columbia River Estuary by NMFS in 1980-81 (Bottom *et al*. 1984), where they are a common food item for river otters in tidal sloughs (Dunn *et al*. 1984).
Lepomis gibbosus (Linnaeus, 1758)	Pumpkinseed are native to central and eastern North America and widely introduced west of the Rocky Mountains either as food or game fish, as forage for food or game fish, for insect control, or accidentally planted along with other fish. Collected in the Columbia River Estuary by NMFS in 1980-81 (Bottom *et al*. 1984).
Lepomis gulosus (Cuvier, 1829)	Warmouth are native to central and eastern North America and widely introduced west of the Rocky Mountains, probably primarily as a food or game fish. Collected in the Columbia River Estuary by NMFS in 1980-81 (Bottom *et al*. 1984).
Lepomis macrochirus Rafinesque, 1819	Bluegill are native to central and eastern North America and widely introduced west of the Rocky Mountains, probably primarily as a food or game fish. Collected in the Columbia River Estuary by NMFS in 1980-81 (Bottom *et al*. 1984).
Micropterus salmoides (Lacepéde, 1802)	largemouth bass are native to central and eastern North America and intentionally introduced west of the Rocky Mountains as a food and game fish. Possibly planted in central California by 1879, and first planted in Washington state in 1890 (Cohen & Carlton 1995). Collected in the Columbia River Estuary by NMFS in 1980-81 (Bottom *et al*. 1984).

Pomoxis annularis Rafinesque, 1818	White crappie are native to central and eastern North America and intentionally introduced west of the Rocky Mountains as a food and game fish. First recorded introduction on the Pacific Coast was near Seattle in 1890, followed by plantings near San Diego in 1891 (Cohen & Carlton 1995). Collected in the Columbia River Estuary by NMFS in 1980-81 (Bottom *et al*. 1984).
Pomoxis nigromaculatus (Lesueur, 1829)	Black crappie are native to central and eastern North America and intentionally introduced west of the Rocky Mountains as a food and game fish. First recorded introduction on the Pacific Coast was near Seattle in 1890, followed by plantings near San Diego in 1891 (Cohen & Carlton 1995). Collected in the Columbia River Estuary by NMFS in 1980-81 (Bottom *et al*. 1984).
Perca flavescens (Mitchill, 1814)	Yellow perch are native to central and eastern North America and intentionally introduced west of the Rocky Mountains as a food and game fish. Collected in the Columbia River Estuary by NMFS in 1980-81 (Bottom *et al*. 1984).
Chordata: Mammalia	
Myocastor coypus (Molina, 1782)	Nutria are native to Argentina, Brazil, Bolivia, Chile, Paraguay and Uruguay. They were imported into the U.S. for fur farming, and were first reported in the wild along the Columbia and Willamette rivers in the 1930s. High marsh areas in the Estuary were found to be important feeding, denning and rearing areas for nutria (Dunn *et al*. 1984).
Ondatra zibethicus (Linnaeus, 1766)	Muskrat are native to the eastern United States, and were introduced to the West as either escapes or deliberate releases from fur farms. Marsh areas in the Estuary were found to be important feeding, resting and rearing areas for muskrat (Dunn *et al*. 1984).

Table B4. Brackish or Salt Water Cryptogenic Organisms Established in the Lower Columbia River Estuary

