Ballast Water and Shipping Patterns in Puget Sound

Considerations for Siting of Alternative Ballast Water Exchange Zones

Puget Sound Water Quality Action Team

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Executive Summary

Purpose

The Puget Sound Water Quality Action Team has a legislative mandate to coordinate local, state and federal action to protect and restore the health of Puget Sound. Aquatic nuisance species have been identified by the Action Team for priority attention during the 1999-2001 state biennium (Puget Sound Water Quality Work Plan). Ballast water is a significant pathway for the introduction of nonindigenous species to ports around the world and, potentially, to Puget Sound.

During the year 2000, the Action Team will prepare a new program on aquatic nuisance species for the *Puget Sound Water Quality Management Plan.* One use of this report will be to help the Action Team consider how to address ballast water in the aquatic nuisance species program. There are already a number of federal and regional programs in place to address ballast water. The Action Team will coordinate with those programs, and with stakeholders, to determine an appropriate approach to ballast water in the management plan and any immediate steps the Action Team should take regarding ballast water.

This report summarizes current shipping trends and ballast water practices in the Puget Sound/Georgia Basin area as well as ballast water exchange programs on the Pacific coast. In addition, the report outlines a series of institutional, operational, oceanographic and biological considerations for locating alternative zones for ballast water exchange for vessels entering the Strait of Juan de Fuca. Existing information and management gaps are identified and possible directions are proposed. These findings will be made available to the Puget Sound/Georgia Basin Task Force, the Pacific Ballast Water Group and other interested parties for further consideration.

Findings

Ship's ballast water is a vector for the transport of aquatic species (Carlton and Geller, 1993). Transport of ballast water among the ports of the world has resulted in the introduction and establishment of numerous nonindigenous species. Many of these species have caused large-scale economic damage and ecological change.

The International Maritime Organization has published guidelines for ballast water management and is drafting an international treaty to address the ballast water issue. The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, the National Invasive Species Act (NISA) of 1996 and Executive Order 13,122 address the issue of nonindigenous aquatic nuisance species—including the issue of ballast water—at the national level. Current U.S. Coast Guard regulations encourage ships to voluntarily exchange their ballast water in the open ocean (at least 200 miles from shore and in waters at least 2,000 m deep) in order to minimize species introductions (64 Fed. Reg. 26672 (May 17, 1999)).

However, there are important exceptions to the current government programs. Coast Guard regulations for implementing NISA requirements only apply to vessels entering the Exclusive Economic Zone. Vessels engaged in coastwise trade are not subject to the Coast Guard regulations and do not usually reach the open ocean during their travels. Also, some intercoastal vessels are unable to exchange ballast water in the open ocean due to the danger caused by high seas.

In order to determine the risk posed by ballast water, this study evaluates regional shipping patterns. Puget Sound shipping data for 1998 was provided by the Puget Sound Steamship Operators Association. Georgia Basin shipping data was obtained from the Port of Vancouver. Based on these summaries, it is clear that coastwise trade represents a significant portion of Puget Sound shipping:

1998 Puget Sound Shipping Data

- Puget Sound ports received 3,861 vessel calls in 1998.
- Japan was the most common last port of call, followed by California, Alaska and Washington.
- Of all ships arriving in Puget Sound, 17 percent represented a high probability of ballast water discharge.
- Of these 17 percent, 73 percent of the vessels were engaged in coastwise trade.
- The ballast water capacity of the vessels with a high probability of ballast water discharge was estimated at 9.4 million metric tons, or 25,800 metric tons per day.
- Bulk and tanker vessels accounted for over 90 percent of the ballast water discharged.
- The U.S. Coast Guard and the Puget Sound Steamship Operators Association have voluntary ballast water exchange programs in place for Puget Sound.

1998 British Columbia Shipping Data

- Summary data for Georgia Basin ports does not exist.
- The Port of Vancouver is the major Georgia Basin port.
- The Port of Vancouver received 2,743 vessel calls in 1998.
- Japan is Vancouver's most common trading partner (by tonnage), followed by South Korea, China, Taiwan and Brazil.
- Vancouver is primarily an export port, receiving 5.5 million tons of inbound cargo and dispatching 62 million tons of outbound cargo.
- By tonnage, 84 percent of Vancouver's cargo is bulk cargo.
- The Port of Vancouver has a mandatory ballast water exchange program in place.

Currently, the only widely available solution to the ballast water problem is open-ocean exchange. However, experts generally agree that it is only a short-term solution. Identifying alternative discharge zones for vessels that cannot conduct open-ocean exchanges is a possible intermediate solution for ballast water management. The long-term solution is to treat ballast water onboard or onshore. A combination of treatment and exchange could be tailored to specific circumstances.

The oceanography of Puget Sound, the Strait of Juan de Fuca and the Washington coast is complex and changes over time. Drift card studies can be used to determine how surface currents behave and, therefore, how organisms released in ballast water are likely to be transported. Drift card studies in the Pacific Northwest region showed that material released in Puget Sound and the Strait of Juan de Fuca had a higher recovery rate on shore than material released off the coast of Washington. Drift card studies also identified several prominent eddies in the eastern Strait of Juan de Fuca. Two prominent patterns emerged from these studies. Approximately three quarters of the recoveries were made on northern shores and one quarter were made on southern shores. Nearly half of the recoveries were made in three specific locations: Victoria, the San Juan Islands and Dungeness Spit.

In Washington, there are numerous biologically sensitive areas that could be harmed by nonindigenous species. Carlton et al. (1995) define sensitive coastal areas as "restricted sites where great value (environmental, social, aesthetic, economic or otherwise) is placed on maintaining resources as they are, and where focused disturbances could easily and radically alter those values." Sensitive areas on the Washington coast include aquaculture sites, regions of naturally productive finfish and/or shellfish fisheries, marine protected areas and endangered species habitat.

Several West Coast ballast water exchange programs are currently in place. The Port of Vancouver has a mandatory ballast water exchange policy for vessels arriving from any foreign ports, except those along the Pacific coast north of Cape Mendocino, California. The U.S. Coast Guard promotes a voluntary ballast water exchange program that asks ships to exchange ballast water 25 nautical miles from shore while engaged in coastwise trade. The Puget Sound Steamship Operators Association has recommended that its members comply with the Coast Guard program. Recently, the Port of Oakland, California adopted a ballast water exchange program modeled on the Port of Vancouver policy. In October 1999, the State of California legislature enacted a statewide mandatory ballast water exchange program that became effective January 1, 2000.

In 1998, 54 percent of vessels entering Puget Sound were engaged in coastwise trade and most likely could not conduct an open-ocean exchange of their ballast water. In order to fill this regulatory gap, some industry groups and ports are establishing alternative exchange locations. Alternative zones for ballast water exchange are areas that, due to oceanographic characteristics, provide a lower risk of species introduction even though they are located nearshore.

Based on literature review and expert interviews, the following considerations for siting alternative zones for ballast water exchange were identified:

Institutional:
- Conformity with existing laws and agreements
- Location of military or restricted areas

Operational:
- Safety of vessel and crew
- Location of trade routes and shipping lanes
- Time required to complete ballast water exchange

Oceanographic:
- Regional circulation patterns
- Variability
- Localized circulation patterns

Biological:
- Location of sensitive biological areas (aquaculture, fisheries, marine protected areas and endangered species habitat)

Although the selection of alternative ballast water exchange zones will partially fill the management gaps in the current system, it seems clear that ballast water exchange will continue to be only an interim solution. The ultimate direction of ballast water management nonetheless remains ballast water treatment, either on board the vessel or on shore. Based on these conclusions, there are several opportunities for continued work or study that merit further investigation or discussion, including the following:

- Continue and improve coordination among participants in West Coast ballast water management including British Columbia and Alaska.
- Investigate the suitability of alternative ballast water exchange zones that are already in use.
- Investigate alternative ballast water exchange zones for vessels entering Puget Sound.

- Encourage the use of best management practices to reduce the probability of organism uptake during ballasting.
- Encourage the use of onboard or onshore treatment of ballast water as the next, most appropriate step in ballast water management.
- Use the Coast Guard/Smithsonian Environmental Research Center database to assess the risk and effectiveness of the current management regime.
- Investigate ballast water and shipping patterns for vessels engaged in coastwise trade.
- Encourage additional research on issues including: treatment technology, shipping patterns and behavior of ballast water once it is discharged.
- Investigate the use of a matrix to evaluate vessel risk based on individual vessel characteristics, ports of origin and other risk criteria.

Introduction

Purpose

The Puget Sound/Georgia Basin Task Force and the Puget Sound Water Quality Action Team have identified the introduction of nonindigenous species as a significant threat to the biological health and integrity of the shared marine waters of Washington and British Columbia. A top priority for both groups is to ensure that introductions to the shared waters are minimized. Ballast water is a pathway of significant concern for the introduction of nonindigenous species.

This report summarizes current Puget Sound/Georgia Basin shipping trends and ballast water practices, as well as the existing local ballast water exchange programs on the Pacific coast. In addition, this report outlines a series of institutional, operational, oceanographic and biological considerations for locating alternative zones for ballast water exchange for vessels entering the Strait of Juan de Fuca. Existing information and management gaps are identified and possible directions are proposed. These findings will be made available to the Puget Sound/Georgia Basin Task Force, the Pacific Ballast Water Group and other interested parties for further consideration.

Background

Ship's ballast water is a vector for the transport of aquatic species (Carlton and Geller, 1993).The transport of ballast water among the ports of the world has resulted in the introduction and establishment of numerous nonindigenous species. These nonindigenous species have resulted in large-scale economic and ecological impacts. For example, the ballast water introduction of the zebra mussel into the Great Lakes has resulted in costs totaling $5 billion annually (Pimentel et al., 1999). Equally alarming is the negative effect that the population explosion of the zebra mussel has had on the ecology of the Great Lakes, thereby impacting numerous native species.

Current United States Coast Guard regulations encourage voluntary exchange of ballast water in the open ocean (at least 200 miles from shore and in waters at least 2,000 meters deep) in order to minimize ballast water introductions (Interim regulations implementing National Invasive Species Act (NISA) of 1996 issued by the U.S. Coast Guard. 64 Fed. Reg. 26672 (May 17, 1999)). However, vessels engaged in coastwise trade do not usually reach the open ocean during their travels between coastal ports. In addition, some vessels encounter high seas, which can make open-ocean ballast water exchange dangerous. Some industry groups and ports are establishing alternative exchange locations closer to shore that, due to oceanographic characteristics, provide a lower risk of species introduction despite their location closer to shore. For example, members of the Puget Sound Steamship Operators Association (PSSOA) that are involved in coastwise trade voluntarily exchange their ballast water 25 miles offshore, rather than in port.

The question of how to manage the risk associated with vessels that are unable to complete an open-ocean exchange has risen to the forefront of the ballast water issue. In order to address this emerging concern, resource managers need additional information about the institutional, operational, oceanographic and biological dimensions of the ballast water problem.

What is Ballast Water?

"Ballast is any solid or liquid placed in a ship to increase the draft, to change the trim, to regulate the stability, or to maintain stress loads within acceptable limits" (National Research Council, 1996). Generally, ships carry ballast when they are not fully loaded with cargo in order to lower the vessel in the water, increasing stability and vessel safety. However, vessels may also take on ballast to aid in propulsive efficiency or maneuverability, to compensate for consumption of drinking water or fuel, to provide for increased comfort at sea under unfavorable weather conditions or to clean the decks or holds (Carlton et al., 1995).

When vessels ballast, they take on water by pump or gravitation. The ballast water that is taken on board is the water surrounding the vessel. Ballast intakes are located several meters below the water line and are covered by a grate or strainer, usually with openings of 1.0 to 1.5 cm in diameter. Often these grates are rusted, resulting in larger diameter openings. Organisms or sediments that are suspended in the surrounding water and are smaller than the holes on the ballast intake grate will also be taken on board during ballasting (Carlton et al., 1995).

Suspended sediments that are taken on board during ballasting settle out during a voyage and accumulate in the ballast tanks of vessels. Accumulated sediments can harbor nonindigenous species, such as the resting cysts of toxic dinoflagellates, which cause red tides. Ballast sediments are difficult to remove during normal ballast operations because ballast pumps usually are not able to remove all of the ballast water on board. The amount of unpumpable ballast water varies among vessel types. Weathers and Reeves (1996) report that vessels claiming to have only unpumpable ballast on board were carrying an average of 157.7 metric tons of water and sediments. Of 343 cargo vessels sampled in Australia, at least 65 percent "were carrying significant amounts of sediment on the bottom of their ballast tanks" (Hallegraeff and Bolch, 1992).

During a voyage and in port, vessels routinely deballast (remove water from the vessel by pump or gravitation) and reballast (take water back into the vessel after deballasting). During a voyage, a vessel may deballast and/or reballast to compensate for density changes in the surrounding water, to avoid ballast water freezing, to compensate for internal condensation, to modify fuel temperature, to increase speed in calm seas where less ballast is necessary, to discharge polluted water or to flush out accumulated ballast sediments (Carlton et al., 1995). In port it is customary to ballast in order to increase vessel draft and therefore allow the vessel to fit under bridges or cranes. It is also common for vessels to continuously deballast and reballast during cargo loading and unloading in order to maintain stability (NRC, 1996).

Why is Ballast Water a Problem?

As described above, organisms that are present in the surrounding water and are large enough to fit through the ballast intake grate will likely be taken on board during ballasting. As time passes after ballasting species richness in ballast tanks decreases due to organisms dying. However, many organisms can survive for weeks or even months inside ballast tanks (Chu et al., 1997). Carlton and Geller (1993) sampled ballast water from 159 vessels arriving in Coos Bay, Oregon from Japanese ports. They found 367 taxa, representing all major marine habitat and trophic groups, leading the authors to state that "ballast water... acts as a phyletically and ecologically nonselective transport vector." Similarly, Chu et al. (1997) sampled twelve container ships arriving in Hong Kong from ports on both sides of the Pacific. At least 81 species were found, representing most major marine taxonomic groups. Among the most numerous organisms transported were diatoms, dinoflagellates, algae, seagrasses and zooplankton (primarily planktonic organisms, as well as larvae).

Not all of the species released into a new environment become established. The requirements for species establishment are not well understood and they vary from species to species. Common factors that contribute to species establishment include the rate of introduction, the life stage at which species are released and the conditions of the new environment. According to Carlton (1996), "a vessel may move a species between two ports for 100 years, and then the species 'takes' [becomes established] in the 101st year." For example, it is likely that the zebra mussel, *Dreissena polymorpha*, was released in the Great Lakes region for decades before it was discovered living there in the late 1980s. Since then, the zebra mussel has experienced a population explosion in the Great Lakes and has spread to many of the fresh water systems east of the Rocky Mountains.

It is difficult to prove whether specific species were introduced and became established due to the release of ballast water. There are numerous other pathways for the introduction of nonindigenous aquatic species including ship hull fouling or boring, aquaculture, live bait, the packaging associated with shipments of aquaculture or live bait, movement of recreational boats, shipment of live seafood, releases from scientific or research institutions, public and private aquaria, biological control releases, plantings for marsh restoration or erosion control and disposal of dredge spoils (Cohen and Carlton, 1995 and Carlton, 1994). By eliminating the possibility of introduction via other possible pathways, researchers have determined that some introductions are likely the result of ballast water transport. In San Francisco Bay alone, 27 species were probably introduced via ballast water and another 60 species are possible ballast water introductions, totaling 87 species or 37 percent of the known San Francisco Bay introductions (Cohen, 1998).

Invasions due to ballast water appear to be increasing in frequency. Cohen and Carlton (1998) found that about half of all invasions of San Francisco Bay in a 145-year period were reported in the last 35 years, which equates to a new species every 14 weeks from 1961 to 1995. Similarly, Puget Sound has 52 documented nonindigenous species and the percentage of these that are probably due to ballast water has increased over time (Cohen et al., 1998).

What are the Effects of Nonindigenous Species?

The establishment of a nonindigenous species does not necessarily result in serious negative consequences. Many species have been introduced intentionally and have become highly beneficial. For example, the Japanese oyster, *Crassostrea gigas*, was imported to the Pacific Northwest in the early 1900s. In 1993, sales value of this aquaculture species in Washington were estimated at nearly $17 million and in British Columbia at over $4 million Canadian. Although there were negative effects associated with the accidental introduction of species inadvertently shipped with the oyster spat, currently there are few negative impacts of the Japanese oyster (Elston, 1997).

It cannot even be said that those species that have been accidentally introduced are universally detrimental to the native ecosystem. The Manila clam, *Venerupis philippinarum*, is an example of a nonindigenous species that was accidentally introduced in shipments of Japanese oyster spat and that is now a major aquaculture species. The 1993 sales value of the Manila clam industry in Washington was estimated at over $11 million and there are no known negative effects of this introduced species (Elston, 1997).

However, there are numerous nonindigenous species that have become aquatic nuisance species (ANS) after becoming established in a new environment. Their introduction is extracting an increasing cost from the economy, the environment and human health.

Economic effects: The prime example of an ANS that is also a probable ballast water introduction is the zebra mussel, *Dreissena polymorpha*. The first North American sighting of the mussel was in Canada at Lake St. Clair in 1988. From Lake St. Clair, the zebra mussel spread throughout the Great Lakes and then into the river systems of the eastern United States, most probably by attaching to boats navigating these areas (USGS website). Zebra mussels colonize water supply pipes for hydroelectric and nuclear power plants, public water supply plants, and industrial facilities, resulting in reduced flow through these pipes. Zebra mussel densities were as high as 700,000 per square meter at one Michigan power plant. Both recreational and commercial ships must contend with the increased drag from attached mussels. Small mussels can interfere with engine cooling systems causing overheating and damage. Navigational buoys have sunk due to the excess weight of attached mussels. Prolonged zebra mussel attachment can cause disintegration of dock pilings and corrosion of steel and concrete resulting in decreased structural integrity (USGS website).

The costs associated with zebra mussel damage and control in the United States are projected to reach $5 billion per year by the year 2000 (Pimentel et al., 1999). The annual cost associated with all identified nonindigenous species in the United States is estimated at over $138 billion. This estimate does not include the effects of species extinction, losses in biodiversity, ecosystem functions, and aesthetics, which are difficult to measure monetarily (Pimental et al., 1999).

Environmental effects: The ecological effects of nonindigenous aquatic nuisance species are substantial. Second only to habitat loss and degradation as a threat to biodiversity, competition with and predation by "alien" species affects 49 percent of imperiled species in the United States (Wilcove et al., 1998). About 42 percent of the species listed as threatened or endangered under the Endangered Species Act of 1973 are at risk primarily because of nonindigenous species (Pimental et al., 1999). Due to the effects of ballast water mediated introductions of nonindigenous species, Carlton and Geller (1993) suggest that "...bays, estuaries, and inland waters with deep water ports—marine analogs of despoiled, highly invaded oceanic islands—may be among the most threatened ecosystems on the planet."

Zebra mussels, for example, can dramatically alter the ecosystem by eliminating native mussels and filtering out phytoplankton, therefore altering the food web and decreasing populations of economically or ecologically important species. Although there is little currently known regarding the effect of the zebra mussels in the Great Lakes on native mussel populations, evidence from Europe suggests that there is the potential for zebra mussels to severely impact the feeding, growth, locomotion, respiration and reproduction of native mussel populations. Zebra mussels are detrimental to native mussels primarily because they prefer to attach to live native mussels, and they do so at very high densities, sometimes tripling or quadrupling a native mussel's own weight. Since zebra mussels are filter feeders, they have caused a dramatic improvement in water clarity in the Great Lakes, resulting in both positive and negative effects. The increase in water clarity allows more light to penetrate to the lake bottom, causing an increase in plant growth. The plants can serve as nurseries for some species of fish. However, by reducing phytoplankton, the zebra mussel is effectively removing a major base of the food web, which can result in drastic changes in food web dynamics (USGS website; WA State ANS Management Plan, 1998).

