Pathways and Management of Marine Nonindigenous Species in the Shared Waters of British Columbia and Washington

FINAL REPORT January 1997

Prepared for Puget Sound Water Quality Authority U.S. Environmental Protection Agency, Region 10 Department of Fisheries and Oceans, Canada by Ralph Elston, Ph.D. AquaTechnics, Inc. P.O. Box 687 Carlsborg, WA 98324 USA

Executive Summary

The introduction of nonnative or nonindigenous species (NIS) to new environments can cause environmental and economic problems. Such problems have occurred worldwide, including in the shared marine waters of British Columbia and Washington (defined for the purposes of this report as the Straits of Georgia and Juan de Fuca, Puget Sound including Hood Canal, and the smaller straits and waters surrounding the San Juan and Gulf Islands).

This report was commissioned by the Puget Sound Water Quality Authority through an agreement between the U.S. Environmental Protection Agency (EPA) and the Canadian Department of Fisheries and Oceans (DFO). Its purpose is to assist the Washington and British Columbia Working Groups on Minimizing the Introduction of Exotic Species in developing their recommendations to the British ColumbiaWashington Environmental Cooperation Council. It assesses the status and management of NIS introductions into the shared marine waters of British Columbia and Washington. Pathways of NIS introduction are evaluated, and the management programs in place to reduce risks from these pathways are described. It is intended that from this report and from the work groups that will consider it, recommendations will emerge that address risk and management of NIS introductions, and needs for further information.

Pathways of NIS introduction to the shared marine waters include aquaculture activities; the aquarium trade; public aquaria; releases of NIS by individuals; commercial, military, and recreational marine vessels; research institutions; and seafood commodity distribution. Risk of NIS introduction from aquaculture is well defined, the industry is highly regulated, and active processes are underway for continuous review of aquaculture activities as they involve NIS. Risk of NIS introduction from aquarium activities and release of NIS by individuals is poorly defined, and only limited information is available to define the risks from research, seafood distribution, and marine recreational vessel activities. The relative risk associated with the large inoculation of marine NIS from ballast water discharges is assessed from shipping industry data and relevant scientific literature. Management of NIS in other selected states and countries is briefly reviewed.

More complete and detailed baseline information regarding the presence and distribution of native and NIS in shared waters is needed, because in some cases, there is disagreement on whether particular species are native or introduced, or whether or not particular NIS are established. Risk standards for genetic effects and ecological interactions are needed if NIS management is going to address these areas.

There is presently an opportunity to reduce the frequency and negative effects of future NIS introductions by expanding and improving a voluntary ballast water exchange program, by developing educational materials addressing several of the NIS introduction pathways, and by enhancing intergovernmental communication. Protocols and operational codes for aquarium activities and research could also reduce the risks of NIS introductions. In order to determine the risk of NIS introduction from aquariumrelated activities, research, live seafood distribution, and marine recreational vessel movements, more detailed information is required.

Shipping, food production and processing, and other marine activities with the potential to affect NIS introductions will continue. A zerorisk condition is unattainable; a more realistic objective of NIS management should be to reduce the frequency of unintended introductions, and to understand and minimize negative consequences of introduced species.

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INTRODUCTION

Purpose of this Report[1]

The introduction of nonnative or nonindigenous species (NIS) to new environments can cause environmental and economic problems. Such problems have occurred worldwide, including in the marine waters of British Columbia and Washington. The Environmental Cooperation Council of Washington and British Columbia was established soon after the 1992 signing of the Environmental Cooperation Agreement between British Columbia and Washington. The council, consisting of the deputy minister of the British Columbia Ministry of Environment, Lands, and Parks (MELP) and the director of the Washington Department of Ecology, convened the Marine Science Panel to identify the most pressing environmental issues facing the shared inland marine waters of Washington and British Columbia (Figure 1). The panel recommended that preventing the introduction of additional nonnative species to the shared marine waters, which can result in major, irreversible changes to the ecosystem, is a highpriority issue amenable to joint actions of government agencies, scientists, and citizens of the province and state.