Organism	Records
Annelida: Polychaeta	
Capitella capitata (Fabricius, 1780)	Collected in the Lower Columbia River by CREDDP in 1978-80 (Holton *et al*. 1984; Draheim 2002). Generally considered to be a cryptogenic species complex (Carlton & Cohen 1995; T N & Associates 2002; Draheim 2002).
Glycinde polygnatha Hartman, 1950	Collected in Baker Bay in 1980-81 (Furota & Emmett 1993), but not collected by sampling in Trestle Bay around 1995 (Hinton & Emmett 2000). Reported as cryptogenic in the Lower Columbia River (Draheim 2002, p. 9, Draheim *et al*. 2003), though also reported as native on the Pacific Coast (T N & Associates 2002).
Heteromastus filiformis (Claparede, 1864)	Native to the northwestern Atlantic. First collected on the Pacific Coast in San Francisco Bay in 1936, and introduced with oyster aquaculture, or possibly in hull fouling or ballast water. Collected in the Lower Columbia River (Draheim 2002:63). Previously listed as exotic on the Pacific Coast (Carlton 1979; Cohen & Carlton 1995); later reported as a possible species complex and listed as cryptogenic (T N & Associates 2002, Draheim *et al*. 2003).
Manayunkia aestuarina (Bourne, 1883)	Collected in the Lower Columbia River by CREDDP in 1978-80, in Baker Bay in 1980-81, and by LCRANS at Station 23 in 2002 (Furota & Emmett 1993; Draheim *et al*. 2003: 10, App. 3). Listed as native to Europe though possibly a species complex by T N & Associates (2002), but listed as cryptogenic in the Lower Columbia River (Draheim 2002:64).
Owenia fusiformis Delle Chiaje, 1844	Collected by CREDDP in 1978-80 (Draheim *et al*. 2003). A probable species complex reported as cryptogenic on the Pacific Coast (T N & Associates 2002), but listed as native in the Lower Columbia River (Draheim *et al*. 2003).
Polydora cornuta Bosc, 1802	Collected in Baker Bay in 1980-81 (Furota & Emmett 1993). Reported as native to the North Atlantic (T N & Associates 2002; L.H. Harris, pers. comm.), but listed as cryptogenic in the Lower Columbia River (Draheim 2002). Has commonly been reported as *P. ligni*.
Pseudopolydora kempi (Southern, 1921)	Native to Japan and probably introduced with oyster aquaculture, or possibly in hull fouling or ballast water. First recorded on the Pacific Coast in 1951. Collected by CREDDP in Baker Bay in 1980-81, by BSWQP in 1990-92 (as *P. k. japonica*) and by EMAP in 1999-2000 (Holton *et al*. 1984; Furota & Emmett 1993; Draheim *et al*. 2003: 10, App. 3). Was the third most dominant benthic species in Baker Bay in terms of biomass in 1980-81 (Holton *et al*. 1984). Has generally been listed as exotic on the Pacific Coast (Carlton 1979; Cohen & Carlton 1995; T N & Associates 2002), but was listed as cryptogenic in the Columbia River (Draheim *et al*. 2003).
Pygospio elegans Claparede, 1863	Collected in Baker Bay in 1980-81 (Furota & Emmett 1993). A wide-ranging form that may be a species complex, it has generally been reported as cryptogenic on the Pacific Coast (Cohen & Carlton 1995; T N & Associates 2002; Draheim 2002).
Scolelepsis squamata (Schmarda 1861)	Collected in Trestle Bay around 1995 (Hinton & Emmett 2000). A possible species complex reported as cryptogenic on the Pacific Coast (T N & Associates 2002; Draheim 2002, p. 9).
Spiophanes bombyx (Claparede, 1867)	A possible species complex that has collected in the Lower Columbia River and reported as cryptogenic on the Pacific Coast (T N & Associates 2002; Draheim 2002).
Streblospio benedicti Webster, 1879	Native to the Atlantic and introduced by oyster aquaculture, or possibly in hull fouling or ballast water. First recorded on the Pacific Coast in San Francisco Bay in 1932. Collected in Baker Bay in 1980-81, by BSWQP in 1990-92, by EMAP in 1999-2000, and by LCRANS in 2002 (Furota & Emmett 1993; Draheim *et al*. 2003). Previously listed as exotic on the Pacific Coast (Carlton 1979; Cohen & Carlton 1995); but later described as a possible species complex, and listed as cryptogenic (T N & Associates 2002, Draheim *et al*. 2003).

Arthropoda: Crustacea: Copepoda	
Eurytemora affinis (Poppe, 1880)	Collected in the Lower Columbia River Estuary by NMFS in 1980-81, and by LCRANS at Stations 17 and 25 in 2002 (Jones & Bottom 1984; Cordell *et al*. 1992; Draheim *et al*. 2003). In 1980-81 it was the most abundant zooplankton species in the Estuary with densities of over 100,000 individuals/m^2, and was collected in all salinity zones in the Estuary (Jones & Bottom 1984). Reported as native to eastern North America and introduced into brackish waters of San Francisco Bay with plantings of striped bass, *Morone saxatilis*, in 1879 or 1881 (Orsi 2001), though reported as native in the Lower Columbia River (Draheim *et al*. 2003).
Arthropoda: Crustacea: Isopoda	
Saduria entomon (Linnaeus, 1767)	Collected in the main stem of the Lower Columbia River in 1963-65, by CREDDP in 1978-80, in Baker Bay in 1980-81 and by EMAP in 1999-2000 (Haertel & Osterberg 1967; Furota & Emmett 1993; Draheim *et al*. 2003). A possible species complex that has been reported as cryptogenic (T N & Associates 2002; Draheim 2002; Draheim *et al*. 2003).

Appendix C. An Offer to Analyze Sea Spiders

From the SCAMIT website (December 3, 2003):

Dear All,

We are currently working on the first 'big' attempt to propose a molecular phylogeny of the Pycnogonida or commonly called sea spiders. These are fascinating, bizarre small arthropods, usually cryptic and not abundant. However, they inhabit all marine habitats around the world and this is why I am kindly asking for your collaboration. In case you find pycnogonids in your samples, e.g. trawlings, dredging, associated to molluscs, echinoderms, washings of algae or intertidal samples, etc, I would enormously appreciate you could keep and preserve any specimen in 90% Ethanol and refrigerated. These creatures are difficult to find and not very well-known so collaboration from marine invertebrate specialists or basically anyone going out to the sea is very much appreciated. I can run with shipping charges and any other costs. I hope to hear from any of you soon, any relevant information or assistance would be greatly appreciated and any collaboration would be acknowledged as it corresponds.

Please excuse the liberty I've taken sending this email through the E-lists.

My best wishes to all,

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