Human health effects: Nonindigenous species can also impact human health. Ballast water can be a vehicle for the transmission of the epidemic Cholera bacterium, *Vibrio cholerae* (McCarthy and Khambaty, 1994). Ballast water and sediments can also harbor toxic dinoflagellates, the organisms that cause paralytic shellfish poisoning (PSP) (Hallegraeff, 1998). PSP has a 15 percent mortality rate and results from consumption of shellfish contaminated with alkaloid toxins from 11 species of plankton dinoflagellates. Many dinoflagellates produce a resistant stage, called a resting cyst, in response to unfavorable conditions. These cysts settle out of the water column and into bottom sediments and are very resistant to changes in environmental conditions. Once conditions improve, the organisms germinate. Viable toxic dinoflagellate cysts have been documented in ballast water sediments and, in several cases, ballast water is the probable pathway for the introduction of nonindigenous dinoflagellates (Hallegraeff, 1998). Dinoflagellate cysts are difficult to manage because the volume of ballast water transported is not necessarily the best risk indicator and ballast water exchange is only partially effective at removing cysts because it only partially removes the sediments containing cysts (Hallegraeff, 1998). Treatment with heat is a promising method for managing dinoflagellate cysts, however, the temperature and duration of heating that appears to result in cyst mortality does not effectively kill *Vibrio cholerae* (Hallegraeff, 1998).

Assumptions

Ballast water can originate from either a freshwater, marine or estuarine environment. The salinity, and thus the density, of the ballast water depends upon the type of system from which the water originates. Once ballast water is released, its density affects its position in the water column and, therefore, which currents control the movement of the water and the organisms contained in that water. Ideally, the origin and salinity of ballast water, as well as the salinity along the water column, is known before release, enabling predictions of the fate of the released organisms. However, the origin of ballast water is not often known because the last port of call is not a good indicator (Carlton et al., 1995). The conclusions in this report are based on the assumption that discharged ballast remains in or near the surface layer. A more comprehensive, three-year study of the dispersion of organisms released in ballast water in the Strait of Juan de Fuca is being conducted by Dr. Colin Levings and Dr. Mike Foreman at the Department of Fisheries and Oceans Canada (DFO).

The Current State of Affairs

The issue of ballast water management brings together different sets of interest groups and represents an intersection between different academic disciplines. The primary dimensions of the ballast water problem identified here are institutional, operational, oceanographic and biological. In order to understand and effectively address the ballast water problem, descriptions of these four primary dimensions follow.

Institutional Structure

The institutional response to the ballast water problem has occurred at multiple levels of government and through several varieties of non-governmental organizations. Institutional responses that affect the state of Washington are described below. The major parties are summarized in Table 1 and more complete discussion of these parties and the laws that govern the ballast water issue can be found in Appendix A.

Internationally, the major participant in the ballast water issue is the International Maritime Organization (IMO). The IMO published "Guidelines for the Control and Management of Ship's Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens" in 1997 and the Marine Environment Protection Committee of the IMO is currently working on developing an international treaty to address the ballast water problem.

Nationally, the United States has two laws that specifically address the ballast water issue: the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) of 1990 and the National Invasive Species Act (NISA) of 1996. These acts created the Aquatic Nuisance Species Task Force and authorized the creation of regional panels of the task force, such as the Western Regional Panel, to encourage and coordinate aquatic nuisance species efforts at the national and regional levels. More recently, Executive Order 13,112, issued in February of 1999, addresses the invasive species issue as a whole. The order directs the establishment of the Invasive Species Council to coordinate federal work on both terrestrial and aquatic nonindigenous species.

Mandated by NISA, the U.S. Coast Guard issued an interim rule implementing a ballast water program effective in July 1999. Under the interim rule, vessels entering U.S. waters should voluntarily conduct an open-ocean ballast water exchange in waters at least 200 miles from shore and at least 2,000 meters in depth, retain the ballast water on board, use an alternative and approved method of ballast water management or discharge ballast water into an approved reception facility. A vessel may, "under extraordinary conditions, conduct a ballast water exchange within an area agreed upon by the Captains of the Port at the time of the request, or after notification to the Captain of the Port, within an area listed as an Alternate Exchange Zone" (U.S. Coast Guard, 1999). In addition, the U.S. Coast Guard program includes mandatory reporting of ballast water operations from vessels entering U.S. waters, although there are currently no penalties for non-reporting. A vessel that has not conducted an open-ocean ballast water exchange due to high seas may claim a safety exemption. The regulations apply only to those vessels entering the U.S. Exclusive Economic Zone (EEZ) therefore, vessels engaged in coastwise trade are not regulated (U.S. Coast Guard, 1999).

At a regional level, there are several groups that are voluntarily working together to reach a solution to the ballast water problem. There are also several industry and environmental organizations that have played and continue to play a role in the ballast water management debate.

Washington State is a leader in managing aquatic nuisance species. The state's Aquatic Nuisance Species Management Plan was the fourth in the nation to be approved by the National Aquatic Nuisance Species Task Force.

Table 1. The Institutional Structure of the Ballast Water Issue in Washington State

Organization	Subgroup	Source of Authority/ Involvement	Members	Responsibilities/Role
Mandated/Governmental				
INTERNATIONAL:				
Internal Maritime Organization (IMO)	Marine Environment Protection Committee	United Nations Convention adopted in 1948	157 member states, including the U.S.	Guidelines for ballast water management; Annex to MARPOL
Puget Sound/Georgia Basin Task Force	Exotics Work Groups	Environmental Cooperation Agreement of 1992	Representatives from U.S., Canada, WA and B.C.	Coordinates protection of the shared inland marine waters
UNITED STATES:				
Aquatic Nuisance Species Task Force (ANS Task Force)	Ballast Water and Shipping Committee	NANPCA of 1990	NOAA, USFWS, USCG, EPA, Dept. of Army, Agriculture, State and 10 non-federal reps	Coordinate governmental ANS efforts in U.S. with the private sector and internationally
Western Regional Panel on Aquatic Nuisance Species (part of ANS Task Force)	Coastal Committee	NISA of 1996	48 representatives from federal, state, local and environmental government and and commercial groups	Coordinate western U.S. response, inform ANS Task Force
U.S. Coast Guard	NA	NISA of 1996 (West Coast (ballast water authority)	NA	National Voluntary Ballast Water Exchange Program
Smithsonian Environmental Research Center	National Ballast Information Clearinghouse	NISA of 1996	NA	Analysis of data from Coast Guard ballast water exchange program
Invasive Species Council	NA	Executive Order 13,112 (Feb. 3, 1999)	Secretaries of Interior, Agriculture, Commerce, State, Treasury, Defense and Transportation and Administrator of EPA	Coordinate U.S. response, provide guidance to federal agencies, prepare national invasive Species Management Plan
Environmental Protection Agency (EPA)	NA	Clean Water Act	NA	Respond to recent petition to classify ballast water as pollution under the Clean Water Act
Washington State Dept. of Fish and Wildlife	Aquatic Nuisance Species Management Program	RCW 77.12.020, RCW 77.12.030, RCW 77.12.040 and WAC 232-23-1701	NA	Prevents collection, import, transport and possession of certain species including zebra mussels; can designate wildlife as nuisance species
Dept. of Ecology	Oil Spill Prevention Program	RCW 88.46.050	NA	Includes ballast water exchange as a criteria in the ranking of vessel risk
Zebra Mussel/ Green Crab Task Force	NA	Washington Session Law, Ch. 153, Law of 1998	Federal, tribal and state government, industry, environmental groups and academic community	The group no longer exists. It developed recommendations for legislative consideration in 1998.

Table 1 *(continued)***.** The Institutional Structure of the Ballast Water Issue in Washington State

Organization	Subgroup	Source of Authority/ Involvement	Members	Responsibilities/Role
Washington Aquatic Nuisance Species Planning Committee	NA	Voluntary	Federal, tribal and state government, industry, environmental groups and academic community	The group no longer exists. It developed the Washington State Aquatic Nuisance Species Management Plan in 1998
Washington Ports	NA	Local Authority	Anacortes, Bellingham, Everett, Olympia, Port Angeles, Seattle and Tacoma	No ports have developed a formal ballast water policy
Voluntary Groups:				
WORKING GROUPS				
West Coast Regional Working Group on Ballast Water Management	NA	Voluntary	Port of Vancouver, B.C., other B.C. Ports, USCG, Department of Fisheries and Oceans Canada, Transport Canada and others	Educational dialogue and coordination between Washington and British Columbia
Pacific Ballast Water Group (PBWG)	NA	Voluntary	Shipping industry, scientists, state and federal government and environmental groups	Create cooperative and coordinated regional response to solving the ballast water problem
Puget Sound Marine Committee (PSMC)	Ballast water subcommittee	Voluntary	Broad-based stakeholder representation	Creates a forum for interest groups to address environmental problems proactively and voluntarily; resulted in PSSOA policy on ballast water
INDUSTRY				
Pacific Merchant Shipping Association (PMSA)	NA	Voluntary	35 owners and operators of U.S. and foreign flag vessels operating in the Pacific basin	Represents the interests of members in the passage of legislation and regulation
Puget Sound Steamship Operators Association (PSSOA)	NA	Voluntary	45 vessel operators and agencies engaged in maritime commerce in Puget Sound and Grays Harbor	Promotes best interests of members, has created a voluntary ballast water policy for members
ENVIRONMENTAL				
People for Puget Sound	NA	Voluntary	Citizens	Signatory to EPA petition
Friends of San Juans	NA	Voluntary	Citizens	Signatory to EPA petition
Northwest Environmental Advocates	NA	Voluntary	Citizens	Signatory to EPA petition
Washington Environmental Council	NA	Voluntary	Environmental groups	Representative on ballast water subcommittee of PSMC
Puget Soundkeeper Alliance	NA	Voluntary	Citizens	Representative on ballast water subcommittee of PSMC
Adopt-a-Beach	NA	Voluntary	Citizens	Coordinates citizen monitoring and *Spartina* control efforts

Puget Sound/Georgia Basin Shipping Practices

Puget Sound Ports

The primary ports in Puget Sound are Seattle and Tacoma. Additional deep water ports in Puget Sound include Olympia, Port Angeles, Everett, Bellingham and Anacortes. In a shipping study mandated by Congress under the NANPCA of 1990, Carlton et al. (1995) studied the ballast water trends in multiple U.S. ports, including Seattle and Tacoma. United States Census Bureau data from 1991 was used to estimate information about vessels entering 17 different port areas. Estimates show the number of vessels arriving from foreign ports in ballast or loaded with ballast rather than cargo, and the last port of call for each vessel. The results of the Carlton et al. (1995) report include:

- The ports of Seattle and Tacoma received 4,282 vessel calls in 1991.
- Of these vessels, 530 vessels (12 percent) were in ballast (compared with overall rate of 21 percent for all ports sampled)
- Seattle and Tacoma received an estimated 2,688,018 metric tons of acknowledged ballast water in 1991 (see Table 2).
- The combined ports of Seattle and Tacoma ranked 6th among 17 ports in the volume of acknowledged ballast water discharged.
- Of the acknowledged ballast water discharged in Seattle and Tacoma, the majority was discharged by bulk vessels (2,573,183 metric tons), followed by tank vessels (104,026 metric tons). Very little was discharged by general cargo vessels (10,808 metric tons).

Acknowledged ballast is ballast water from vessels that contain no cargo and thus report being "in ballast." Vessels that are not fully loaded with ballast water or cargo are said to be "with ballast" and these vessels do not usually report their ballast water to the port or government. Therefore, vessels classified as "with ballast" discharge unacknowledged ballast water.

Table 2. Acknowledged Ballast: Summary by Vessel Type and Port (adapted from Carlton et al., 1995)

	Acknowledged Ballast (metric tons)			
Port	**Bulkers**	**Tankers**	**Gen Cargo**	**Total**
New Orleans	12,279,891	963,472	240,384	13,483,747
Norfolk	9,227,554	75,434	22,157	9,325,145
Long Beach/Los Angeles	2,587,217	3,258,723	31,885	5,877,824
Houston/Galveston	2,089,514	916,438	232,944	3,238,896
Baltimore	2,822,969	0	10,760	2,833,729
Tacoma/Seattle	2,573,183	104,026	10,808	2,688,018
Tampa	1,454,492	106,667	137,301	1,698,460
Portland	1,427,755	203,294	27,553	1,658,602
Anchorage	859,373	305,719	0	1,165,091
New York	437,036	291,538	9,018	737,591
Savannah	224,246	32,154	50,254	306,654
Charleston	205,026	0	8,621	213,647
Miami	0	0	154,168	154,168
Oakland/San Francisco	82,367	35,934	13,226	131,526
Honolulu	6,562	67,276	4,993	78,831
Boston	65,014	8,533	4,351	77,898
San Diego	0	0	0	0
Total	36,342,197	6,369,206	958,424	43,669,827

The following description of the current trade patterns in Puget Sound ports is based on 1998 Puget Sound vessel call data provided by the Puget Sound Steamship Operators Association (PSSOA). The database that was used is not standardized, meaning that not all of the information category entries for each vessel call were made, and the entries do not always adhere to a standard format. For example, the entry for the last port of call may contain a terminal number, a waterway name, the name of a geographical feature, or a port or country name. The World Port Index (1984) was used in order to determine the location of the last port of call. Lastly, the database includes an entry for each vessel movement. Therefore, a vessel that enters port and anchors before proceeding to a terminal is recorded as two vessel calls. The first is from the last port of call to anchor and the second is from anchor to the destination port. Due to these aspects of the database, the following analysis provides only a preliminary picture of Puget Sound shipping traffic.

There were 3,861 vessel calls to Puget Sound in 1998. The majority of the vessels were container ships, followed by tanker ships and then by bulk vessels (see Figure 1). A variety of other specialized vessels made up a minority of vessel traffic in Puget Sound. The most common last port of call for vessels was Japan, followed by California, Alaska and Washington, each with 500 or more vessel calls to Puget Sound in 1998 (see Figure 2). In total, 2,083 vessels, or 54 percent of the vessel traffic in 1998 came from another Pacific coast port (Alaska, Canada, Washington, Oregon, California or Mexico) (see Figure 3). These 2,083 vessels would not have to be regulated under the new U.S. Coast Guard Ballast Water Exchange Program.

Puget Sound Shipping Patterns (1998)

These were:

- 3,861 vessel calls to Puget Sound ports in 1998.
- Container ships were the most numerous, followed by tankers and bulk vessels.
- The most common last port of call was Japan, followed by California, Alaska and Washington.
- 54 percent of the traffic arriving in Puget Sound originated at Pacific Coast ports.
- 17 percent of vessels (658 out of 3,861) that arrived in Puget Sound during 1998 represented a high probability of ballast water discharge.
- Of the 17 percent, the vast majority were bulk and tanker vessels.
- Of the 17 percent, 73 percent originated from other Pacific Coast ports.
- The ballast water capacity of these high risk vessels is estimated at approximately 9.4 million metric tons.
- It is estimated that bulk vessels and tankers accounted for over 90 percent of the 9.4 million metric tons capacity.
- The total ballast water arrival volume for all vessels calling to Puget Sound in 1998 is estimated at nearly 21 million metric tons.

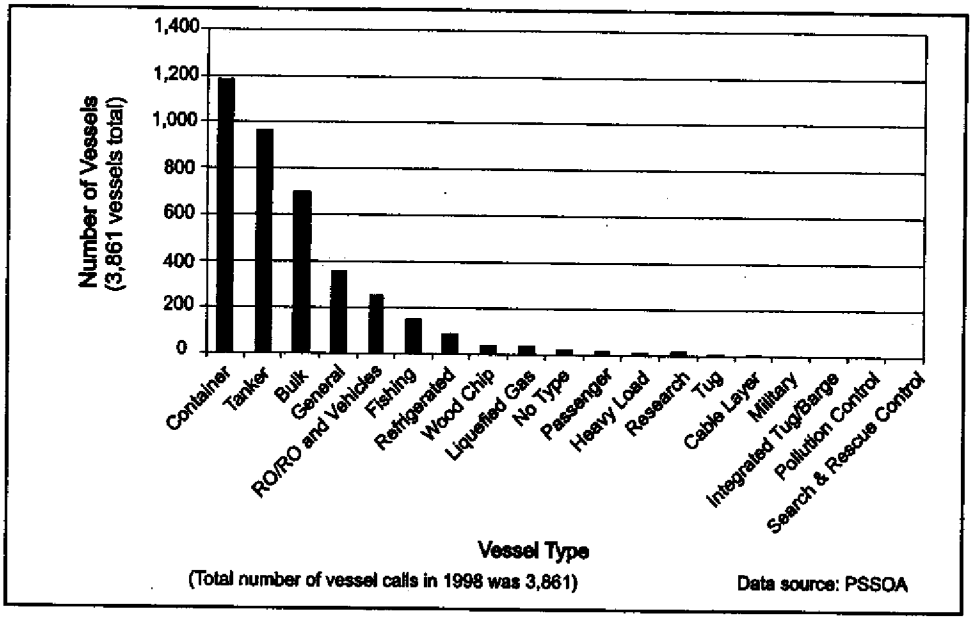


Figure 1. Vessel Types for Vessels entering Puget Sound in 1998

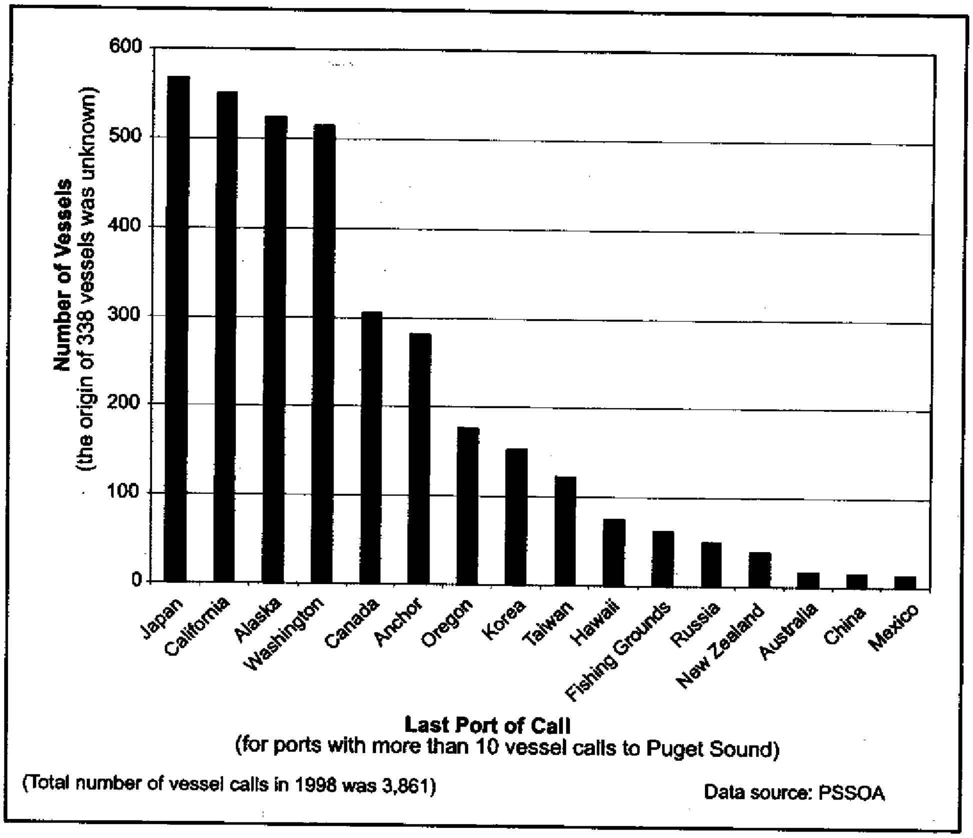
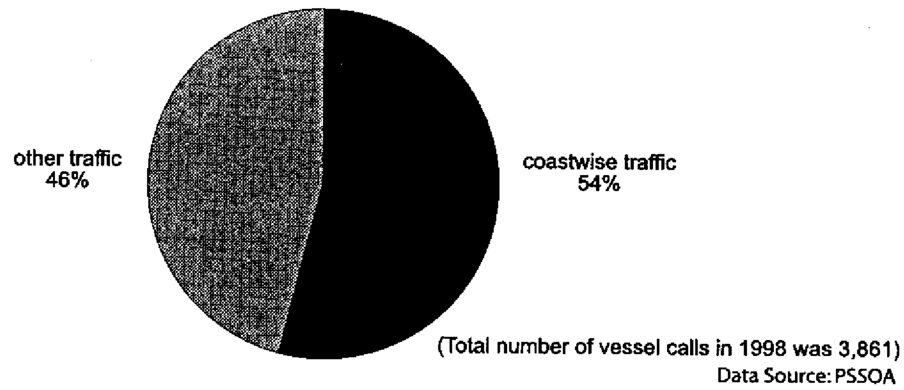


Figure 2. Last Port of Call for Vessels Calling in Puget Sound in 1998.