Following receipt of the panel report, the Environmental Cooperation Council convened the Puget Sound/Georgia Basin International Task Force, which is addressing the principal issues identified by the panel through several sets of parallel working groups in Washington and British Columbia. The working groups are charged with making recommendations through the task force to the council. The recommendations will propose actions to improve the management and protection of the shared marine waters. This report was commissioned by the Puget Sound Water Quality Authority through an agreement with the U.S. Environmental Protection Agency (EPA) and the Canadian Department of Fisheries and Oceans (DFO). The report will assist the Washington and British Columbia Working Groups on Minimizing the Introduction of Exotic Species in developing their recommendations to the Task Force, and ultimately to the council. The report assesses the status and management of nonnative or NIS introductions into the shared marine waters of British Columbia and Washington. Pathways of NIS introduction are evaluated, and the management programs in place to reduce risks from these pathways are described. It is intended that the work groups will use this report to help develop recommendations that address risk analysis and management of NIS introductions, and that identify areas in which further information is needed. WThis report will provide an assessment of pathways of entry and existing regulations or policies that limit entry of nonintentional introductions in the shared waters, and of the adequacy of review and management of proposed intentional introductions. A limited discussion is included to summarize pertinent information on some existing NIS that have become established in or near the shared waters. Like the recent U.S. Office of Technology Assessment (OTA) analysis (OTA 1993), the report focuses on introductions that may cause economic or environmental harm, with limited attention to the beneficial attributes of some introduced species. As an overview and firstorder assessment of NIS in shared waters, this report is not and was not intended as a quantitative risk analysis. The scope of this report is limited to the prevention of future undesirable effects of marine exotic species introductions. Brief discussions of the management of established NIS that are in the coastal waters of Washington and British Columbia or that have become established close enough to threaten them are also included. Although it is clear that the colonization of introduced exotic species is to some degree a continuous process and that many years may pass before a relatively stable condition of colonization has

[1] Shared Inland Marine Waters of British Columbia and Washington. For the purpose of this report, these waters are considered to be the Strait of Georgia, Puget Sound including Hood Canal, the Strait of Juan de Fuca, and the smaller straits and waters surrounding the San Juan and Gulf Islands.

been achieved, the management of such species is a complex subject beyond the scope of this report. The specific objectives of this report are as follows:

Provide a brief overview of NIS pathways of introduction.

Review regional management regarding potential harmful nonintentional introductions.

Assess the management and regulatory structure for future intentional introductions.

Assess the adequacy of the NIS knowledge base to support management.

Assess regulatory as well as voluntary and educational programs aimed at preventing negative impacts of NIS.

Make recommendations based on the above assessments.

Definitions

Definition of terms relating to NIS have been proposed in other national and subnational assessments. The following definitions adapted from the review by OTA (1993) are applied in this report:

> **Nonindigenous (or nonnative) species** A species living beyond its natural range or natural zone of potential dispersal, including all domesticated and feral species, and all hybrids except for naturally occurring crosses between indigenous species.
>
> **Indigenous species** A species living within its natural range or natural zone of potential dispersal, excluding feral species descended from domesticated ancestors.
>
> **Natural range** The geographic area a species inhabits or would inhabit in the absence of significant human influence.
>
> **Natural zone of potential dispersal** The area a species would disperse to in the absence of significant human influence.
>
> **Introduction** All or part of the process by which a nonindigenous species is imported to a new locale and is released or escapes into a freeliving state.
>
> **Established** The condition of a species that has formed a selfsustaining, free living population at a given location.

The concept of a naturalized species was proposed in the Chesapeake Bay Policy for the Introduction of Nonindigenous Aquatic Species (Chesapeake Bay Program 1993). That policy defines a naturalized species as an NIS that has established a selfsustaining population that has persisted for at least 10 years. This definition suggests that no further efforts may be needed to manage the species. However, some introduced species may be in the process of range extension, with concurrent impacts, for periods well beyond 10 years. Examples in the shared waters include the cordgrasses (Spartina alterniflora, S. anglica, and S. patens) and Japanese oyster drill (Ceratostoma inornatum). Thus, an arbitrary definition of naturalization could be inappropriate; rather, the question of whether species are to be considered naturalized and an integral part of the local ecosystem must be made on a casebycase basis. Specific recommendations on this topic could be made in another report, but will not be made here. The release of genetically engineered organisms may also be considered as a case of NIS introductions, but will not be considered in this report.