Figure 3. Vessels engaged in Coastwise Traffic in Puget Sound in 1998.



It should be noted that the last port of call determines whether a vessel is subject to the Coast Guard ballast water regulations, however, it is not a good indicator of ballast water origin (Carlton et al., 1995). Vessels routinely partially ballast and deballast during a voyage and while in port to make minor adjustments. Therefore, the ballast water contained in most ballast tanks is a mixture of water from a variety of sources. In addition, even if a vessel has fully deballasted and then reballasted in one area, it is likely that the ballast tank will still contain sediment, and thus organisms, from other source regions.

Of the 3,861 vessel calls to Puget Sound in 1998, 658 vessels, or 17 percent of vessels loaded, did not discharge cargo (see Figure 4). These vessels represent a high probability of ballast water discharge. They presumably entered port in ballast and then took on cargo. It is likely that these vessels discharged their ballast water, rather than retaining it on board, while the vessel was loaded with cargo. The remainder of the Puget Sound shipping analysis will focus on these 658 vessels.

Of the 658 vessels that constituted a high probability of ballast water discharge, approximately 300 were bulk vessels and approximately 200 were tanker vessels (see Figure 5). Therefore, over 500 of the 658 vessel calls were from either bulk or tanker vessels. It is probable that there is seasonal variability in the bulk vessel traffic due to higher grain exports during the late summer (personal communication, Harry Hutchins, PSSOA). Although container vessels were the most common vessel type to call in Puget Sound in 1998, only four container vessel calls were considered to have a high probability of ballast water discharge. Various types of wood and oil products were among the most common cargos carried by vessels with a high probability of ballast water discharge (see Figure 6).

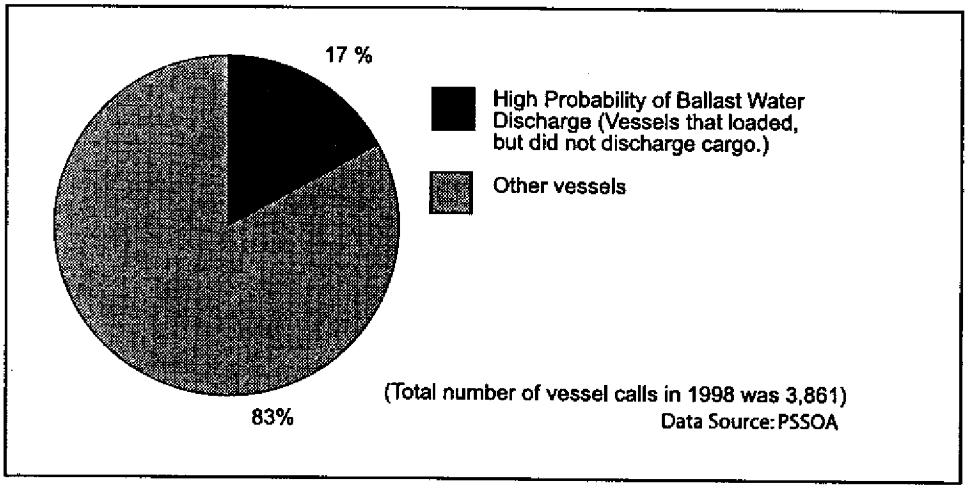


Figure 4. Vessels with a High Probability of Ballast Water Discharge to Puget Sound in 1998

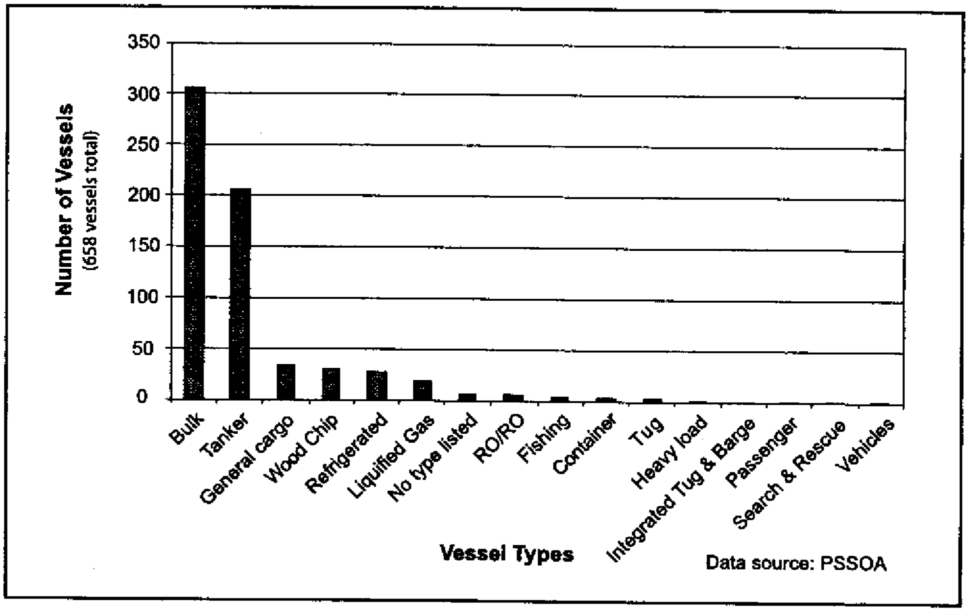


Figure 5. Vessel Types for Vessels with a High Probability of Ballast Water Discharge to Puget Sound in 1998.

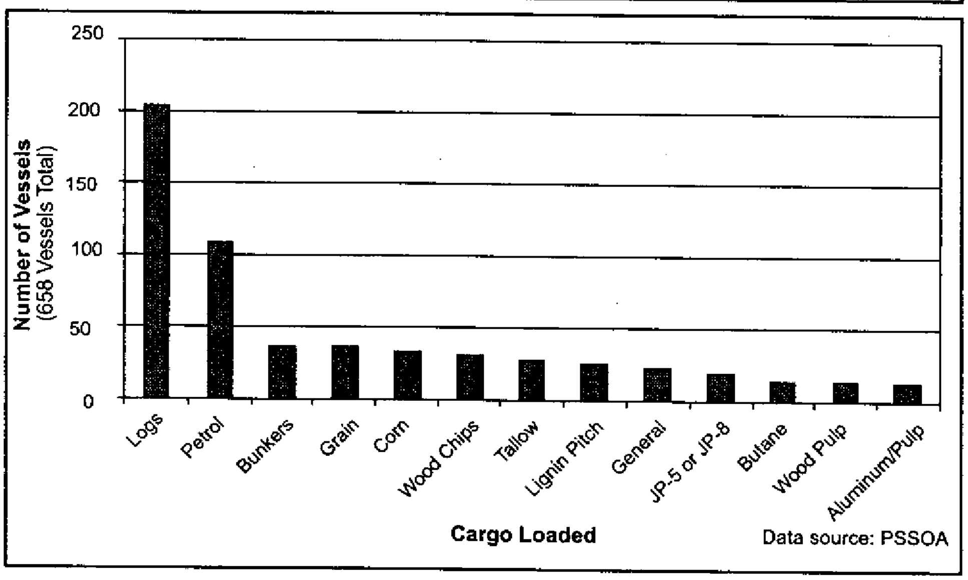


Figure 6. Cargo loaded on Vessels with a High Probability of Ballast Water Discharge to Puget Sound in 1998.

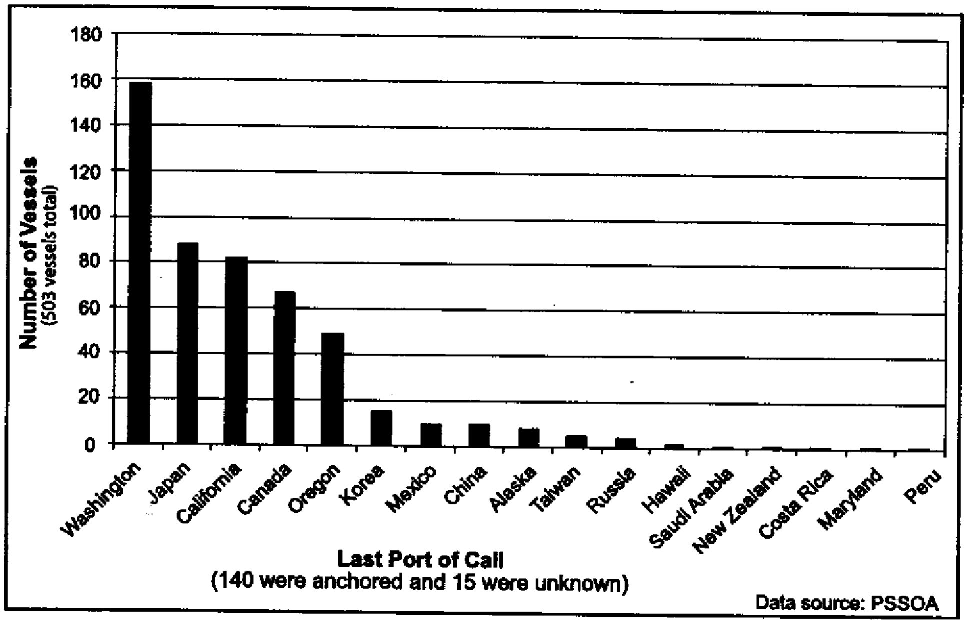


Figure 7. Origin of Vessels with a High Probability of Ballast Water Discharge to Puget Sound in 1998.

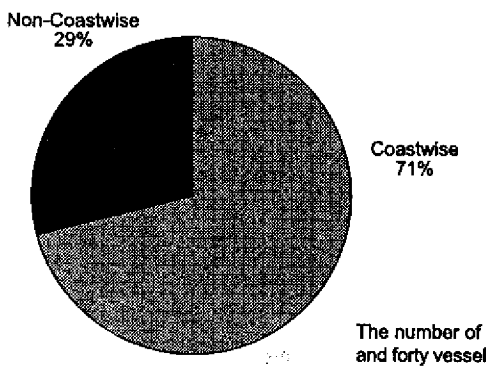
The majority of the vessel calls that constituted a high possibility of ballast water discharge came from ports in Washington, with approximately 180 vessel calls (see Figure 7). Other common last ports of call were in Japan, California and Canada. Overall, 71 percent of high-risk vessel calls originated along the Pacific coast (see Figure 8). In effect, the Coast Guard does not regulate the ballast water operations of 71 percent of the vessels with a high-probability of discharge in Puget Sound.

The methods outlined by Carlton et al. (1995) were used to estimate the ballast water capacity of the 17 percent of vessels that probably discharged ballast water into Puget Sound. According to data generated by the Animal and Plant Inspection Service of the U.S. Department of Agriculture, Carlton et al. (1995) developed basic relationships between summer deadweight tonnage (SDWT) and ballast water capacity (BWCAP) and a relationship between SDWT and average ballast water arrival volumes (BWARR) for various vessel types using a regression analysis. The ratio of BWCAP to SDWT is 0.38 for all vessels, 0.32 for container ships, 0.38 for tankers and 0.43 for bulk vessels. These are the values that were used to estimate the total ballast water capacity for the vessels with a high probability of discharge that entered Puget Sound in 1998. The ratio of BWARR to SDWT is 0.16 for all vessels, 0.15 for container ships, 0.05 for tankers and 0.23 for bulk vessels. These values were used to estimate the total BWARR volumes for vessels that entered Puget Sound in 1998. Other methods for estimating ballast water quantities have been developed and are comparable to this method (see Carlton et al., 1995; Pollutech, 1992)

A conservative estimate of the total of the BWARR volumes for all vessels that arrived in Puget Sound in 1998 is nearly 21 million metric tons. Twenty-one million metric tons of ballast water would fill the Seattle Kingdome more than 10 times. It is not likely that each of the vessels that called in Puget Sound ports in 1998 discharged their entire ballast water arrival volume. However, the ballast water arrival estimate is a value that can be used to assess the risk facing Puget Sound from the ballast water pathway.

The total estimated ballast water capacity for the 658 vessels that presumably discharged ballast water into Puget Sound in 1998 is 9.4 million metric tons. This volume of ballast water would fill the Seattle Kingdome almost five times. Assuming that vessels that enter port unloaded and leave port loaded with cargo discharged their full ballast capacity, an estimated minimum of 25,800 metric tons of ballast water could have been released in Puget Sound per day, or 1,076 metric tons per hour. Bulk vessels and tankers accounted for nearly 90 percent of that total, representing nearly 4.5 and 3.5 million metric tons respectively (see Figure 9).

Carlton et al. (1995) used Census Bureau data to make estimates about ballast water in Puget Sound. The Census Bureau data provided information about the condition of vessels arriving in port. Vessels that arrive in port with no cargo are considered to be "in ballast." Vessels that are partially loaded with ballast water are "with ballast." Vessels that arrive in port fully loaded with cargo have no ballast water on board. The analysis provided in this report, which did not contain information about vessels' ballast water condition upon arrival, came from data provided by the Puget Sound Steamship Operators Association. Due to this difference, it is difficult to make comparisons between the results of the two analyses. However, some broad inferences about ballast water in Puget Sound over time may be made. In 1991, 12 percent of vessels arrived at Puget Sound ports "in ballast." In 1998, as many as 17 percent of vessels may have arrived in ballast (Carlton et al., 1995). In 1991, Carlton et al, (1995) estimate that Seattle received 2.7 million metric tons of acknowledged ballast water. In 1998, vessels arriving in ballast could have discharged as much as 9.4 million metric tons of ballast water and all vessels combined could have discharged over 20 million metric tons of ballast water into Puget Sound. Based on these results, it appears that more ballast water was discharged into Puget Sound in 1998 than in 1991.

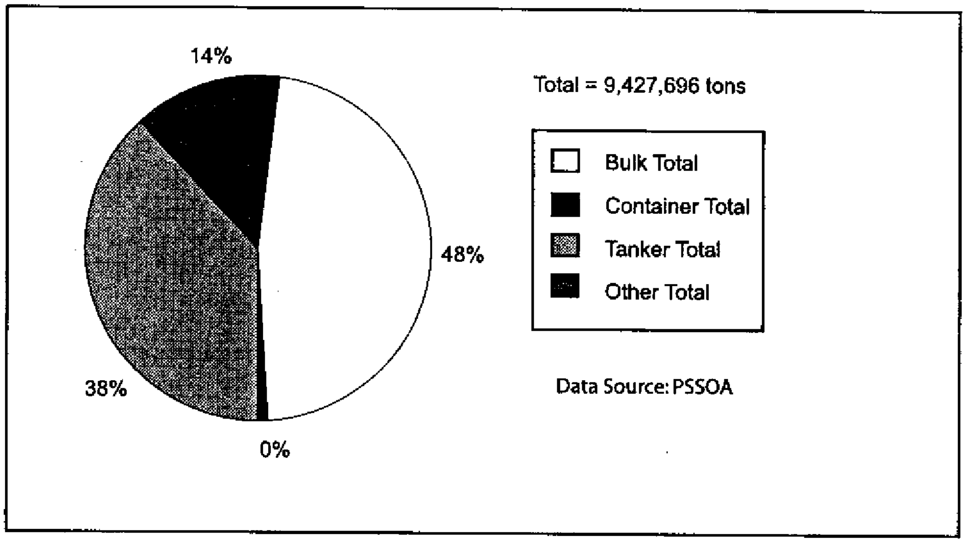


The number of vessels represented is 503. One-hundred and forty vessels with a high probability of ballast discharge were anchored, and the origin of 15 was unknown.

Data source: PSSOA

Figure 8. Vessels with a High Probability of Ballast Water Discharge to Puget Sound that were in Coastwise Traffic in 1998.

Figure 9. Estimated Ballast Water Capacity for Vessels with a High Probability of Ballast Water Discharge to Puget Sound in 1998.



British Columbia Ports

Shipping data like those for Puget Sound do not seem to exist for the Georgia Basin ports. However, summary statistics are available for the Port of Vancouver, the largest and most important port in British Columbia. During 1998, Vancouver handled 72 million metric tons of cargo and experienced a 16 percent increase in container traffic and a 7 percent increase in cruise traffic. In 1998, 2,743 vessels called at Vancouver, representing 91,243,000 total gross registered tonnage. Coal and grain were the most common commodities traveling through Vancouver in 1998, representing over half of the cargo tonnage. The country engaged in the most trade with Vancouver, by tonnage, was Japan. Other principal trading countries included South Korea, China, U.S., Taiwan, Brazil, Mexico, Great Britain, Indonesia and Italy (Vancouver Port Authority website).

There are several aspects of the shipping patterns at the Port of Vancouver that put it at high risk of ballast water discharge. Primarily an export port, Vancouver exported 62.4 million metric tons and received 5.5 million metric tons of foreign cargo in 1998 (Vancouver Port Authority website). As such, it is reasonable to presume that a large number of vessels arrived in ballast, discharged their ballast water and loaded cargo for export. In addition, 84 percent of the cargo tonnage that Vancouver handled in 1998 was bulk cargo. As the Puget Sound summary revealed, the ballast water capacity of bulk vessels is higher (a greater percentage of dead weight tonnage) than other vessel types. However, the Port of Vancouver currently has a mandatory ballast water exchange program in place. Vancouver's analysis of the effectiveness of the ballast water exchange program is not complete.

Ballast Water Practices

Currently, there is very little data describing the patterns of ballast water exchange among vessels entering Puget Sound. There are no statewide or port policies governing the exchange of ballast water. Ballast water practices in Puget Sound are governed primarily by two voluntary exchange programs. The U.S. Coast Guard ballast exchange program encourages vessel operators to exchange ballast water before entering U.S. waters. This program is voluntary and vessels already in U.S. waters are excluded. The PSSOA strongly recommends that its member companies comply with the Coast Guard program. In addition, the PSSOA asks members to conduct ballast water exchanges on coastal voyages if it is safe and if the vessel is at least 25 nautical miles offshore.

The Coast Guard began collecting data about compliance with the voluntary program in July 1999. Ballast water exchange data for vessels entering U.S. waters will be available in approximately three years. However, there are currently no efforts to collect ballast water exchange data for vessels that are engaged in coastwise voyages.

In the Georgia basin, the Port of Vancouver is a leader in ballast water management. Vancouver has had a mandatory ballast water exchange program for over a year. The program requires vessels arriving from ports located outside of the Pacific coast (defined as north of Cape Mendocino, California) to carry out a mid-ocean ballast water exchange (Vancouver Port Authority, 1997). Several other Georgia basin ports have implemented ballast water exchange programs modeled on the Port of Vancouver program. These ports include Port Alberni, Nanaimo and the Fraser River ports (personal communication, John Jordan, Port of Vancouver).

The Port of Vancouver began collecting ballast water exchange data about two years ago, but only recently began entering data into a database. The database does not have enough data entered at this time to make definitive statements about ballast water exchange. However, Assistant Harbor Master Michael Cormier stated that anecdotally less than two percent of the deep-sea vessels arriving in ballast have not exchanged ballast. The reason for noncompliance in these cases was a concern over weather or stability (personal communication, Michael Cormier, Port of Vancouver).

Science and Technology

Open-Ocean Ballast Water Exchange

Currently, the most commonly used tool for ballast water management is open-ocean ballast water exchange. There are two major ecological principals underlying this tool. The first is that there is a low probability of reciprocal introductions. Organisms that are taken from a near-shore environment are not likely to survive the environmental conditions in the open ocean. An open-ocean environment exhibits relatively uniform conditions that are unlike those found in nearshore ecosystems. Similarly, the likelihood of open-ocean organisms surviving in nearshore conditions is low. The second ecological principle at work is that nearshore organisms released into the open ocean are not likely to reach a hospitable nearshore environment through currents or other means during the time frame in which the organisms would remain viable (National Research Council (NRC), 1996).

There are two methods for an open-ocean exchange of ballast water. The empty/refill method requires "pumping out ballast water taken on in ports, estuaries, or territorial waters until the tank is empty, then refilling it with mid-ocean water" (NRC, 1996). The flow through method requires "flushing out ballast water by pumping in mid-ocean water at the bottom of the tank and continuously overflowing the tank from the top until sufficient water has been changed to minimize the number of original organisms remaining in the tank" (NRC, 1996). According to the International Maritime Organization (IMO), "at least three times the tank volume should be pumped through the tank" in order to for a flow through exchange to be effective (IMO, 1997).

Open-ocean ballast water exchange is currently the most utilized risk management method because most vessels can conduct a ballast water exchange without vessel retrofitting. Since exchange occurs during a voyage while crew members have fewer duties, ballast exchange is relatively cheap (estimated at 5.8-8.1 cents per metric ton of ballast water) and can be implemented without delay (Dames and Moore, 1999). However, there are problems with ballast water exchange as a solution to the ballast water problem.

Ballast water exchange methods can put the safety of the vessel and crew in jeopardy (NRC, 1996; Dames and Moore, 1999; Carlton et al., 1995). Ballast water is placed on board to maintain vessel stability. Therefore, the removal or shifting of ballast water during a voyage can result in dangerous vessel instability. Woodward et al. (1994) found that ballast water exchange in wave heights of 20 feet or more could cause moments or shears that exceed design values and pose unacceptable risks for vessel damage (also see Cohen, 1998 for review of safety studies to date). Safety issues play an important role in ballast water management, especially in the Pacific Northwest where winter storm conditions can be very treacherous.

The efficacy of ballast water exchange at removing nearshore organisms from ballast tanks is also of major concern. Original estimates of exchange efficiencies resulting from the empty/refill method were as high as 99.9 percent. However, field tests and investigations have revealed efficiencies of between 70 and 90 percent (Dames and Moore, 1999). Although flow through methods may achieve exchange rates of 95 percent, one study found that 25 percent of original plankton and sediment remain in flushed tanks (Dames and Moore, 1999). Hines et al. (1998) found that ballast water exchange resulted in greater than a 90 percent reduction of coastal plankton. However, 300,000 or more organisms per ship can remain from the original source port following ballast water exchange.

Due to safety and effectiveness concerns, ballast water exchange will not be the ultimate solution to the ballast water problem. Although the effectiveness and safety of ballast water exchange could be improved slightly through changes in vessel design, ballast water exchange is generally viewed as an interim solution to be used until a safer and more effective method is accessible. Due to the variety of vessels, trade routes and cargoes, there will probably not be one solution for every situation. The ballast water problem can be dealt with most effectively using different tools to fit varying circumstances.

Alternative Treatment Technologies

Given that ballast water exchange is not a universal solution, there are several other options that have been suggested or are currently being explored. Possible solutions could be implemented during ballasting in the source port, during the voyage or upon arrival at the destination port (see NRC, 1996). In practical terms, this translates into shore-based solutions, on-board solutions or open-ocean solutions such as ballast water exchange. Proposed on-board solutions include thermal treatment, filtration, ultra violet light, biocides, magnetic fields, deoxygenation, acoustic systems and electric pulse. Shore-based solutions include receiving facilities where ballast water could be unloaded and treated before release, or facilities that could provide clean ballast water. For more information about alternative treatment technologies see NRC, 1996, Carlton et al., 1995 or Cohen, 1998.

Regional Oceanography

One purpose of this report is to suggest considerations for the siting of alternative zones for ballast water exchange for vessels entering Puget Sound. Although vessels entering Puget Sound may transit Canadian waters off of Vancouver Island, those areas will not be described here because they are under Canadian jurisdiction and are not under consideration as alternative exchange zones. Vessels entering Puget Sound transit U.S. waters in the Strait of Juan de Fuca, Puget Sound and off the coast of Washington (see Figure 10).

The oceanography of Puget Sound, the Strait of Juan de Fuca and the Washington Coast is complex and varies along multiple time scales according to season, local conditions and global events such as El Niño. Drift card studies of the region showed that material released in Puget Sound and the Strait of Juan de Fuca had a higher recovery rate on shore than material released off the coast of Washington.

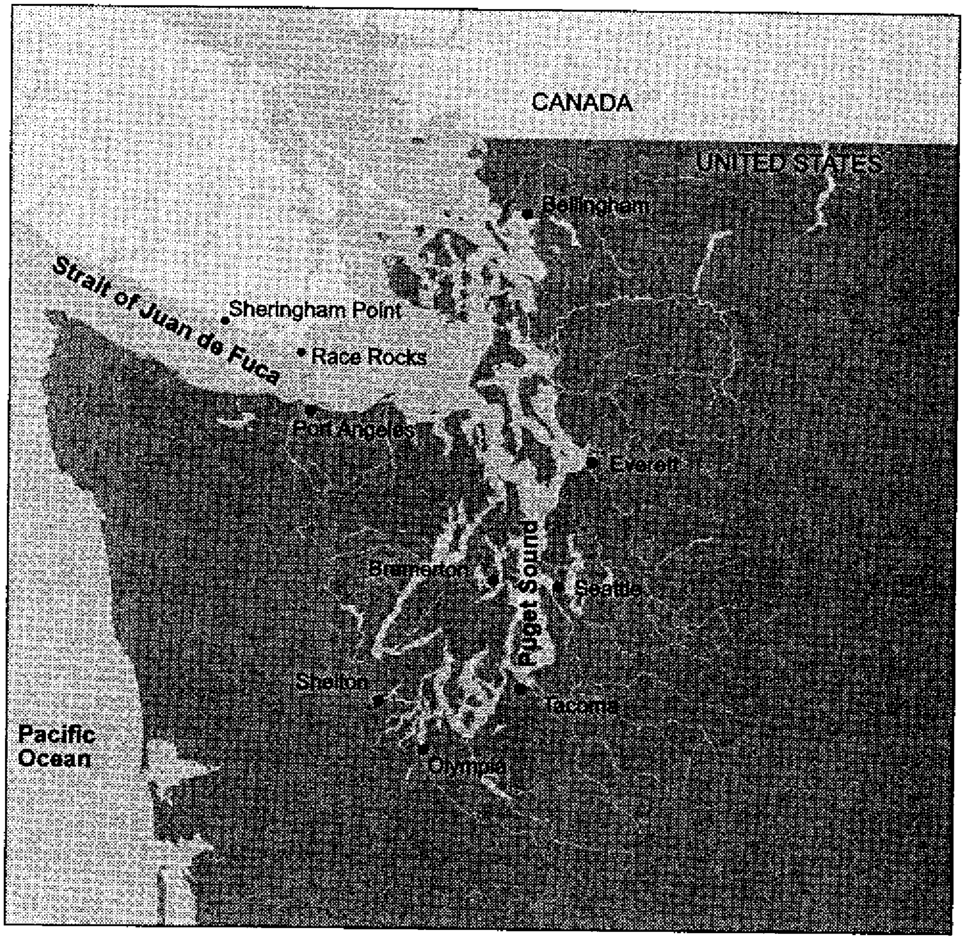


Figure 10. Map of Puget Sound, Strait of Juan de Fuca, and Coastal Washington

Puget Sound

The main basin of Puget Sound is a partially-mixed, fjord-like estuary which connects to the Strait of Juan de Fuca through Admiralty Inlet and extends southward 100 km (55 miles) to Commencement Bay. North of Seattle, the main basin exhibits typical estuarine flow with net seaward flow near the surface due to freshwater input from rivers, and net landward flow at depth (Cannon, 1983; Pashinski and Charnell, 1979; Thomson, 1994). Surface circulation in the main basin is highly influenced by winds and tidal eddies (Pacific Marine Environment Laboratory, 1976; Kawase, 1998; Ebbesmeyer, 1999).

Strait of Juan de Fuca

The Strait of Juan de Fuca exhibits a typical estuarine circulation pattern with fresher surface water flowing seaward above colder, saltier water flowing landward (Ott and Garrett, 1998; Ebbesmeyer et al., 1991(a); Holbrook et al., 1980; Thomson, 1994). Due to the earth's rotation and the width of the strait, the surface seaward outflow is strongest on the northern, Canadian side of the channel and there is a greater subsurface inflow on the southern, U.S. side of the Strait (see Figure 11) (University of Victoria website; Pease et al., 1979; Hickey et al., 1991; Thomson, 1994).

The typical estuarine circulation can be altered by changes in coastal winds. Reversals in surface flow (from seaward to landward) can result from a low-pressure center off Washington that generates southerly coastal winds (Ebbesmeyer et al., 1991(a): Holbrook et al., 1980; Hickey et al., 1991; Thomson,1994). These reversals can last several days and up to a month. Although they usually occur during the winter, reversals have been observed during the summer (Holbrook et al., 1980; personal communication, Dr. Curtis Ebbesmeyer, Evans-Hamilton, Inc.). In addition, tidal eddies strongly influence surface circulation in the Strait. Ebbesmeyer et al (1991(b)) found that 14 prominent eddies were the principal influence on the recovery of drift cards in the eastern Strait. Ebbesmeyer et al. (1991(b)) also revealed that winds were of secondary importance to the recovery patterns in the eastern Strait.

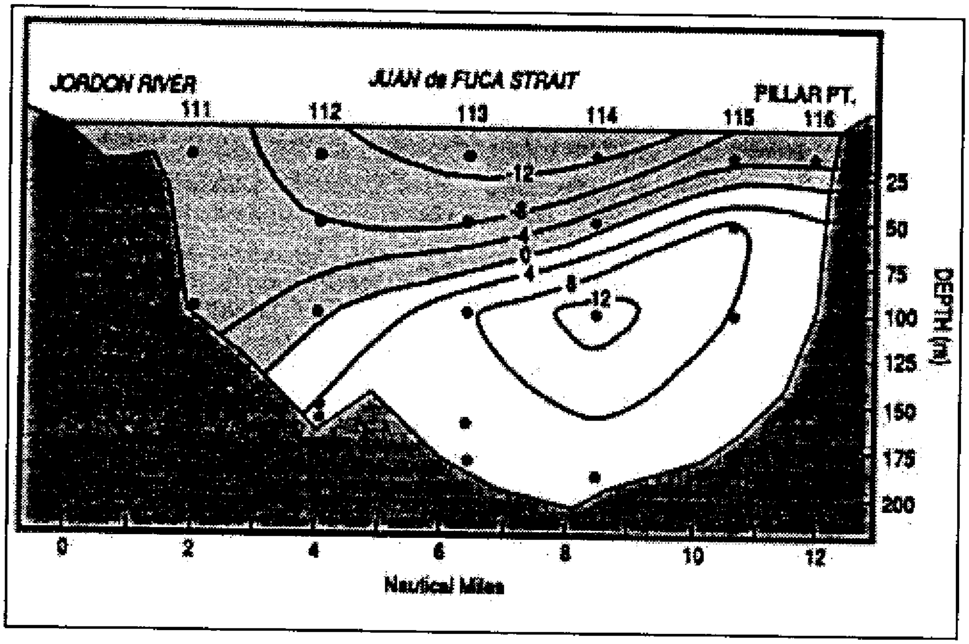


Figure 11. Cross section of residual along channel flow in the central portion of Juan de Fuca Strait for the period of 6 March-14 June 1973 (speed in cm/s). The view is up-strait towards the east. Negative values (shaded) are seaward and positive values are landward. (Thomson, 1994)

Coastal Washington

The California Current System flows off of the Pacific Coast and is composed of the California Current, the Davidson Current, the California Undercurrent and possibly a subsurface Washington Undercurrent (see Figure 12). Currents offshore of Washington exhibit a strong seasonal variability (see Figure 13).

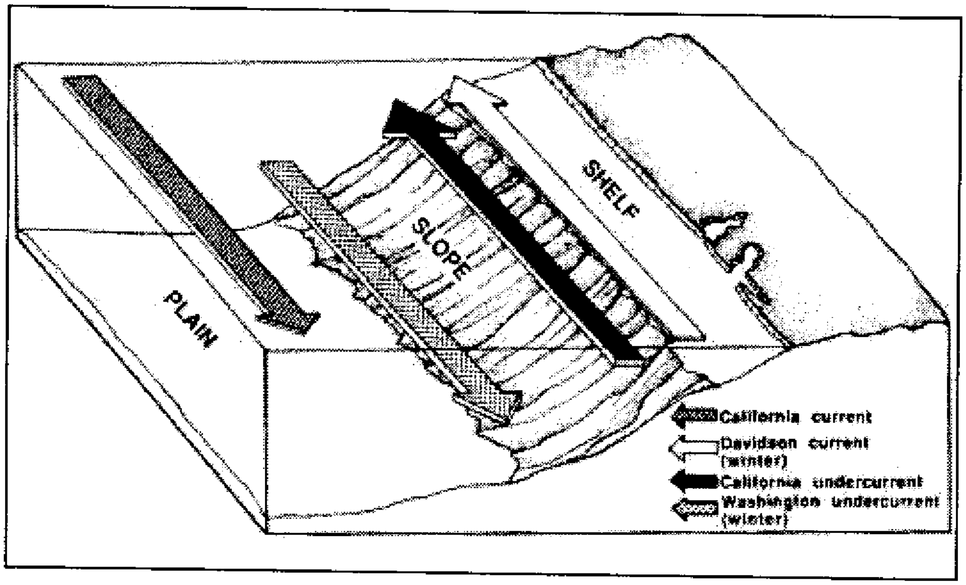


Figure 12. Oceanic and continental slope surface currents (California Current and Davidson Current in winter) and Undercurrents (California Undercurrent and hypothesized Washington Undercurrent in winter) off Washington. (Strickland and Chasan, 1989) Reprinted by permission from Washington Sea Grant Program, University of Washington, 1999.

The California Current flows southward year-round from the shelf break of the Pacific coast to 1,000 km (621 miles) offshore, and it is strongest in the summer to early fall and weakest in the winter (Hickey 1998). It is closer to shore during the summer and further off of the shelf in winter (Strickland and Chasan, 1989). The California Undercurrent is a relatively narrow (10-40 km), subsurface current that flows northward over the continental slope from Baja California to Vancouver Island (Hickey, 1998), and it is strongest in summer and early fall and exhibits minimum northward subsurface flow in the spring (Hickey, 1998). The northward flowing Davidson Current begins to develop inshore of the California Current off of the Washington/Oregon coast in September, is well established in January and disappears by May (Purdy, 1990).

Currents over the shelf generally follow the seasonal pattern of ocean currents, but they are highly variable and are influenced by local winds, bottom and shoreline configuration and freshwater input. "On the average, water flows southward in the upper 100 meters during summer, and northward below that depth. Water over the shelf flows generally northward at all depths during winter; nearshore under the Columbia River plume, southward flow may be found" (Strickland and Chasan, 1989).

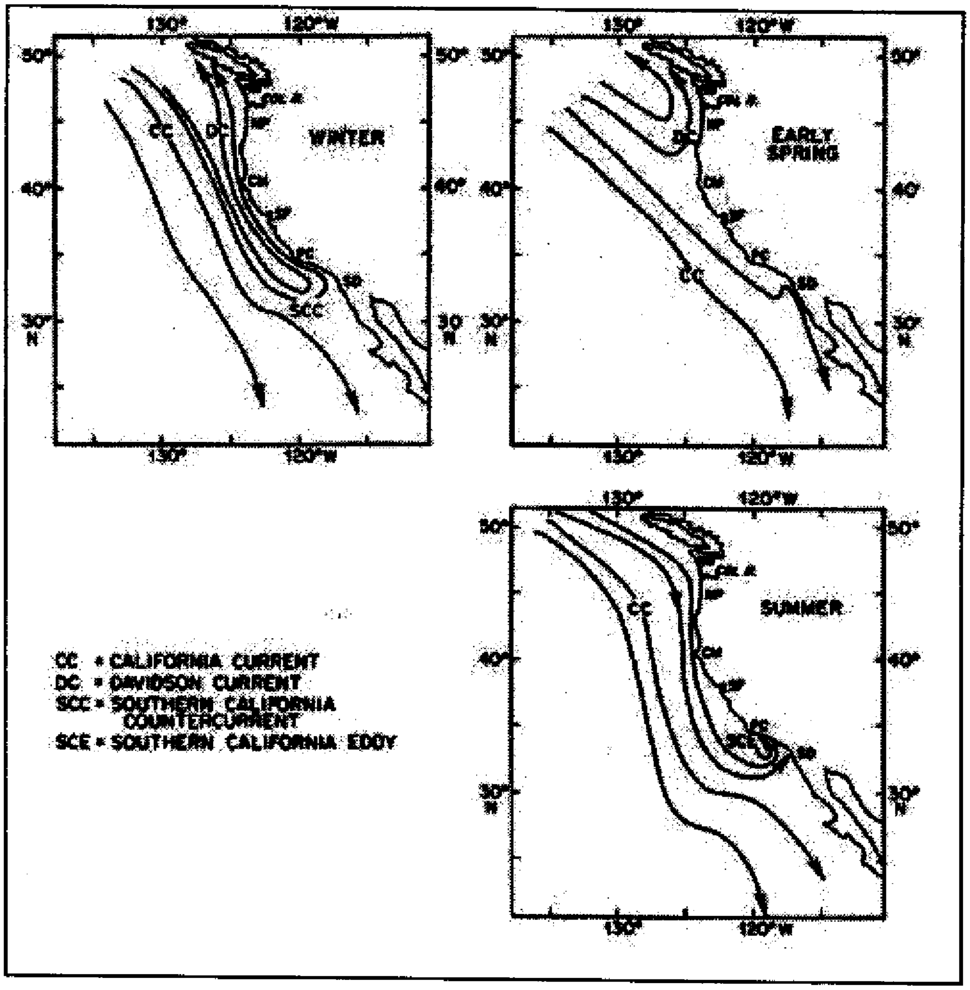


Figure 13. Schematic illustrating seasonal variation of deep-ocean boundary currents off the U.S. West Coast. Abbreviations along the coast signify (from north to south) Neah Bay, Newport, Cape Mendocino, San Fransisco, Point Conception and San Diego. (Hickey, 1989)

Coastal currents vary over a variety of time scales, from minutes to years. Variability within a year and between years is significant off of the Pacific Coast. Much of this variability is due to the El Niño Southern Oscillation phenomena (Hickey, 1998). Overall, during El Niño years, large scale currents flow more northward and coastal sea level is higher than in non-El Niño years (Hickey, 1989).

Wave heights and wavelengths are important due to their effects on structures and the hazards they pose to navigation. The U.S. Pacific Northwest is noted for heavy wave conditions, with measured extremes of wave height ranging from 15 to 29 meters off of the coast of Washington (Purdy, 1990). Maximum and mean wave heights are largest on both the outer shelf and the nearshore during the winter months, October through April (Strickland and Chasan, 1989).

Drift Card Studies

Assuming that organisms released in ballast water will remain in the surface water layer, drift card studies provide important insight into how released organisms might be transported. A drift card study consists of dropping a number of painted, floatable cards at a specific point in the water. These cards are labeled with a message so that once a card reaches shore, anyone who finds it can report its recovery. Although recovery rates can be influenced by proximity to a population center, recovery patterns indicate something about the way that surface currents surrounding the drop point behave. The results of several drift card studies are summarized below in order to provide an overview of how ballast water might behave in various Pacific Northwest waters.

Drift cards released in Puget Sound, south of Admiralty Inlet, had a recovery rate exceeding 50 percent, meaning that one out of every two cards released was found on the shore and reported by the public. The time between release and recovery was on the order of one to several weeks. Drift cards released in the eastern Juan de Fuca Strait, east of the Elwa River, had a recovery rate of approximately 25 percent. Tidal eddies in this area distribute drift cards preferentially to Victoria, Dungeness Spit and the San Juan Islands within days to weeks. Recovery rates from drifters released on the Pacific coast were less than 10 percent. Recovery rates on the coast decreased with the distance of the release site from shore. A small percentage of drifters released beyond approximately 50 miles from shore were found in Hawaii and across the North Pacific (personal communication, Dr. Curtis Ebbesmeyer, Evan-Hamilton, Inc.)

A drift card study by Pashinski and Charnell (1979) revealed that nearly 45 percent of drift cards released in Puget Sound's Main Basin were recovered and almost all of those recoveries occurred in the Main Basin or in the San Juan Islands region (eastern Strait of Juan de Fuca). The recovery rate for cards released in the San Juan Islands region was even higher—nearly 50 percent—and almost all of the cards were recovered in the San Juan Islands region. This recovery rate is high in comparison to the 17 percent recovery rate for cards released in the western Strait of Juan de Fuca.