Rationale for this Report

Beneficial uses of nonindigenous species. NIS are introduced to new areas both intentionally and nonintentionally by human action. Many NIS, regardless of how they were introduced, are widely held to have beneficial uses in the marine environment. Intentional introductions are proposed and made because of the historical beneficial uses that have been made of previous introductions, some intentional and some not, or because of the belief that introductions may solve or moderate some existing problem resulting, for example, from a previously introduced NIS with negative impacts. Many species in both terrestrial farming and aquaculture are nonindigenous and are widely regarded to have significant beneficial effects. Whether or not a beneficial use sufficiently outweighs potential negative effects depends on individual values. It is not the purpose of this report to address the validity of such values.

Negative effects of nonindigenous species. Although the natural dispersion of marine organisms is a continuous process, it is clear that human action has dramatically increased the number of species being dispersed and accelerated the rate of dispersion. The best known recent example of an aquatic NIS with a negative impact is the introduction of the zebra mussel (Dreissena polymorphia) to the Great Lakes and its subsequent spread through the eastern United States and Canada (Mills et al. 1993).

The unpredictability of effects and extent of distribution of NIS underlies the concerns over introductions. Introduction of NIS mediated, for example, by ballast water discharge and other marine vessel activities may be frequent. However, for significant effects to occur, introduction must be followed by successful colonization and establishment. As noted in OTA (1993), serious, documented, negative impacts from introductions (requiring colonization with measurable negative impacts) are infrequent, but a few wellknown cases have fueled concern about NIS. In addition, extensive and severe environmental degradation in locations such as the San Francisco estuary appear to have rendered the environment more susceptible to the establishment of NIS (Alpine and Cloern 1992; Carlton et al. 1990; Nichols et al. 1990; Werner and Hollibaugh 1993).

Assessing Negative Impacts of Nonindigenous Species

Types of negative impacts. Negative impacts of NIS are most often described in terms of economic losses, such as those resulting from interference with aquaculture or from alteration of shoreline properties by nonindigenous plants. Likewise, animal and plant pathogens can infect natural and farmed populations of animals and plants. Introduced fishes can displace other species of economic importance or reduce their populations through competition or predation. Virtually any NIS has the potential for ecological and/or economic impact. Ecological degradation can include declines or loss of species, loss of habitat, changes in substrates, transformation of ecosystems, transmission of disease, competition for food and space by NIS, and replacement of native species. Loss of economically important resources, loss of recreational opportunities, and aesthetic alterations can also occur.

Human health impacts may occur from the introduction of NIS. The introduction of toxic marine phytoplankton spores with ships' ballast waters has been documented, but the significance of these introductions in initiating or amplifying toxic plankton blooms is still poorly understood (ACIL

Economics and Policy Pty. Ltd. 1994). Ballast water may also transport human pathogens, for example, Vibrio cholerae, the causative agent of cholera, which was detected in ballast water in ships in the Gulf of Mexico (McCarthy and Khambaty 1994), but further study is needed to define the degree of this risk.

Measurement of negative impacts. Negative impacts of NIS are usually measured in economic terms; even those concerned about ecological damage, which often does not have immediately apparent economic consequences, frequently cite the economic consequences as justification for further controls on NIS introductions. The significance of particular impacts depends on the valueholder. Agricultural values may conflict with conservation values, for example, in whether or not the degree and extent of environmental change is justified by a change induced by an NIS introduction. A further problem in assessing impacts is that colonization by NIS may be greatly accelerated in a damaged or drastically altered environment, such as in San Francisco Bay. Clearly, NIS introductions can be a significant problem, but in many cases, environmental degradation and the factors that contribute to it may be the more fundamental cause that allows NIS to become established.

Prevention of the spread of infectious animal diseases is the most carefully regulated component of NIS impacts. Regulations exist in all developed countries and most developing countries aimed at preventing the introduction of animal diseases by a variety of vectors. One of the reasons that such regulations are so well developed is that there is general agreement that animal diseases can have negative consequences, that these consequences are more or less quantifiable, and that both control and enforcement, although potentially costly, are reasonably straightforward. The result is that standards exist by which animal health impacts are measured. In contrast, there is no comparable basis or broad agreement on standards of acceptable ecological effects or genetic alterations in animal populations. OTA (1993) cited various problems in estimating economic loss impacts associated with NIS introduction and colonization. Costs tend to be estimated very generally, and the numbers used to estimate economic impacts are often poorly documented. The costs of excluding NIS can be estimated, along with those of addressing impacts of NIS introduction and colonization. In addition, economic activity may be created in dealing with existing NIS. Finally, the cost of regulation and enforcement may be high and difficult to quantify.