Ebbesmeyer et al. (1991(b)) have identified 14 prominent eddies in the eastern Strait of Juan de Fuca and drift card studies in the eastern Strait indicate that the recovery patterns are highly dependent on these eddies. Two prominent patterns emerged from eastern Strait drift card studies: approximately three quarters of the recoveries were made on northern shores and one quarter on southern shores and about half of the recoveries were made in three specific locations—Victoria, the San Juan Islands and Dungeness Spit (Ebbesmeyer et al., 1991(b); Ebbesmeyer et al., 1991(a)).

Biologically Sensitive Areas in the Pacific Northwest Region

In their analysis of the ballast water problem, Carlton et al. (1995) define sensitive coastal areas as "...relatively small, restricted sites where great value (environmental, social, aesthetic, economic, or otherwise) is placed on maintaining resources as they are, and where focused disturbances could easily and radically alter those values. Examples would include (a) mariculture and aquaculture sites, (b) regions of naturally productive finfish and/or shellfish fisheries, (c) reserves and sanctuaries that attempt to preserve remaining 'natural' areas from further human alteration, and (d) sites known to have rare and/or endangered marine or maritime plants and animals." This definition will be used for the purposes of this report.

Aquaculture

Aquaculture is a major source of revenue for Washington, especially in Puget Sound and coastal counties. The major aquaculture facilities in Washington are located in Puget Sound, Willapa Bay and Grays Harbor. The Washington Department of Fish and Wildlife (WDFW) estimates that in 1998, oyster harvests in Willapa Bay and Grays Harbor alone totaled $6,554,644 and $2,279,050 respectively (personal communication, Greg Bargmann, WDFW). The aquaculture industry could be dramatically affected by species introductions, despite the fact that many aquaculture species are themselves nonindigenous. For example, the introduction of the European green crab is blamed for the decline of the soft-shell clam fishery on the East Coast at the turn of the century. It has been suggested that the establishment of the green crab could have a similar effect on the crab and oyster fisheries in Washington.

Other Fisheries

Other fisheries are commercially important in Washington. The value of domestic fisheries landings (excluding aquaculture, except oysters and clams) in Washington State totaled over $123 million in 1998 (NMFS, 1999). Some of the prominent Washington fisheries include salmon, with an estimated value of $785,504; crab, with an estimated value of over $12 million; and bottomfish, with an estimated value of nearly $9 million (personal communication, Greg Bargmann, WDFW). These fisheries could suffer as a result of the introduction of nonindigenous species.

Marine Protected Areas

Washington is known for its natural environment and is home to numerous Marine Protected Areas (MPAs). "MPAs are areas specially managed to protect species, habitats and ecosystems; they are marine areas set aside from otherwise unrestricted human activities" (Murray and Ferguson, 1998(a)). MPAs could suffer severe alteration if invaded by nonindigenous aquatic nuisance species. In fact, many MPAs have already been invaded by saltmarsh cordgrass, *Spartina alterniflora*, resulting in significant changes in the saltmarsh and mudflat ecosystems.

There are at least 102 MPAs in Puget Sound and the Strait of Juan de Fuca (Murray and Ferguson, 1998(b)). Some of these MPAs are quite extensive (see Figure 14). For example, the San Juan Islands National Wildlife Refuge encompasses 83 sites. The Northwest Straits Commission is working to protect and restore the Northwest Straits region, compromising northern Puget Sound and the Strait of Juan de Fuca (Murray-Metcalf Northwest Straits Citizens Advisory Commission, 1998).

Along the Washington Coast, the Washington State Seashore Conservation Area created one intertidal MPA that spans the entire coast (Robinson, 1999). In addition there are 32 other MPAs on the Washington coast (see Table 3) (Robinson, 1999). The Olympic

Coast National Marine Sanctuary spans 3,310 square miles off the Olympic Peninsula, averaging 38 miles seaward and reaching from Cape Flattery to just north of Grays Harbor (Olympic Coast Marine Sanctuary website). In addition to its inland location, the Olympic National Park occupies a 63-mile stretch of land along the coastline of the Olympic Peninsula (Olympic National Park website). The southern coast of Washington is home to numerous national wildlife refuges including Grays Harbor National Wildlife Refuge (1,800 acres) and Willapa National Wildlife Refuge (12,149 acres). In addition, 14 state parks are MPAs and are located along the Washington coast (Washington State Parks website).

Endangered Species Habitat

The marine waters and coastal areas of Washington State are also home to federally endangered and threatened species. There are 23 species listed under the Endangered Species Act of 1973 in Washington State (USFWS website, 1999). Several of these species, including the Western Snowy Plover and the Marbled Murrelet are found along the coast and could suffer from the introduction of nonindigenous aquatic nuisance species. The recently listed Washington salmon creates a much larger area of habitat that warrants protection. For example, the habitat of the Puget Sound chinook and the Hood Canal summer-run chum, both listed as threatened, covers all of Puget Sound and the eastern portion of the Strait of Juan de Fuca (NMFS website).

State Park Areas

(Designated/Developed State Parks and Marine State Parks)

S1	Sequim Bay State Park	S31	McMicken Is. Marine State Park
S2	Camano Island State Park	S32	Polatch State Park
S3	Deception Pass State Park	S33	Squaxin Island State Park
S4	Ebey's Landing	S34	Stretch Point State Park
S5	Fort Casey State Park	S35	Twanoh State Park
S6	Fort Ebey State Park	S36	Cutts Is. Marine State Park
S7	Joseph Whidbey State Park	S37	Eagle Is. Marine State Park
S8	South Whidbey State Park	S38	Joemma Beach State Park
S9	Dosewallips State Park	S39	Kopachuck State Park
S10	Fort Flagler State Park	S40	Penrose Point State Park
S11	Fort Warden State Park	S41	Blind Is. Marine State Park
S12	Mystery Bay Marine State Park	S42	Clark Is. Marine State Park
S13	Old Fort Townsend State Park	S43	Doe Is. Marine State Park
S14	Pleasant Harbor State Park	S44	James Is. Marine State Park
S15	Triton Cove State Park	S45	Jones Is. Marine State Park
S16	Dash Point State Park	S46	Lime Kiln State Park
S17	Saltwater State Park	S47	Matia Is. Marine State Park
S18	Blake Island State Park	S48	Moran State Park
S19	Fav-Bainbridge State Park	S49	Patos Is. Marine State Park
S20	Fort Ward State Park	S50	Posev Is. Marine State Park
S21	Harper State Park	S51	Spencer Spit State Park
S22	Illahee State Park	S52	Stuart Is. Marine State Park
S23	Kitsap State Park	S53	Sucia Is. State Park
S24	Manchester State Park	S54	Turn Is. Marine State Park
S25	Old Man House State Park	S55	Bay View State Park
S26	Scenic Beach State Park	S56	Larrabee State Park
S27	Belfair State Park	S57	Saddlebag Is. Marine State Park
S28	Harstine State Park	S58	Mukilteo State Park
S29	Hope Island Marine State Park	S89	Tolmie State Park
S30	Jarrell Cove State Park	S60	Birch Bay State Park

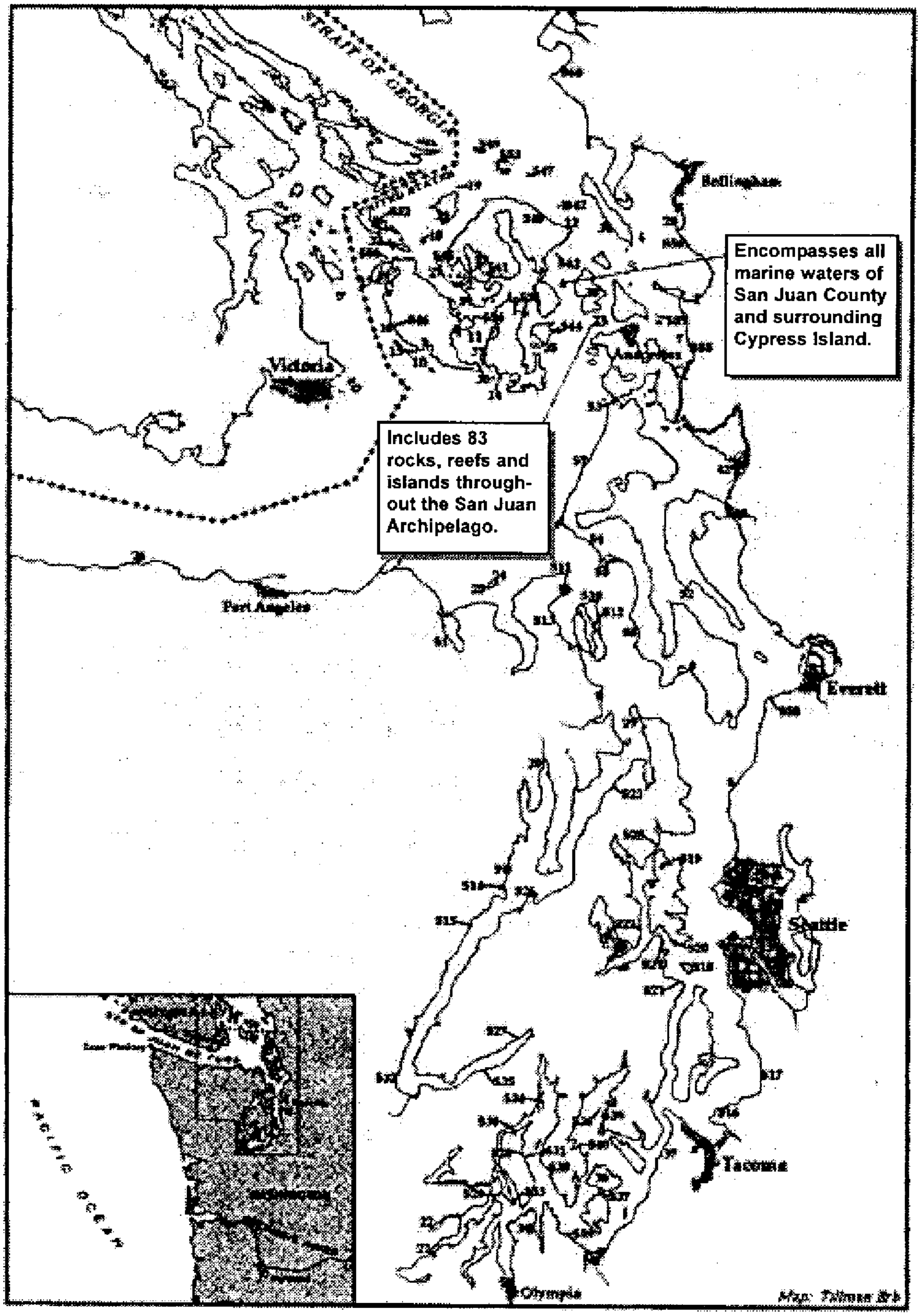


Figure 14. Marine Protected Areas of Puget Sound (Murray and Ferguson, 1998(b))

Table 3. Washington's coastal marine protected areas, their site designation and the government agency with administrative authority over the site. (Robinson, 1999)

Map #	Name or Location	Designation	Agency/Org
1	Friday Harbor to Point Caution	San Juan Islands Marine Preserve Area	WDFW; FHL
2	Yellow and Low Islands	San Juan Islands Marine Preserve Area	WDFW; FHL
3	False Bay	San Juan Islands Marine Preserve Area	WDFW; FHL
4	Argyle Lagoon	San Juan Islands Marine Preserve Area	WDFW; FHL
5	SW Shaw Island	San Juan Islands Marine Preserve Area	WDFW; FHL
6	San Juan County/Cypress I.	Marine Biological Reserve	FHL
7	Padilla Bay	National Estuarine Research Reserve	Ecology
8	Edmonds Underwater Park	Underwater Park	City of Edmonds
9	Sund Rock	Marine Preserve Area	WDFW
10	Haro Strait	Special Management Fishery Area	WDFW
11	San Juan & Upright Channel	Special Management Fishery Area	WDFW
12	Point Lawrence	Voluntary No-Take Bottom Fish Recovery Area	San Juan Co.
13	Bell Island	Voluntary No-Take Bottom Fish Recovery Area	San Juan Co.
14	Charles Island	Voluntary No-Take Bottom Fish Recovery Area	San Juan Co.
15	Pile Point	Voluntary No-Take Bottom Fish Recovery Area	San Juan Co.
16	Lime Kiln Lighthouse	Voluntary No-Take Bottom Fish Recovery Area	San Juan Co.
17	Kellett Bluff	Voluntary No-Take Bottom Fish Recovery Area	San Juan Co.
18	Gull Rock	Voluntary No-Take Bottom Fish Recovery Area	San Juan Co.
19	Bare Island	Voluntary No-Take Bottom Fish Recovery Area	San Juan Co.
20	Dabob Bay	Natural Area Preserve	DNR
21	Kennedy Creek	Natural Area Preserve	DNR
22	Skookum Inlet	Natural Area Preserve	DNR
23	San Juan Islands (83 sites)	National Wildlife Refuge	USFWS
24	Protection Island	National Wildlife Refuge	USFWS
25	Zella M. Schultz/Protection Is.	Seabird Sanctuary	WDFW/USFWS
26	Tongue point	Marine Life Sanctuary	Clallam County
27	Yellow Island	Nature Conservancy Preserve	TNC
28	Chuckanut Island	Nature Conservancy Preserve	TNC
29	Foulweather Bluff	Nature Conservancy Preserve	TNC
30	Goose Island	Nature Conservancy Preserve	TNC
31	Deadman Island	Nature Conservancy Preserve	TNC
32	Sentinel Island	Nature Conservancy Preserve	TNC
33	Waldron Island	Nature Conservancy Preserve	TNC
34	Lummi Island	Natural Area Preserve	WDFW
35	Kimball Preserve, Decatur Is.	San Juan Preservation Trust Preserve	SJPT
36	South Puget Sound	Wildlife Area	WDFW
37	Titlow Beach	Marine Park/Marine Preserve	METRO/Tacoma
38	Cypress Island	Natural Resource Conservation Area	DNR
39	Woodard Bay	Natural Resource Conservation Area	DNR
40	Dungeness	National Wildlife Refuge	USFWS
41	Nisqually	National Wildlife Refuge	USFWS
42	Skagit	Wildlife Area	WDFW

Abbreviations for Agencies and Organizations

DNR - Washington department of Natural Resources

Ecology - Washington Department of Ecology

TNC - The Nature Conservancy

SJPT - San Juan Preservation Trust

FHL - University of Washington's Friday Harbor Laboratories

USFWS - U.S. Fish and Wildlife Service

WDFW - Washington Department of Fish and Wildlife

METRO/Tacoma - Metropolitan Park District of Tacoma

Selected Existing Ballast Water Exchange Programs

A number of port and harbor districts and industry groups have established ballast control programs independent of federal and state rules and regulations. Following is a brief summary of selected programs that are currently in place along the Pacific coast.

Port of Vancouver, British Columbia

Current Ballast Water Exchange Program

On March 1, 1997, the Vancouver Port Authority Harbor Master issued a standing order requiring vessels discharging ballast water into the port to complete a mid-ocean ballast exchange prior to arrival in Canadian waters. The mid-ocean exchange requirements were voluntary during a nine month 'grace period.' The requirements became mandatory on January 1, 1998.

"All vessels destined to arrive at the Port of Vancouver in ballast condition will be required on and from March 1, 1997 to carry out a Mid Ocean Ballast Water Exchange prior to arriving in Canadian Waters. The purpose of this exchange is to limit the possibility of transferring non-indigenous species into Canadian waters. Any vessel conforming to IMO Resolution A 774(18), (Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges), will be considered in compliance with these procedures" (Vancouver Port Authority, 1997).

Harbor Master's representatives board vessels to conduct ballast checks. These officials require a log book entry (in English), an abstract of the log book entry, or a company or other administrative form giving details of the mid-ocean exchange of ballast water. The details must include the following information: position of exchange (latitude and longitude); place where ballast water was originally taken; amount of ballast water; ballast tanks that have had water exchanged; and details if ballast was not exchanged.

Currently, vessels are chosen at random to conduct sampling compliance (personal communication, Michael Cormier, Port of Vancouver). In addition, vessels that claim that they were unable to comply with the standing order due to weather stress or stability issues are also routinely sampled. The Harbor Master's representatives test for compliance using a handheld salinity refractometer to test salinity. They also perform a biological test comparing samples with known indicators, such as "harpacticoid copepods". Sampling takes 1 to 2.5 hours, depending on the physical set-up on the vessel. Vancouver requires vessels that are not found in compliance to "...depart the port and exchange ballast water in the outgoing current of the North side of the Strait of Juan de Fuca, West of Race Rocks" (Vancouver Port Authority, 1997).

Vessels arriving in Vancouver from other Pacific coast ports (north of Cape Mendocino, California) are exempted from the policy if the ballast water to be discharged originated from these waters. Vessels discharging less than 1,000 metric tons of ballast water, and vessels that do not exchange ballast water because of safety concerns, are also exempted.

The alternative zone for ballast water exchange that has been designated by the Port of Vancouver, is at Sheringham Point, in water of at least 100 meters in depth, north of the shipping lanes and west of the military ordinance location (personal communication, Dr. Al Lewis, University of British Columbia). This area is west of Race Rocks and Race Rocks is often casually used to refer to the exchange zone existing between the two points (see Figure 10). At this stage in the Vancouver ballast water exchange program, the port has decided to allow ships to discharge their ballast water in port even if they fail the compliance testing measures (personal communication, Michael Cormier, Port of Vancouver). Therefore, Vancouver has not yet sent any vessels to the alternative exchange zone.

Port of Vancouver Criteria

According to the University of British Columbia's Dr. Al Lewis who advised Vancouver on this issue and Dr. John Jordan at the Port of Vancouver, five criteria were considered in selecting the alternative zone for ballast water exchange (personal communication, Dr. Al Lewis, University of British Columbia and Dr. John Jordan, Port of Vancouver):

- Water circulation, including geostrophic flow and tidal and riverine forcing, was the key factor in the determination. The Sheringham Point area experiences a net outward flow of water from the Strait of Georgia towards the Pacific Ocean, which would transport ballast water away from Puget Sound and the Strait of Georgia.
- Water depth was also an important consideration. A water depth of at least 100 meters was selected for safety reasons and to reduce the chance of ballast water species landing on the shoreline.
- The site was also designated north of the traffic lanes and west of a military ordinance location for safety and operational reasons.
- The selection of an established maritime location was an operational consideration. Vessels take on pilots at Sheringham Point and, therefore, vessel masters are familiar with the location.
- Lastly, seasonal variability was a consideration, but it was only used to steer the selection towards a site where seasonal variability would be minimized (personal communication, Dr. Al Lewis, University of British Columbia and Dr. John Jordan, Port of Vancouver).

The Port of Vancouver explicitly considered several oceanographic and operational criteria in selecting the Sheringham Point/Race Rocks exchange zone. Institutional criteria were also implicitly considered. However, biological issues, such as the location of the Race Rocks Pilot Marine Protected Area, were not considered. Evidence supports the oceanographic factors that were considered by the Port. The site selected for ballast water exchange does experience a net outflow due to the influence of the Fraser River outflow. Although flow reversals have been observed primarily during the winter, resulting in inland flow, the seasonal variability is lessened in the northern portion of the Strait (Ebbesmeyer et al., 1995).

However, there are additional factors contributing to the circulation patterns of the Strait. "The surface manifestation of this estuarine pattern was a broad westward transport of surface water, which supports the commonly held concept that surface trapped material should move seaward. However, the daily ebbing and flooding tidal currents greatly complicate this picture. Eddies, fronts, and complex re-circulation patterns make the prediction of trajectories difficult and limited in accuracy. Results from drift card studies illustrate this, since landings are distributed on beaches peripherally throughout the entire eastern Strait" (Holbrook et al., 1980).

Ebbesmeyer et al. (1991(b)) identified a prominent eddy just off of the Race Rocks area and drift card studies indicate that recovery patterns in the eastern Strait are highly dependent on eddies. Due to these results, Dr. Curtis Ebbesmeyer does "not recommend ballast water activities anywhere in Juan de Fuca Strait" (personal communication, Dr. Curtis Ebbesmeyer, Evans-Hamilton, Inc.). Similarly, other regional oceanographers have suggested that organisms discharged in ballast water at Race Rocks could reach shore while still viable (personal communication, Dr. Barbara Hickey, University of Washington; Dr. Chris Garrett, University of Victoria; Dr. Rick Thomson, Department of Fisheries and Oceans). Due to differing expert opinions concerning the Port of Vancouver exchange site, further study of the suitability of this site is warranted. Dr. Colin Levings and Dr. Mike Foreman are filling this informational gap through a sophisticated three-year study of how ballast water behaves in the Strait.

Puget Sound Steamship Operators Association

Puget Sound Steamship Operators Association Ballast Water Policy

The Puget Sound Steamship Operators Association (PSSOA) identified ballast water as a problem in the mid-1990's through participation in the Puget Sound Marine Committee and subsequently established a recommended ballast water policy. "In order to help control this [the introduction of nonindigenous species into Puget Sound Waters], the PSSOA has strongly recommended to its member companies, that ballast water exchange be conducted in accordance with the Coast Guard rules, and also while on coastal voyages, if it is safe, and if the vessel is at least 25 nautical miles offshore and not in a marine sanctuary" (PSSOA website). The 25 nautical mile rule was not based on oceanographic research, but represents a "best guess" by the PSSOA. It should be noted that the PSSOA has been an industry leader in the management of ballast water and their efforts to date should be commended.

Puget Sound Steamship Operators Association Policy Criteria

The PSSOA did not use any explicit criteria in the selection of their voluntary ballast water exchange zone. However, implicitly, the PSSOA considered institutional criteria by identifying a gap in the existing regulation and operational criteria by considering the position of shipping routes along the West Coast. Since oceanographic factors were not considered, a discussion of the oceanographic merit of the policy follows.

Generally, organisms in the surface layer offshore of Washington, such as crab larvae, do not reach shore. However, there are sufficient onshore transport events to sustain populations of these organisms. It is possible that a portion of organisms released in ballast water within 25 miles of Washington's shore could reach shore and become established (personal communication, Dr. Chris Garrett, University of Victoria and Dr. Richard Thomson, Department of Fisheries and Oceans).

Drift card studies off of the Washington coast reveal that recovery rates decrease as the drop point moves farther offshore. Beyond 50 miles offshore, many drift cards are transported by the California Current and are recovered in Hawaii. For this reason, Dr. Ebbesmeyer recommends that "ballast water activities be restricted to farther than 50 miles from shore" (personal communication, Dr. Curtis Ebbesmeyer, Evans-Hamilton, Inc.). Similarly, Dr. Barbara Hickey recommends that ballast should be released 50 miles from the coast during the summer and, if possible, at least 100 miles from shore in winter (personal communication, Dr. Barbara Hickey, University of Washington).

Port of Oakland, California

On August 1, 1999, Item Number 02215 of the Port Ordinance 2833 took effect, requiring vessel operators to exchange ballast water before entering San Francisco Bay. The new ballast water exchange program is voluntary until August 1, 2000, in order to allow time for dissemination of information about the program.

"No vessel using Port terminal facilities shall discharge ballast from the vessel into San Francisco Bay, or the Gulf of the Farallones National Marine Sanctuary offshore of San Francisco Bay, including open waters within the Port Area of the City of Oakland, unless the vessel immediately before arrival in San Francisco Bay has carried out an ocean ballast water exchange to limit the possibility of transferring non-indigenous species into San Francisco Bay. Exchange shall occur in the ocean westerly of the western boundaries of established marine sanctuaries adjacent to the West Coast of California" (Port Ordinance No. 2833, 1999).

Vessels arriving from ports located between Baja California and Alaska are exempted from this requirement as long as the ballast water that they are discharging originated from those locations. Vessels in compliance with the IMO's "Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges" are also exempted from the above requirements. Lastly, vessels may claim exemption from the policy due to weather, stability or hull stress concerns.

Like the Port of Vancouver, the Port of Oakland requires all incoming vessels to complete a ballast water reporting form, containing information about the location, amount, type of exchange, and, if exchange did not take place, the reason for non-compliance. The Oakland reporting procedure does include vessels that are engaged in coastwise voyages.

Unlike the Port of Vancouver, Oakland has not designated an alternative zone for ballast water exchange for vessels that have not complied with the ballast water exchange policy. The penalty for non-compliance at the Port of Oakland is non-release of ballast water in port. However, the Port of Oakland does not require an open-ocean exchange of ballast water. The Port Ordinance only specifies that the exchange take place immediately before entering the west of the Gulf of Farallones National Marine Sanctuary and adjacent to the coast of California (Port Ordinance No. 2833). In essence this means that although it is not referred to as such, the alternative exchange zone is west of the Marine Sanctuary and adjacent to the coast, and is the same as the regular exchange zone.

The criteria that were used in the selection of this exchange zone were biological. According to Jody Zaitlin at the Port of Oakland, this area was designated because the San Francisco Bay is a sensitive biological area, as are the National Marine Sanctuaries (personal communication, Jody Zaitlin, Port of Oakland). Therefore, by the process of elimination, the exchange zone was established in the area west of the sanctuaries.

State of California

In October 1999, the governor of the State of California signed Assembly Bill 703 into law creating a statewide ballast water management program. The State Lands Commission, in consultation with other state and federal agencies, directs the program that became effective on January 1, 2000. California state agencies, boards, commissions or departments are prohibited from imposing different requirements prior to January 1, 2004 unless mandated by federal law. The program is scheduled to sunset in 2004.

The program requires all vessels that enter the territorial sea of the United States, with a number of important exceptions, to manage ballast water according to prescribed measures. These measures are intended to prevent the introduction and spread of aquatic nuisance species into any of the state's rivers, estuaries, bays or coastal areas.

All vessels must perform at least one of the following management practices to prevent the release of nonindigenous species into state waters:

- exchange ballast water in areas not less than 200 nautical miles from any shore and in waters more than 2,000 meters deep before entering the waters of the state;
- retain ballast water on board the vessel;
- use an alternative method approved by the state;
- discharge ballast water to an approved facility; or,
- exchange ballast water in an area agreed to by the state.

To minimize the uptake and release of nonindigenous species, the state adopted the International Maritime Organization's "Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges" as state operating policy.

The state will take sample ballast water and sediment, examine documents and assess vessels' compliance with the program. Vessel operators must provide certain information required by the National Invasive Species Act to the State Lands Commission.

The law also directs the state to conduct three studies and report the findings to the legislature:

- By December 31, 2002, complete an evaluation of alternatives to managing ballast water.
- By December 31, 2002, complete a study of baseline conditions in coastal and estuary waters, including an inventory of the location of nonindigenous species.
- By September 1, 2002, complete an evaluation of the effectiveness of the program in reducing nonindigenous species introductions.

The State Lands Commission is authorized to levy an appropriate and reasonable fee on vessels, not to exceed $1,000 per vessel voyage, and to deposit these revenues into a dedicated Exotic Species Control Fund.

Considerations for Locating an Alternative Zone for Ballast Water Exchange

The Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) of 1990 (Public Law 101-646, section 1102(a)(1)(b)) describes alternative or back-up exchange zones as "areas within the Waters of the United States and the exclusive economic zone, if any, where the exchange of ballast water does not pose a threat of infestation." These areas are meant to be available for vessels that are unable to exchange their ballast water in the open ocean (in waters greater than 2,000 meters in depth) (Carlton et al., 1995). The U.S. Coast Guard has not designated acceptable alternative exchange zones in the recent ballast water regulations. However, the NANPCA also authorized the National Ballast Water Control Program, which sponsored a "Ballast Exchange Study," a draft of which was made available in 1999. This study recommends possible alternative zones for ballast water exchange for 10 coastal regions of the United States based upon regional circulation patterns. In the Pacific Northwest, the draft study recommends that "vessels approaching the Oregon and Washington region should exchange ballast water no closer than in or along the California Current, whose position varies; in areas that the Current passes close to shore, exchange should take place to the west of the Current" (Beeton et al., 1998).

Considerations Used in the "Ballast Exchange Study"

The authors of the "Ballast Exchange Study" utilized oceanographic and biological considerations in the selection process for alternative zones for ballast water exchange. "The a priori requirement for selection of back-up exchange sites is predefined under the National Ballast Water Control Program as those 'areas...if any, where the exchange of ballast water does not pose a threat of infestation or spread of aquatic nuisance species in the Great Lakes and other waters of the United States" (Beeton et al., 1998).

The variables that this study examined and that may influence the transport of released organisms include "wind stress and thus near surface rapid response changes to such stress, coastal buoyancy fluxes, tidal fronts, along coast currents, eddies, shingles and filaments, coastal-trapped waves, alternating periods of convergence and divergence, unpredictable flow reversals, and numerous other phenomena" (Beeton et al., 1998). Furthermore, the study examined the presence of Marine Protected Areas (MPAs,) but not other biologically sensitive regions.

Although this list of considerations used in the "Ballast Exchange Study" is useful, it will not be used here for several reasons. This list of oceanographic considerations is overwhelming and in some cases, surface circulation patterns can be nicely summarized with drift card data. Therefore, each of the above listed phenomena may not need to be examined separately.

By restricting the list to a number of oceanographic considerations and one biological factor, the resulting recommendations do not fully outline an adequate solution to this problem. For example, in the Oregon and Washington region, the draft study recommends that ballast water exchange take place in or west of the California Current (Beeton et al., 1998). However, the position of the California Current is not stationary and the California Current system is complex and not entirely understood, making that a difficult benchmark for locating the exchange zone.

The authors of the report highlight an additional operational problem with their siting recommendations. "Because of this great variability in inshore and nearshore circulation, and in order to minimize the probability that planktonic organisms that are released from ballast water and sediments—and that would be capable of living at least two or more weeks in the water column—would be able to settle in nearshore environments, it is generally more appropriate to define backup exchange zones based on distance from shore in order to ensure the entrainment of deballasted organisms in offshore waters or currents...The inevitable result is that these potential back-up exchange zones, while not of course as distant from the continent as mid-ocean stations, may not always match vessel requirements seeking lower sea status or more protected waters. It is thus to be reemphasized that the selection criteria were governed by the initial mandated focus on 'areas...if any, where the exchange of ballast water does not pose a threat of infestation or spread of aquatic nuisance species'" (Beeton et al., 1998).

Recommended Considerations

As the previous examples of ballast water policies illustrate, different ports rely on different sets of considerations in their selection of an alternative zone for ballast water exchange. The Port of Oakland relied solely on biological criteria, primarily the existence of numerous protected areas in and around the harbor. Conversely, the Port of Vancouver considered a ballast water exchange site that was already well known to the maritime community. Such an area may not be available in every case. The following list of considerations is provided to aid discussion about alternative discharge zones for the Puget Sound. Some of these considerations will only be applicable in specific situations.

Institutional Considerations

Any ballast water policy must conform to all existing local, state, national and international laws and agreements. Clearly this consideration is necessary in order for a ballast water policy to be successful. The International Maritime Organization (IMO) ballast water guidelines state that "...port States should provide ships with the following information: location and terms of use of alternative exchange zones" (IMO Resolution A.868(20), adopted 27 November 1997). The Coast Guard Navigation and Vessel Inspection Circular No. XX-99 also refers to an "Alternative Exchange Zone" as an area that is acceptable for ballast water exchange under extraordinary conditions. Section 1102(a)(1) of the NANPCA of 1990 required the ANS Task Force to complete the "Ballast Exchange Study: Consideration of Back-Up Exchange Zones and Environmental Effects of Ballast Exchange and Ballast Release." This study recommended areas for designation as alternative zones for ballast water exchange. Therefore, it seems clear that the designation of alternative zones for ballast water exchange is in compliance with existing law. However, it is possible that the areas available for selection will be limited due to international law concerning the bounds of national jurisdiction in marine waters.

A specific institutional consideration in the siting of an alternative exchange zone is the location of restricted or military areas. The Port of Vancouver example illustrates that the location of military or restricted areas can have a very practical effect on location decisions.

Operational Considerations

The primary operational consideration is the safety of vessel and crew. This consideration is important because ballast water exchange can result in dangerous instability if it is conducted under the wrong circumstances. Although the stability of the vessel will depend partially on vessel and cargo type as well as amount and location of cargo onboard, the stability will also be affected by the conditions under which the exchange occurs. Therefore, the location and timing of ballast water exchange directly affects the safety of the operation.

In the Pacific Northwest, the highest and most dangerous seas typically occur during the winter months (October through April). Closer to shore, the seas are often slightly calmer. These aspects of the local oceanography and meteorology must be considered during the selection of an alternative zone for ballast water exchange.

A second operational consideration is the location of trade routes and shipping lanes. It is impractical to require vessels to deviate drastically from their established trade routes in order to complete a ballast water exchange, but vessels completing a ballast water exchange also should not interfere with traffic flow.

A third important operational consideration is the time required to complete a ballast water exchange. It takes 10-15 hours to complete an empty/refill ballast water exchange and it can take as long as 3-4 days to complete an entire flow through exchange. Therefore, a ballast water exchange zone would ideally be a large section along an established trade route. This would allow vessels to exchange ballast water while in transit rather than having to spend extra time exchanging ballast water in a more restricted area.

Lastly, during the selection of an alternative exchange zone, the locations of established maritime sites should be considered. As in the Port of Vancouver case, establishment of an alternative exchange zone in an area known to the maritime community will presumably make the transition to a new ballast water policy easier.

Oceanographic Considerations

The most important oceanographic attributes to consider are circulation patterns. The fate of organisms in discharged ballast water will depend primarily on surface currents. There are several scales to circulation patterns. Large scale currents (such as the California Current), shelf currents, tidal currents and eddies must all be considered. Each of these current types interact and combine to cause the movement of released organisms. Unfortunately, the way in which these currents will interact at any one time is difficult to predict. Therefore, drift card studies are helpful in explaining the circulation patterns of the surface layer.

Drift cards released in Puget Sound south of Admiralty Inlet had a recovery rate exceeding 50 percent, meaning that one out of every two cards released was found on the shore and reported by the public. The time between release and recovery was on the order of one to several weeks. Drift cards released in the eastern Juan de Fuca Strait, east of the Elwa River, had a recovery rate of approximately 25 percent. Tidal eddies in this area distributed drift cards preferentially to Victoria, Dungeness Spit and the San Juan Islands within days to weeks. Recovery rates from drifters released on the Pacific coast were less than 10 percent. Recovery rates on the coast decreased with the distance of the release site from shore. A small percent of drifters released beyond approximately 50 miles from shore were found in Hawaii and across the North Pacific (personal communication, Dr. Curtis Ebbesmeyer, Evans-Hamilton, Inc.).

Based on these drift card studies, Dr. Curtis Ebbesmeyer, an oceanographer with Evans-Hamilton, recommends that "ballast water activities be restricted to farther than 50 miles offshore" (personal communication, Dr. Curtis Ebbesmeyer, Evans-Hamilton, Inc.). Likewise, Dr. Barbara Hickey, a physical oceanographer at the University of Washington, recommends that ballast water be released 50 miles from the coast during the summer and, if possible, at least 100 miles from shore in the winter (personal communication, Dr. Barbara Hickey, University of Washington).

According to Dr. Richard Thomson of the Institute of Ocean Sciences in British Columbia, there is nowhere in the Puget Sound/Strait of Georgia/Strait of Juan de Fuca system that is safe for ballast water exchange. However, should it be impossible to exchange ballast water offshore, he suggests "the central portion of Juan de Fuca Strait, just north of the separation line (between the U.S. and Canada), not too close to the entrance" as an alternative zone for ballast water exchange. By discharging in the middle of the Strait of Juan de Fuca, east of the entrance, there is a greater likelihood that organisms will be carried seaward to the continental slope region where they will be advected southward during summer and northward during winter (personal communication, Dr. Richard Thomson, Department of Fisheries and Oceans).

A second oceanographic factor to be considered is the variability in the system. Many currents reverse on a seasonal basis and storms occur more often during the winter. Seasonal changes need to be considered because they result in changes in circulation patterns and because they affect the stability of a vessel during ballast water exchange. Likewise, variations in circulation occur on an interannual basis due to El Niño.

Once a general area has been identified for further investigation as an alternative zone for ballast water exchange based on the regional circulation patterns and the variability of the system, a specific area can be selected based on the local circulation patterns. These patterns depend on multiple local factors and must be investigated on a case by case basis. Unfortunately, localized circulation patterns are often highly variable and difficult to predict. However, drift card studies provide one tool that can be used to help understand local surface circulation patterns.

Salinity and temperature affect the survival of organisms discharged in ballast water. At this time, accurate information about ballast water origin is not available. Therefore, it is difficult to predict what organisms may be released and what temperature and salinity conditions would help or be detrimental to the survival of those organisms. Furthermore, even if exchange zones were selected in order to ensure that environmental conditions were outside of the physiological tolerances of known invaders, it is possible that those locations would provide ideal environmental conditions for unknown invaders, allowing them to survive. Ballast water can serve as a pathway for a wide variety of species. Each of these species has different tolerances and will be able to survive in different environmental conditions. Therefore, temperature and salinity are not recommended as considerations for the selection of alternative zones for ballast water exchange.

Biological Considerations

Biological considerations are proximity to sensitive biological areas or proximity to areas where the negative effects of ANS (Aquatic Nuisance Species) would result in greater damage. As outlined in Carlton et al. (1995), there are four primary measures of biological sensitivity: areas of high aquaculture use, biologically productive fishing grounds, marine protected areas and endangered species habitat. Each of these is included below as a biological consideration in the selection of an alternative zone for ballast water exchange.

Aquaculture, particularly oyster growing, is an important source of revenue for the state of Washington. The primary aquaculture regions are Puget Sound, Willapa Bay and Grays Harbor. Therefore, if possible, these areas should be avoided in the selection of a ballast water exchange zone.

Other fisheries are also an integral part of the Washington economy and culture. Specific information about the locations of key Washington fisheries was not available in time for this report. However, fisheries locations are widespread throughout the marine and fresh waters of the state. If possible, key fisheries areas should be avoided in the selection of an alternative zone for ballast water exchange.

There are many Marine Protected Areas (MPAs) in Washington State. In fact, in order to avoid all of Washington's MPAs, one would have to avoid virtually all of the coastal and estuarine regions of the state. Therefore, the consideration of MPAs would lead to the selection of an alternative exchange zone as far away from shore as possible.

Washington State is home to several marine and coastal species federally listed as endangered and threatened. Together, the habitat of these species covers much of the nearshore areas in the state. For example, the habitat of two newly listed salmon runs alone covers all of Puget Sound and the eastern Strait of Juan de Fuca. The habitat of endangered and threatened species should be avoided in the selection of an alternative zone for ballast water exchange, if possible.

Clearly, the biological considerations are not very helpful in the selection of an alternative site for vessels entering Puget Sound. The result of considering these criteria is that almost the entire coastal or estuarine portion of the state can be classified as biologically sensitive and should be avoided. However, these issues must be considered on a case by case basis and they may provide more direction when applied to other situations.

Summary of Findings

Regulatory and Informational Gaps

Several regulatory and informational gaps exist in the context of the ballast water problem. Analysis of these gaps is essential in order to address the problem adequately.

Regulatory gaps

Vessels engaged in coastwise trade:
Vessels engaged in coastwise trade represent a significant regulatory gap in ballast water management. The U.S. Coast Guard ballast water program applies only to vessels entering the U.S. Exclusive Economic Zone (EEZ). Vessels traveling between U.S. Pacific coast ports are not included in this program. The Puget Sound Steamship Operators Association (PSSOA) recommends that its members exchange ballast water 25 nautical miles from shore while they are engaged in coastwise trade. This voluntary program partially fills the coastwise trade gap. However, not every vessel is a member of the PSSOA.

Information Gaps

Ballast water origin:
Many marine exchanges and other groups keep records on vessel calls. This information often includes the last port of call for each vessel. However, Carlton et al. (1995) found that the last port of call was not a good indicator of ballast water origin. Vessels routinely ballast and deballast throughout a voyage, resulting in a mixture of ballast water and sediments from multiple sources. It is difficult to determine the origin of the ballast water in each vessel. Ballast water origin information is valuable in assessing the risk posed by individual vessels to the region.