Some authors have attempted to evaluate ecological alterations in terms of economic impact. This approach is problematic, because it is not feasible to measure all impacts, and because standards do not now exist to define an acceptable impact or the value of various alterations. More important, perhaps, is the view that no cost can be assigned to alteration of the natural environment, because its worth transcends economic valuation. There are various degrees to which people hold to this value. At its extreme, no alteration of the natural environment is permissible. Although many would reject this approach, others believe that human activities should minimize negative alterations to the environment and that intentional or consequential alterations should be balanced by beneficial uses.

Managing Nonindigenous Species Introductions

The negative effects of NIS have been considered from a national (Gauthier and Steel 1995; OTA 1993) and regional (Anonymous 1993) perspective in recent years, amid increasing debate and concern. The OTA convened a panel that published a detailed report and assessment of NIS and made recommendations for management. In the United States, the individual states have authority to permit intentional introduction of NIS, and in Washington, a system to manage such proposals is in place. In British Columbia, the provincial and federal governments both have authority, and recommendations are taken from a committee that consists of federal and provincial agency representatives. In both Canada and the United States, introduction of NIS with ballast water is considered a federal issue.

Shipping, food production and processing, and other marine activities with the potential to affect NIS introductions will continue. The complete exclusion of NIS from an area is essentially unattainable; a more realistic objective of NIS management should be to reduce the frequency of unintended introductions, and to understand and minimize negative consequences of introduced species.

Risk Analysis

Risk analysis is the term applied to systematic and quantitative evaluation of activities. A draft report called Generic Nonindigenous Aquatic Organisms Risk Analysis Review Process was developed under the auspices of the Aquatic Nuisance Species Task Force, which was created to assist government agencies to meet goals of the Aquatic Nuisance Prevention and Control Act of 1990 (Risk Assessment and Management Committee 1996). The stated goal of this review process is to provide a standardized process for evaluating the risk of introducing nonindigenous organisms into a new environment and, if needed, determine the correct risk management steps needed to mitigate that risk. It is important to note that this review process was based on the Generic NonIndigenous Pest Risk Assessment Process (Risk Assessment and Management Committee 1996; Orr et al. 1993), which was developed by the Animal and Plant Health Inspection Service (APHIS) of the U.S. Department of Agriculture. The APHIS process has been used in a number of risk analysis processes and provides a standardized and comprehensive method to evaluate risk. The resulting review process is a useful tool for evaluating aquatic NIS introductions, but like all risk analysis processes, it depends on available and valid information for the particular case under consideration.

PATHWAYS OF NONINDIGENOUS SPECIES INTRODUCTIONS Pathways for NIS introduction have been identified previously by various authors (e.g., Carlton 1993); they are listed in Table 1 and are summarized below. Following these summaries, the specific vectors in relation to the inland marine waters of Washington and British Columbia are considered, along with the present regulations and management in place to reduce the risk of unwanted introductions and their consequences.

Table 1. Pathways for Nonindigenous Species Introduction to Marine Coastal Waters of Washington and British Columbia

PATHWAY

ADEQUACY OF INFORMATION AVAILABLE NTO ASSESS RELATIVE RISK OF NIS

INTRODUCTION

Aquaculture Good
Aquarium Trade/Public Aquaria Poor
Releases by the Public Poor
Marine Vessels/Commercial Limited
Marine Vessels/Recreational, Military Poor
Research Institutions Limited
Seafood Commodities Limited

Natural Dispersion of Marine Organisms

Natural dispersion of marine organisms is by definition not considered a mechanism of NIS introduction. However, the natural dispersion of marine organisms is a continuous process, aided by ocean currents, climatic changes, and natural drift. A regional consideration of the importance of human activities that increase the rate and type of transport cannot be made without a consideration of natural processes. For example, if large numbers of particular marine organisms are commonly transported from estuaries and fjords along the Gulf of Alaska to the waters considered in this report, then the human mediated transport of similar organisms on fishing vessel hulls would have less importance than it would if there were hydrological boundaries that prevented such natural transport. To provide some perspective on this issue, a brief consideration of natural transport of marine organisms in shared Washington and British Columbia waters will be made in the following section.

Aquaculture

Marine aquaculture is practiced in tropical and temperate zones around the world. Shellfish aquaculture has been practiced for over 100 years in the shared waters of Washington and British Columbia, and intensive salmon culture has been practiced since the mid 1980s, particularly in British Columbia and to a much lesser degree in Washington. Aquatic farmed products are consumed in all countries of the world, and aquaculture is a rapidly growing industry on a worldwide basis. As in terrestrial agriculture, technology and markets drive the production of large quantities of a relatively few number of species, although there are multiple minor species in production in both terrestrial agriculture and aquaculture. Therefore, as markets demand more of these high production species, the areas of production tend to expand with the associated introduction of the farmed species, which may be nonindigenous. Historically, NIS introductions for aquaculture have been made throughout the world, often implemented by government agencies. Such introduced species have in many cases become well established in aquaculture. In developed countries, such introductions are now usually preceded by review processes (e.g., see Risk Assessment and Management Committee 1996) that evaluate the potential for deleterious effects. British Columbia and Washington have had such procedures in place for at least the last decade, and the intentional introduction of aquaculture species is far more restricted now than it was in the past. Nonetheless, as aquaculture becomes an increasingly important means of food production in the world, and as consumption increases and markets develop, there will be a continuing desire to introduce species to new areas for cultivation.

Technology can assist in reducing the risk of exotic species introductions. An example is by the use of triploid fish, which are sterile and therefore do not reproduce in the environment. Improving technology has increased the effectiveness of methods for the production of triploids so that it approaches or equals 100% in some cases (Lincoln and Scott 1983). The result is a substantial reduction of the risk that animals that escape from farm containments will reproduce in natural waters.

Aquarium Trade and Public Aquari

Tropical fish for the retail market are imported to the United States primarily from Asia. Tropical fish are also cultured in farms in Florida and in closed systems in many other locations in North America. Plants, as well as fish and invertebrates, are sold in retail pet fish outlets, and some of these are saltwater species, or saltwater tolerant to some degree. A more limited but undefined market for temperate saltwater species also exists.

Public aquaria often import NIS for display purposes and make expeditions specifically for this purpose. Fish, invertebrates, plants, and associated microorganisms imported for such activities have the potential to escape or to be released from confinement in aquaria.

Individual Nonindigenous Species Importations and Releases

Individuals may be a significant source of NIS introductions through their careless discard of live seafood products, aquarium plants and animals, or marine species collected elsewhere. Risk assessment of this source is difficult; however, individuals may be responsive to public education and involvement efforts aimed at eliminating these releases. There are voluntary groups, such as the AdoptABeach program in Washington, that work to control the spread of cordgrasses or other introduced nuisance species, and such groups could assist in further public education efforts relative to NIS.

Research and Teaching Institutions

Academic, government, and private research institutions may import NIS for research and testing purposes. For example, marine phytoplankton species used in research, including some that produce toxins, are cultured and easily transported in culture tubes. A variety of plants, invertebrates, and fish that are nonindigenous are also used in research and teaching programs, and some laboratories conduct research on animal pathogens that affect marine fish and invertebrates. Although some laboratories have appropriate protocols and comply with existing regulations, research institutions are often considered by regulatory agencies to represent significant risk for local introduction of NIS. In addition, a number of biological suppliers and institutions sell and ship live marine organisms for teaching or research purposes. As a service to researchers, for example, the Marine Biological Laboratory at Woods Hole, Massachusetts, has provided live marine organisms throughout the world for many years. Companies such as Carolina Biological Supply and Wards Natural Science Supply deliver living plants and animals (including aquatic and marine) to researchers and educators in both the United States and Canada.

Live Seafood

There is an active trade in live seafood products, both wildcaught and farmed, and there are indications that this trade is increasing in the diversity of species and total volume it represents. Although most of the living seafood products transhipped at ports of British Columbia and Washington are locally harvested and exported, small quantities of live seafood are also imported. Live seafood products may be shipped directly from distributors to consumers, or consumers may purchase them in regional markets. Even processed seafood has been suspected of carrying infectious animal disease organisms, but based on an assessment that found this vector to be of very limited risk, dead fish products bound for markets in the United States are excluded from federal inspection for animal diseases (50 CFR Part 16; Injurious Wildlife: Importation of Fish and Wildlife Eggs). Live packing material consisting of marine plants, which can also harbor live invertebrates, has been used to ship living seafood products, such as oysters or other shellfish (Miller 1969) but there is no readily available information to assess the current extent of this practice.