There is also reason to be concerned about ballast water transported between coastal ports. Nonindigenous species are not uniformly distributed along the coast (see Figure 15). There are 234 known nonindigenous species in San Francisco Bay (Cohen et al., 1998). There are only 52 documented nonindigenous species in Puget Sound (Cohen et al., 1998). Although analysis of a recent survey is incomplete, there appear to be even fewer nonindigenous species established in Prince William Sound. At least five non-indigineous species have been documented there, however. (Hines et al., 1998).

Ballast water exchange patterns and compliance:
Summary information about the patterns of ballast water exchange, including information such as ballast water volume, location of exchange and method of exchange, is valuable in assessing the risk posed by individual vessels. It can also help determine if there is the need for additional regulation.

Although this information has been previously unavailable for most areas of the country, it will be provided in the foreseeable future. For example, the Port of Vancouver has recorded this type of information for several years, however, their database was just being completed at the time this report's publication. In addition, the U.S. Coast Guard started collecting this data in 1999. The Smithsonian Environmental Research Center will analyze it and make recommendations to the Coast Guard.

Summary shipping information for the combined Georgia Basin ports:
A summary of shipping patterns for the ports of the Georgia Basin is not available. Currently, no database about vessel calls to the area exists. For example, the Marine Exchange of Puget Sound records information such as the cargo loaded and offloaded, the last and next port of call, vessel type and size, and so on, for every vessel that calls in a Puget Sound port. Although this database does not include information on ballast water exchange, it does provide a valuable tool for summarizing traffic patterns.

The relationship between the volume of ballast water discharged and the number of species introduced:
To manage ballast water for the lowest possible risk of invasion, managers need to know if there is a relationship between the volume discharged and the risk of invasion. However, there are multiple factors that presumably affect the establishment of a nonindigenous species in a new environment. These factors include time of year, environmental conditions, life stage of the organism and the density of organisms in the ballast water. It is essential that this relationship be better defined in order to ensure accurate risk assessments.

More sophisticated modeling of regional oceanography:
Regional oceanographic patterns are complex. Additional study of these systems would help to examine the effects of ballast water discharged into the system.

Opportunities for Further Work or Study

The introduction of nonindigenous aquatic nuisance species through the transport and release of ballast water is a substantial problem with no simple solutions. Currently, the only widely available solution to the ballast water problem is open-ocean exchange of ballast water. However, vessels that are engaged in coastwise trade often do not reach the open ocean between coastal ports. In addition, high seas may make open-ocean ballast water exchange too dangerous for some vessels. These vessels are unable to complete an open-ocean exchange.

Several studies have suggested the use of alternative zones for ballast water exchange in order to address these gaps in the current management regime. In theory, these sites would allow vessels that are unable to complete an open-ocean exchange to exchange ballast water before entering port. This would reduce the risk of nonindigenous species introductions. Prevailing currents would carry discharged organisms away from shore. Hopefully, these areas would be close enough to shore to decrease the safety hazard associated with exchange in high seas and allow vessels engaged in coastwise trade to reach them in the course of their customary route.

Unfortunately, once oceanographers began to investigate the possible presence of alternative exchange zones, they were faced with a difficult reality. The draft "Ballast Exchange Study" revealed that there were sites in each of the 10 regions studied that would "ensure the entrainment of deballasted organisms in offshore waters or currents." However, these areas are so far from shore that they "may not always match vessel requirements seeking lower sea states or more protected waters" (Beeton et al., 1998).

Although the selection of alternative zones for ballast water exchange will partially fill the management gaps existing in the current system, it seems clear that ballast water exchange will continue to be only an interim solution. The ultimate direction of ballast water management is ballast water treatment, either on-board the vessel or on the shore. Based upon these conclusions, there are several opportunities for further work or study. The following is a list of issues that merit additional investigation and discussion:

Continue and improve coordination among participants in West Coast ballast water management.

It is essential that Pacific coast participants in the U.S., Canada and Mexico, cooperate to develop a consistent management approach that state, provincial or local governments can implement. This approach could be developed within the existing infrastructure, primarily through the work of the Pacific Ballast Water Group.

A large number of regulatory and non-regulatory groups, at the local, state, national and international level are involved in the management of ballast water. Those listed in Table 1 are only the most influential. There are many more groups that play smaller roles in the ballast water arena. Not only are there numerous participants involved in ballast water management, but there are also multiple laws that apply to the issue. Ports and other state or local entities are continuously proposing additional ballast water policies. Without coordination a complex web of programs and regulations could emerge along the Pacific coast. This could pose a burden for the shipping industry and for government programs.

Investigate the suitability of alternative zones for ballast water exchange already in use.

There is debate about the suitability of locally established alternative exchange zones and further study of these sites is warranted. Dr. Colin Levings and Dr. Mike Forman are engaging in such a study focusing on the Strait of Juan de Fuca. Additional studies of this type for other northwest regions would assist ballast water managers.

Investigate an alternative zone for ballast water exchange for vessels entering Puget Sound.

According to shipping data provided by the PSSOA, approximately 54 percent of vessels arriving in Puget Sound come from other Pacific coast ports. In addition, an unknown number of vessels are unable to exchange ballast water in the open ocean due to dangerous seas. These vessels represent a gap in the U.S. Coast Guard ballast water program. Although the selection of an alternative exchange zone for these vessels would only partially fill this gap, it would still be an important step towards decreasing the risk of introductions of nonindigenous species. This report identifies the major considerations that should be involved in selecting an alternative exchange site. Ideally, the selection of alternative zones for ballast water exchange for vessels entering the Strait of Juan de Fuca would be a joint U.S./Canadian effort, in order to decrease regulatory overlap and complexity.

Encourage the use of best management practices to reduce the probability of taking up organisms during ballasting.

The International Maritime Organization (IMO) developed a list of guidelines for ballasting that can be employed to reduce the risk of organism uptake. The uptake of ballast water should be minimized in:

- areas with outbreaks, infestations or known populations of harmful organisms and pathogens;
- areas with current phytoplankton blooms (algal blooms, such as red tides);
- areas near sewage outfalls;
- areas where a tidal stream is known to be more turbid;
- areas where tidal flushing is known to be poor;
- darkness, when bottom-dwelling organisms may rise up in the water column;

- very shallow water; or
- areas where propellers may stir up sediment (IMO Resolution A.868(20))

Vessels entering Puget Sound could be encouraged to use these practices.

Encourage the use of on-board or on-shore treatment of ballast water.
Although ballast water exchange is currently the best ballast water management method available, it is widely regarded as an interim solution. Ballast water exchange is not always possible and is only 70 to 90 percent effective depending on the exchange method employed. Ballast water pumps are simply not designed to remove all of the ballast water or accumulated sediments in a ballast water tank. Therefore, research and development of alternative technologies to address the ballast water problem are needed.

Use the Coast Guard/Smithsonian Environmental Research Center database to assess risk and the effectiveness of the current management regime.
The U.S. Coast Guard, in cooperation with the Smithsonian Environmental Research Center (SERC), will analyze the Coast Guard data to assess the effectiveness of the voluntary program of ballast water exchange. This will provide valuable new information about ballast water exchange and ballast water sources for the West Coast region. These results could fill many of the information gaps identified in this report.

Investigate ballast water/shipping patterns for vessels engaged in coastwise trade.
Vessels entering the EEZ will be included in the Coast Guard/SERC study. However, vessels arriving at a U.S. West Coast port from another U.S. West Coast port will not be included. Since approximately 50 percent of traffic in Puget Sound originates from other West Coast ports (U.S., Canadian and Mexican), this represents a significant data gap. To obtain a complete understanding of shipping traffic and ballast water patterns in Puget Sound, a separate sample of vessels engaged in coastwise trade is needed.

Encourage additional studies.
There are several other information needs. Dr. Colin Levings and Dr. Mike Forman are modeling the dispersal of organisms released in ballast water in the Strait of Juan de Fuca. Studies such as this should be encouraged in order to obtain more information about the effects of ballast water discharge. Summary shipping data sets for the combined Georgia Basin ports, such as those available from the Marine Exchange in Puget Sound, are also needed.

Investigate the use of a matrix to evaluate vessel risk.
There are several factors that increase the risk posed by individual vessels. These factors include vessel type, the origin of the ballast water on board, the amount of ballast water discharged, concentration of organisms in ballast water, etc. It is possible that as more information about each of these factors becomes available, managers could evaluate vessels based on their individual characteristics and apply appropriate preventive measures to address that risk. Many vessels pose little or no risk of contributing to the introduction of nonindigenous species through ballast water. For example, many container vessels are designed to shift ballast between tanks, decreasing or eliminating the need for continuous ballasting and deballasting during cargo loading and unloading operations. The use of a risk evaluation matrix would eliminate some vessels from management protocols and could reduce the burden that programs for managing ballast water have on the shipping industry. Australia is developing a Decision Support System to evaluate vessel risk (Hallegraeff, 1998). It is possible that a similar system could be useful in the U.S.

Appendix A. Institutional Structure

The ballast water issue has resulted in a complex institutional response for several reasons. Ballast water transport is the result of global shipping. Therefore, there is an international response in the form of ballast water management. Some countries are more vulnerable to invasion or more protective of the natural environment and are responding to the problem at the national level. Further complicating the situation is that ports are managed in a variety of ways and at a variety of government levels. Lastly, the results of introductions of nonindigenous species are usually felt at the local level and, therefore, local communities are starting to become involved. The information in this section is summarized in Table 1.

Major Laws and Agreements Governing Ballast Water Management

International

There are two major international treaties, the Convention on Biological Diversity and the United Nations Convention on the Law of the Sea (UNLOS), which address nonindigenous aquatic nuisance species. However, the United States is not a party to either treaty.

More importantly, the International Maritime Organization (IMO) has developed voluntary guidelines for ballast water management (Guidelines for the Control and Management of Ship's Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens). Established by means of a Convention adopted in 1948, the IMO is a specialized agency of the United Nations, and is responsible for measures to improve the safety of international shipping and to prevent marine pollution from ships (IMO website). There are currently 157 member nations of the IMO, including the United States. The IMO works as an international forum for the adoption of legislation. Member countries that accept an IMO convention are expected to implement the convention as part of their own national law. Committees such as the Marine Environment Protection Committee (MEPC), which is responsible for the ballast water issue, carry out the technical work of the IMO (IMO website).

The IMO guidelines, developed by the MEPC, outline operational methods that reduce the risk of ballast water introductions of nonindigenous species. For example, vessels should avoid loading ballast in areas of known outbreaks of disease or aquatic nuisance species in order to reduce the risk that these organisms will be transported. The guidelines also outline the various steps that ships, as well as port states, should take to minimize the risk of species introductions. Notably, section 8.2.1 states that "...port

States should provide ships with the following information...location and terms of use of alternative exchange zones" (IMO, 1997).

The ballast water working group of the MEPC is now developing mandatory ballast water exchange regulations which were expected to be introduced as Annex VII to the International Convention for the Prevention of Pollution from Ships (MARPOL). Unfortunately, the MEPC was unable to make enough progress on the ballast water issue during the last meeting to move the annex process along. It now seems apparent that the IMO will be introducing ballast water regulations as an independent treaty rather than a MARPOL annex, and that any ballast water treaty will not be passed until well after the expected year 2000 date (Singapore Shipping Times, 1999). However, if an annex is passed, then member nations that accept the annex will be legally bound to implement the regulations it contains.

Washington/British Columbia Environmental Cooperation Agreement of 1992

In the Pacific Northwest, an additional international agreement affects environmental management. The Washington/British Columbia Environmental Cooperation Agreement of 1992 established the Environmental Cooperation Council (ECC). The ECC in turn established the Puget Sound/Georgia Basin Task Force (WA State ANS Management Plan, 1998). The agreement stated that British Columbia and Washington State will "...promote and coordinate mutual efforts to ensure the protection, preservation and enhancement of our shared environment for the benefit of current and future generations." The Task force members include representatives from: the U.S. Environmental Protection Agency; the Northwest Fisheries Science Center; the Department of Fisheries and Oceans Canada; the Department of Environment Canada; the Washington Departments of Fish and Wildlife; the Washington Departments of Natural Resources and Ecology; the Puget Sound Water Quality Action Team; the British Columbia Ministry of Environment, Lands and Parks; and the Northwest Indian Fisheries Commission. In 1994, the Marine Science Panel of the task force identified nonindigenous species as a problem in the shared waters and recommended that "...serious efforts be made to prevent the introduction of exotic species into the shared and adjacent waters" (British Columbia/Washington Marine Science Panel, 1994). The result was the establishment of the Puget Sound exotic species workgroup, which sponsored a report on the pathways and management of nonindigenous species in the shared waters (see Elston, 1997). The workgroup recommended the creation of an aquatic nuisance species coordinator position. Once the Washington Department of Fish and Wildlife secured funding for that position, the Puget Sound exotic species workgroup dissolved.

Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990

At the federal level, Congress responded to the zebra mussel invasion of the Great Lakes with the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA)of 1990 . The five purposes of the act are as follows:

1. to prevent unintentional introduction and dispersal of nonindigenous species into waters of the United States through ballast water management and other requirements;
2. to coordinate federally conducted, funded or authorized research, prevention control, information dissemination and other activities regarding the zebra mussel and other aquatic nuisance species;
3. to develop and carry out environmentally sound control methods to prevent, monitor and control unintentional introductions of nonindigenous species from pathways other than ballast water exchange;
4. to understand and minimize economic and ecological impacts of nonindigenous aquatic nuisance species that become established, including the zebra mussel; and

5. to establish a program of research and technology development and assistance to states in the management and removal of zebra mussels (USGS NANPCA website).

The act mandated several studies and provided states with the opportunity to create management plans for aquatic nuisance species in general, and for the zebra mussel specifically, and submit them for funding.

The NANPCA also created the Aquatic Nuisance Species Task Force (ANS Task Force), which is responsible for coordinating government efforts related to nonindigenous aquatic species in the United States with those of the private sector and other North American interests (ANS Task Force website). The task force is co-chaired by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Fish and Wildlife Service and includes representatives from the U.S. Coast Guard, U.S. Environmental Protection Agency (EPA), and departments of Army, Agriculture and State and 10 ex-officio members from non-federal groups. Within the ANS Task Force, the Ballast Water and Shipping Committee is responsible for developing a program of testing and demonstrating ballast water management technologies, monitoring the effectiveness of ballast water regulations, and being the focus for consultation and coordination of ballast water and shipping issues for the task force.

National Invasive Species Act of 1996

The National Invasive Species Act (NISA) of 1996 (P.L. 104-332) reauthorized and amended NANPCA. NISA expanded the mandatory ballast exchange program in the Great Lakes and directed the Secretary of Transportation to establish record keeping for the purposes of compliance monitoring. NISA also authorized funds for several studies of ballast discharge and possible control mechanisms and directed the secretary to develop control guidelines nationally.

The U.S. Coast Guard issued an interim rule implementing the ballast water program mandated by NISA. Under the interim rule, effective July 1, 1999, vessels entering U.S. waters should do one of the following:

- voluntarily conduct an open-ocean ballast water exchange in waters at least 200 miles from shore and at least 2,000 meters in depth;
- retain their ballast water on board;
- use an alternative and approved method of ballast water management;
- discharge ballast water into an approved reception facility; or
- "under extraordinary conditions, conduct a ballast water exchange within an area agreed upon by the Captains of the Port at the time of the request, or after notification to the Captain of the Port within an area listed as an Alternate Exchange Zone" (USCG Navigation and Inspection Circular, 1999).

In addition, the U.S. Coast Guard program includes mandatory reporting of ballast water operations from vessels entering U.S. waters. There are currently no penalties for non-reporting. A vessel that has not conducted an open-ocean ballast water exchange due to high seas may claim a safety exemption. The regulations apply only to those vessels entering the U.S. EEZ. Vessels engaged in coastwise trade are not regulated (USCG Interim Rule, 1999).

NISA created the National Ballast Information Clearinghouse, which is run by the Smithsonian Environmental Research Center. If the joint Smithsonian/Coast Guard monitoring program reveals that voluntary guidelines do not result in a high enough compliance rate during a three year period, the guidelines will be made mandatory and will carry civil and criminal penalties. Vessels will be selected for compliance testing on a random basis. The Coast Guard will board selected vessels and record answers to 20 questions similar to those on the written report form. Following the interview, the officers will collect ballast water samples and conduct a salinity test using a handheld salinity refractometer to assess the likelihood that an exchange was conducted. A salinity measurement of less than 30 parts per thousand is interpreted as indicating that either an exchange did not occur or was very inefficient (USCG NVIC, 1999).

NISA also authorized the formation of a Western Regional Panel on Aquatic Nuisance Species as part of the ANS Task Force. This panel "will identify priorities and make recommendations on an education, monitoring, prevention and control program to prevent the spread of aquatic nuisance species in the Western region" (P.L. 104-323). The Western Regional Panel on Aquatic Nuisance Species, formed in July 1997, includes 48 representatives from federal, state, and local agencies as well as private environmental and commercial groups. The western region consists of all of the states and provinces west of the 100th Meridian in addition to Guam, Hawaii and Alaska. Since the introduction and spread of aquatic nuisance species represents a transboundary issue, there are representatives from Canadian provinces on the panel. Although the panel was formed according to U.S. law and the recommendations will be for U.S. actions, the presence of Canadian representatives is an important step in the collaboration between nations to address this problem. The purposes of the WRP are to:

1. identify western region priorities for responding to aquatic nuisance species;
2. make recommendations to the ANS Task Force regarding an education, monitoring (including inspection), prevention and control program to prevent the spread of the zebra mussel west of the 100th Meridian;
3. coordinate, where possible, other aquatic nuisance species program activities in the West not conducted pursuant to the act;
4. develop an emergency response strategy for federal, state and local entities for stemming new invasions of aquatic nuisance species in the region;
5. provide advice to public and private individuals and entities concerning methods of preventing and controlling aquatic nuisance species infestations; and
6. submit an annual report to the ANS Task Force describing activities within the western region related to aquatic nuisance species prevention, research and control (Western Regional Panel website)

Section 1204 of the NISA allows for a federal cost-share for implementing state management plans that have been approved by the ANS Task Force. Washington is one of the few states to have an approved plan.

Executive Order

On February 3, 1999, President Clinton issued Executive Order 13,112, creating the Invasive Species Council. The council is co-chaired by the Secretary of Interior, the Secretary of Agriculture and the Secretary of Commerce. Additional Council members include the Secretary of State, the Secretary of the Treasury, the Secretary of Defense, the Secretary of Transportation, and the Administrator of the EPA. The Council may invite additional federal agency representatives. The responsibilities of the Invasive Species Council are:

1. to see that the federal agency activities concerning invasive species are coordinated, complementary, cost-efficient and effective;
2. to encourage planning and action at local, tribal, state, regional and ecosystem-based levels in cooperation with interest groups and existing organizations addressing invasive species;
3. to develop recommendations for international cooperation;
4. to develop, in consultation with the Council on Environmental Quality, guidance to federal agencies pursuant to the National Environmental Policy Act on prevention and control of invasive species;

5. to facilitate establishment of a coordinated, up-to-date information sharing system; and
6. to prepare and issue a national Invasive Species Management Plan within 18 months (Executive Order No. 13,112, 64 Fed. Reg. 6183 (1999))

The Executive Order directs federal agencies to identify agency actions that affect the status of invasive species and not to authorize, fund, or carry out any activities that will promote the introduction of invasive species. In addition, it directs federal agencies to engage in activities that prevent introduction of invasive species, monitor or control invasive species, restore native populations or habitat, research control and prevention technologies, or educate the public about invasive species.

The Clean Water Act

Although it does not specifically address the introduction of nonindigenous species, the Clean Water Act (CWA) governs the protection of water quality in the United States. Section 301 of the CWA prohibits all point source discharge of pollutants into the waters of the United States unless a permit has been issued under the National Pollutant Discharge Elimination System (NPDES) or under the regulations covering dredge and fill activities. The CWA specifies that vessels are point sources (33 U.S.C. Section 1362(14)) and nonindigenous species qualify as biological pollutants (33 U.S.C. 1362(6)). Ballast water has not previously been regulated nationally under the CWA because the EPA regulations state that any discharge incidental to the normal operation of a vessel do not require NPDES permits (40 CFR Section 122.3(a)).

In January 1999, several environmental and fisheries organizations petitioned Carol Browner, the administrator of the EPA, for the repeal of 40 CFR Section 122.3(a), the regulation which exempts ballast water discharges from the NPDES system (Johnson, 1999). Instead, these groups advocate that ballast water discharges be regulated under the CWA.

Washington State

Statutory authority exists for the Washington Department of Fish and Wildlife (WDFW) to classify wildlife into categories subject to specific statutes and rules [RCW 77.12.020], and to regulate the collection, importation and transportation of wildlife [RCW 77.12.030], including the taking possession, sale or distribution of wildlife and deleterious exotic wildlife [RCW 77.12.040]. WDFW plays a role in the aquatic nuisance species issue primarily through the efforts of the Aquatic Nuisance Species Coordinator. The coordinator chaired the Washington Aquatic Nuisance Species Planning Committee, which completed the Washington State Aquatic Nuisance Species Management Plan in June of 1998. The coordinator also chaired the Zebra Mussel and Green Crab Task Force created by the legislature in 1998 (Chapter 153, Laws of 1998). This task force was "...charged with developing recommendations for legislative consideration to prevent or control the spread of these two Aquatic Nuisance Species (ANS)." (Zebra Mussel/Green Crab task force, 1998). The task force published its final report and recommendations in December of 1998, but the legislature did not pass the recommendations.

The Washington Department of Ecology oil spills program routinely boards high-risk cargo and passenger vessels. Vessels are surveyed based on a variety of factors including pollution prevention, training, planned maintenance system operating procedures and ballast water. If a vessel has not completed a mid-ocean ballast water exchange it will receive points in the ballast water category. Vessels not achieving an adequate level of compliance may face fines or other actions. In addition to calculating ballast water exchange into the risk matrix, the Department of Ecology provides each boarded vessel with information on safe ballast water discharge.

At this time, no local governments or port districts in Washington have a formal ballast water program in place. An informal survey of the ports of Anacortes, Bellingham, Everett, Olympia, Port Angeles, Seattle and Tacoma revealed that none of them have any formal ballast water policy, and they are currently relying on existing management measures (personal communication, Eric Johnson, Washington Public Port Association).

Non-Regulatory Groups

Working Groups

The West Coast Regional Working Group on Ballast Water Management is a joint British Columbia/Washington group that was formed in early 1999. The Working Group was not legally mandated, but was formed to create educational dialogue and coordination between the neighboring state and province. Members of this small group represent the Port of Vancouver, other B.C. ports, the U.S. Coast Guard, the Department of Fisheries and Oceans Canada, and Transport Canada.

The Pacific Ballast Water Group (PBWG) is similar to the West Coast Regional Working Group, but it included representatives from California, Oregon and Washington. Representatives from British Columbia have been invited to attend. The PBWG was formed in February 1999 by representatives from the shipping industry, state and federal agencies, environmental organizations and scientists who recognized the need for a cooperative and coordinated regional response to solving the ballast water problem. Since its formation, the PBWG has grown to include over 30 members who are rapidly compiling an informational report and making recommendations in order to foster the prompt implementation of practical solutions. The PBWG meets approximately bimonthly in various West Coast cities. Since the PBWG is interested in including representatives from B.C. and the West Coast Regional Group wishes to address coastwise goals, these two similar groups are expected to align closely or to merge.

The Puget Sound Marine Committee (PSMC) was formed in October of 1997 to "...provide a proactive forum for identifying, assessing, planning, communicating and implementing those environmental measures that promote safe and efficient use of Puget Sound and adjacent waters." The PSMC addresses issues facing Puget Sound, the Strait of Juan de Fuça and the Washington coast. The PSMC was formed as a broad-based collection of interest groups, who would meet and create solutions without mandate or government control. The PSMC is a consensus-based group with members from a diverse set of groups ranging from environmental organizations to petroleum shippers to recreational boaters (Schneidler, 1999). The PSMC works through standing committees that were created based on general subject areas and that include representatives from outside the PSMC. The Ballast Water Subcommittee was formed two years ago and has been chaired by a representative of the Washington Environmental Council. The accomplishments of this subcommittee include the adoption of voluntary policy of ballast water exchange by the Puget Sound Steamship Operators Association.

Industry

The Pacific Merchant Shipping Association (PMSA) is a non-profit organization that represents owners and operators of U.S. and foreign flag vessels operating in the Pacific Basin. The PMSA represents its 35 members' interests on matters concerning issues affecting the maritime industry including legislation and regulations (personal communication, Kenny Levin, PMSA). The PMSA does not have an official policy on ballast water issues, but the PMSA is a member of the Pacific Ballast Water Group and is working towards solutions in that capacity.

The Puget Sound Steamship Operators Association (PSSOA) is composed of 45 vessel operators and agencies engaged in maritime commerce in Puget Sound and Grays

Harbor ports. The PSSOA is a non-profit organization that works to encourage the best interests of its members by promoting commerce, international friendship and industries and to ensure uniformity among the actions of its members (PSSOA website). The PSSOA has developed a voluntary ballast water exchange policy and has recommended that its members abide by that policy. "...The PSSOA has strongly recommended to its member companies, that ballast water exchange be conducted in accordance with the Coast Guard rules, and also while on coastal voyages, if it is safe, and if the vessel is at least 25 nautical miles offshore and not in a marine sanctuary" (PSSOA website).

Environmental Groups

There are numerous environmental groups that have played a role in the ballast water issue. People for Puget Sound, Friends of the San Juans and Northwest Environmental Advocates all signed the petition to Carol Browner, administrator of the EPA, to regulate ballast water discharge under the Clean Water Act. The Washington Environmental Council and Puget Soundkeeper Alliance have been active through the work of the chairman of the Ballast Water Subcommittee of the Puget Sound Marine Committee. Adopt a Beach has been active in volunteer monitoring of aquatic nuisance species and in the control of *Spartina alterniflora,* an invasive non-native estuarine plant.

Appendix B. Regional Oceanography

The purpose of this report is to suggest considerations for the siting of alternative zones for ballast water exchange for vessels entering Puget Sound. Although vessels entering Puget Sound may transit Canadian waters off of Vancouver Island, those areas will not be described here as they are under Canadian jurisdiction and are not under consideration for alternative exchange zones. Vessels entering Puget Sound transit U.S. waters in the Strait of Juan de Fuca, Puget Sound and off the coast of Washington (see Figure 10).

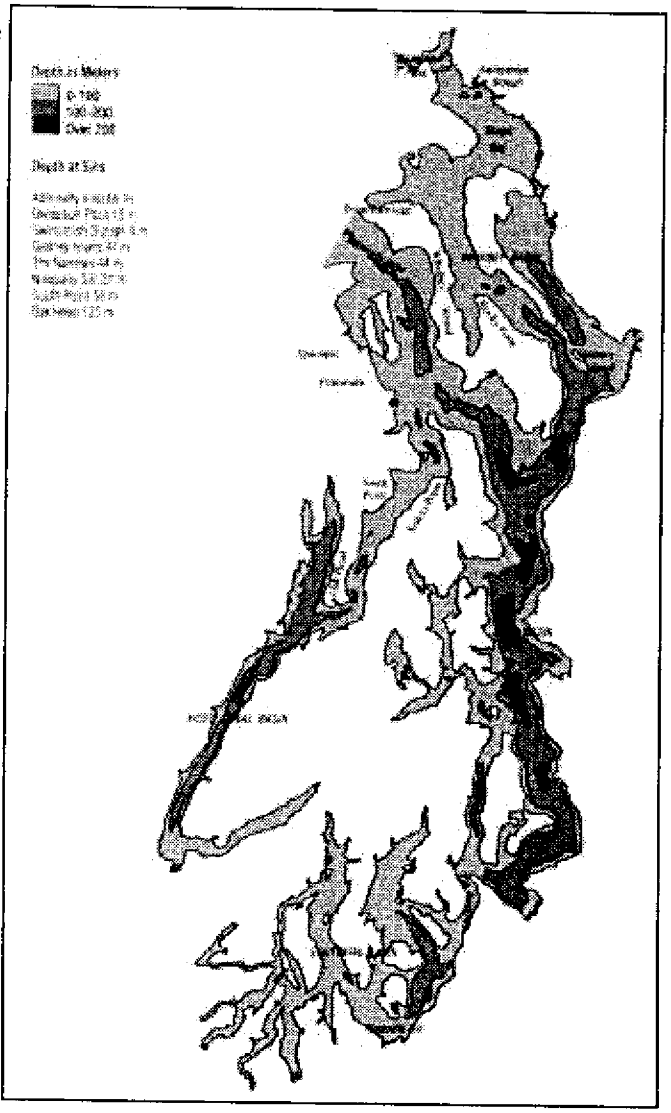


Figure 15.
Puget Sound bathymetry at 100 meter intervals. (Burns, 1985) Reprinted by permission from Washington State Sea Grant program, University of Washington, 1999.

Puget Sound

Puget Sound is divided into four subdivisions, or basins: the Main Basin, Whidbey Basin, Southern Basin, and Hood Canal Basin (Burns, 1985). These basins are defined geographically, but also by their bathymetry. "The term basin implies a depression in the seafloor where deeper water in the middle is separated by shallower depths from deeper water beyond. In a general sense, the shallower depth separating one basin from another may be relatively insignificant, or it may be a full-fledged barrier preventing flow of water from one basin to another" (Burns, 1985).

The Main Basin of Puget Sound is a partially-mixed, fjord-like estuary which connects to the Strait of Juan de Fuca through Admiralty Inlet and extends southward 100 km (55 miles) to Commencement Bay. A sill at Admiralty Inlet impedes the circulation between the Strait of Juan de Fuca and the Main Basin (see Figure 15). A sill is a shallow area of the seafloor that separates two basins from one another or a coastal bay from the adjacent ocean (Burns, 1985). North of Seattle, the Main Basin exhibits a typical estuarine pattern of net seaward flow near the surface, due to freshwater input from rivers, and net landward flow at depth (Cannon, 1983; Pashinski and Charnell, 1979; Thomson, 1994).

Surface circulation in the Main Basin is highly influenced by winds and tidal eddies (Pacific Marine Environmental Laboratory, 1976; Kawase, 1998; Ebbesmeyer, 1999). A drift card study by Pashinski and Charnell (1979) revealed that nearly 45 percent of drift cards released in the Main Basin were recovered and almost all of those recoveries occurred in the Main Basin or in the San Juan Island Region (eastern Strait of Juan de Fuca). The recovery rates for cards released in the San Juan region were even higher—nearly 50 percent—and almost all of these cards were recovered in the San Juan region. These recovery rates are high in comparison to the 17 percent recovery rate for cards released in the western Strait of Juan de Fuca.

Strait of Juan de Fuca

The Strait of Juan de Fuca, connecting the Main Basin of Puget Sound to the Pacific Ocean, is 160 km long, ranges from 22 to 60 km wide and is, on average, 250 m deep (University of Victoria website). The Strait exhibits a typical estuarine circulation pattern with fresher surface water flowing seaward above colder, saltier water flowing landward (Ott and Garrett, 1998; Ebbesmeyer et al., 1991(a); Holbrook et al., 1980; Thomson, 1994). Due to the earth's rotation and the width of the strait, the surface seaward outflow is strongest on the northern, Canadian side of the channel and greater inflow occurs on the southern, U.S. side of the Strait (University of Victoria website; Pease et al., 1979; Hickey et al., 1991; Thomson, 1994).

The typical estuarine circulation pattern can be altered by changes in coastal winds. Reversals in surface flow (from seaward to landward) can result from a low-pressure center off Washington that generates southerly coastal winds (Ebbesmeyer et al., 1991(a); Holbrook et al., 1980; Hickey et a;., 1991; Thomson, 1994). These reversals can last several days and although they usually occur during the winter, reversals have been observed during the summer (Holbrook et al., 1980). In addition, tidal eddies strongly influence surface circulation in the Strait. Ebbesmeyer et al. (1991(b)) found that 14 prominent eddies were the principal influence on the recovery of drift cards in the eastern Strait. Ebbesmeyer et al. (1991(b)) also revealed that winds were of secondary importance to the recovery patterns in the eastern Strait.

Due to the high variability in the circulation in the Strait of Juan de Fuca, especially in the eastern Strait, Holbrook et al. (1980) determined that pollution from oil spills occurring in the Strait would probably reach shore before being carried out to the Pacific Ocean. "Observations presented in this report imply that a spill resulting from a tanker accident within the Strait could impact the ecologically sensitive near-shore zone and beaches before flushing into the coastal ocean. Intrusions of coastal water generated by coastal winds are common during winter and have been observed year-round; therefore, an oil slick could have an eastward trajectory well into the eastern basin region. Because of the complex pattern of eddies, fronts, and shore-directed current components, the potential for oil slick beaching increases with eastward distance into the system" (Holbrook et al., 1980).

Coastal Washington

The coastline of Washington is relatively smooth and has an approximate north-south orientation. The coast is punctuated by the Strait of Juan de Fuca, Grays Harbor, Willapa Bay and the Columbia River. Each of these estuaries is fed by at least one river. The Chehalis, Humptulips, North, Hoquiam and Wishkah rivers feed Grays Harbor. The Willapa, North and Naselle rivers feed Willapa Bay. The Columbia River is the only significant river entering the Columbia River estuary. The Columbia River discharge, which peaks in June, is responsible for 77 percent of the total drainage into the Pacific between San Francisco Bay and the Strait of Juan de Fuca. The freshwater effluent, which is generally 5-20 m thick and less dense than the surrounding seawater, generally flows to the north off the Washington coast during the winter and south off of the Oregon coast during the summer (Hickey, 1989).

Generally, the bathymetry of the Washington coast is smooth due to sediment accumulation. The continental shelf off of Washington varies in width from 25 to 60 km (15 to 35 miles) and is broken by six canyons: Juan de Fuca, Quinault, Grays, Guide, Willapa and Astoria (Strickland and Chasan, 1989). These canyons are typically 5-20 km wide and at least 1,000 m deep (Hickey, 1989).

The driving force for the surface winds off of the Pacific Coast is the strength of the gradient between the North Pacific high and the continental thermal low over California. This gradient is strongest in the summer, creating northerly winds offshore, and weakest in the winter, resulting in southerly winds off of Oregon and Washington (Hickey, 1979). Thus, upwelling occurs along much of the coast in spring and summer, and downwelling occurs at northern latitudes in the fall and winter (Hickey, 1998).

Large-Scale Currents

The coasts of Washington and Oregon are located in an eastern boundary current system, wherein the West Wind Drift divides into the northward flowing Alaskan Current and the southward flowing California Current (Hickey, 1989). The California Current System is composed of the California Current, the Davidson Current, the California Undercurrent and possibly a subsurface Washington Undercurrent.

The California Current flows southward year-round from the shelf break of the Pacific Coast to 1,000 km offshore and is strongest in the summer to early fall and weakest in the winter (Hickey, 1998). The width of the current varies from 600-1,000 km, with no well-defined western boundary (Purdy, 1990). The current carries colder, fresher subarctic water at mean speeds of 10 cm per second. The current is strongest at the surface, but extends through the top 500 m of the water column. The position of the current is also seasonal in nature. The California Current is closer to shore during the summer and further off of the shelf in winter (Strickland and Chasan, 1989).

Hickey (1979) distinguished an offshore region of strong southward flow, which she defined as the main branch of the California Current, from a nearshore region of southward flow, which occurs primarily on the continental shelf. The offshore maximum is located 250-350 km from the Washington/Oregon coast during the summer and late fall. The nearshore maximum occurs in spring and late summer off of the Washington/Oregon coast.

The California Undercurrent is a relatively narrow (10-40 km), subsurface current that flows northward over the continental slope from Baja California to Vancouver Island (Hickey, 1998). The current has a jet-like structure, with a jet core located just seaward and a little below the shelf break. The current is strongest at 100-300 m depths and transports warmer, saltier, equatorial water. The California Undercurrent is strongest in summer or early fall and minimum northward subsurface flow occurs in the spring (Hickey, 1998). There is speculation that the Davidson Current could be a surface expression of the California Undercurrent (Hickey, 1979).

During the winter, when the southward flowing California Current is weaker and further offshore, the northward flowing Davidson Current develops. The Davidson Current begins to develop inshore of the California Current off the Washington/Oregon coast in September, is well established in January and disappears by May (Purdy, 1990). Flow in March and April are transitional and can be in either direction (Hickey, 1979). The Davidson Current is 100 km in width and extends seaward of the slope, carrying warmer, saltier, low oxygen, high phosphate, equatorial water. There is evidence that there is a second region of northward flow that is found several hundred kilometers away from shore and is separated from the Davidson Current by the southward flow of the California Current (Hickey 1979).

There is some evidence that a southward undercurrent, the Washington Undercurrent, occurs along Washington and Oregon slopes during the winter (Purdy, 1990). The Washington Undercurrent is deeper (300-500 m) than the southward flowing California Undercurrent (Hickey, 1998).

Shelf Currents

Currents over the shelf generally follow the seasonal pattern of ocean currents, but they are highly variable and are influenced by local winds, bottom and shoreline configuration and freshwater input. "On the average, water flows southward in the upper 100 m during summer, and northward below that depth. Water over the shelf flows generally northward at all depths during winter; nearshore under the Columbia River plume southward flow may be found" (Strickland and Chasan, 1989).

Off the Washington coast, the late summer southward flow reaches a maximum on the outer shelf and slope, and summer flow on the inner shelf is more northward than off the Oregon coast. During winter, the flow over the inner shelf of Washington is more southward than that off Oregon, and the seasonal mean flow off Washington is stronger on the outer shelf than the mid-shelf (Hickey, 1989).

Tidal Currents

Off the Washington coast, tides are semidiurnal mixed, meaning that tidal currents reverse four times daily. Tidal currents are stronger during the spring tides associated with full and new moons, and weaker during the neap tides around the quarter moons. Tidal currents are greatest during the periods of greatest tidal amplitude, such as May through July and November through January (Strickland and Chasan, 1989).

"Tidal currents on the shelf tend to flow in an elliptical rotary pattern, northeastward on the flood and southwestward on the ebb. Floating objects follow such ellipses as they drift in the direction of the underlying wind-driven and other currents" (Strickland and Chasan, 1989). Typical maximum tidal current speeds on the open shelf are 10 cm/sec. However, current speed is variable. Nearshore, tidal currents are influenced by estuarine flow and are much larger than wind-driven currents.

Variability

As noted above, currents vary over a variety of time scales from momentarily to seasonally. They also vary interannually. Interannual variability in water properties, current, zooplankton biomass and steric height is significant off of the Pacific Coast and much of this variability is due to the El Niño Southern Oscillation phenomena (Hickey, 1998). During El Niño years, the California Current is unusually weak, the California Undercurrent is unusually strong, the water in the upper 500 m is unusually warm, the zooplankton biomass is unusually low and nutrients, phytoplankton biomass and fish catch are greatly reduced (Hickey, 1998). Overall, during El Niño years, large scale currents flow more northward and coastal sea level is higher than in non-El Niño years (Hickey, 1989).

Waves/Storms

Wave heights and wavelengths are important due to their effects on structures and their hazards to navigation. The U.S. Pacific Northwest is noted for heavy wave conditions, with measured extremes of wave height range from 15 to 29 m off the coast of Washington (Purdy, 1990). Maximum and mean wave heights are largest on both the outer shelf and the nearshore during the winter months (October through April) (Strickland and Chasan, 1989).

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List of Acronyms

ANS- Aquatic Nuisance Species
ANSTF or ANS Task Force- Aquatic Nuisance Species Task Force
DFO- Department of Fisheries and Oceans Canada
EPA- Environmental Protection Agency
IMO- International Maritime Organization
MPA-Marine Protected Areas
NANPCA- Nonindigenous Prevention and Control Act of 1990 (P.L. 101-646)
NIS- Nonindigenous Species
NISA-National Invasive Species Act of 1996 (P.L 104-332)
NOAA- National Oceanic and Atmospheric Administration
PBWC- Pacific Ballast Water Committee
PMSA- Pacific Merchant Shipping Association
PSMC- Puget Sound Marine Committee
PSSOA- Puget Sound Steamship Operators Association
SERC- Smithsonian Environmental Research Center
UN- United Nations
USCG- United State Coast Guard
USFWS- United States Fish and Wildlife Service
USGS- Unites States Geological Survey

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