Shipping Industry

Ballast water. Transport of marine organisms in ballast water has received increasing attention in recent years (Carlton et al. 1995; Gauthier and Steel 1995; Hallegraeff and Bolch 1992). Ballast water taken on by ships to add stability, particularly when ships are not laden with cargo, is often transported between continents. A large number of nonindigenous marine organisms has been found in ballast water and in ports where ships deballast (Carlton 1985); ballast water discharge constitutes a large volume of frequent inoculation of NIS. Some living organisms from the ballast water tend to fall out of suspension and are incorporated into the sediment within ships. Thus, these sediments are particularly rich in organisms (Kelly 1993), including encysted forms that may be activated upon discharge into receiving waters. Modern vessels using sea water as ballast and the increased size, numbers, and speed of ships have undoubtedly increased the frequency of transfer of living marine organisms. However, inoculation of receiving waters with organismrich ballast water does not guarantee that these species will become established. Establishment and spread of inoculated species may in fact be relatively rare, and are not well understood.

Ballast water is believed to be the vector for the transplantation of the freshwater zebra mussel from Europe to the Great Lakes (Carlton 1996). The cost of the resulting and ongoing zebra mussel invasion in the United States has focused attention on this important vector of freshwater and marine NIS introductions.

In the United States, concern about ballast watermediated NIS invasions resulted in a study of the role of shipping in the introduction of NIS to coastal United States waters and analysis of control options (Carlton et al. 1995). The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 directed the U.S. Coast Guard (USCG) to issue mandatory ballast exchange requirements for the Great Lakes and part of the Hudson River, and voluntary ballast water exchange guidelines for other United States waters. More recently, in October 1996, the National Invasive Species Act of 1996 became law. This act directs the U.S. Secretary of Transportation to provide guidelines for a voluntary national ballast water exchange program, and if the voluntary program is not judged adequate, to implement a mandatory national program.

Ballast water has been suggested as a means for the introduction of toxic dinoflagellates to Japan from Europe and North America, and from Japan to Australia (Bolch and Hallegraeff 1993; Scholin et al. 1994) and possibly for the release of pathogenic bacteria into receiving waters (Munday et al. 1994). Ballast water is recognized as a significant vector for marine organism transport, but some caution is due in assigning cause and effect. Even though Bolch and Hallegraeff (1993) argued that the occurrence of toxic dinoflagellate blooms in Australia resulted from the discharge of organisms from ships, they also emphasized the role of increasing urbanization and estuarine enrichment, and suggested the need for further study of such phenomena and of climatological changes. It is known that discharged ballast water and sediments can contain viable dinoflagellates, yet there are a variety of other plausible explanations for the new occurrence of toxic algal blooms.

Therefore, although the potential problem of ballast watermediated transport of such organisms is a problem that needs to be addressed, the association between ballast discharges containing resting stages of toxic marine phytoplankton and blooms of noxious or toxic algae remains hypothetical.

Ships originating and taking on ballast water in temperate latitudes of one hemisphere and translocating the ballast across the equator to another temperate location may reduce risk of transport of marine organisms due to the heating of ballast water that takes place when ships cross warm tropical waters. However, this is likely to be a variable effect that depends on ship construction, volume of ballast water, and duration of voyage.

Open ocean exchange of ballast water while a ship is underway may be a means of reducing ecological risk without causing delays, at least for ships under 50,000 tons dry weight. However, most ships in operation today are not designed for exchange of ballast water while underway. Many can exchange ballast water by pumping ballast chambers while at sea, but for ships greater than 50,000 tons dry weight, this procedure could compromise structural integrity of the ship, reduce stability, cause propeller exposure, and cause delays in vessels reaching their destination (Gauthier and Steel 1995).

Marine vessels. Carlton (1993) listed a variety of means by which marine organisms can be attached to ships. Organisms and plants can attach to ship hulls (or to trailers for small boats) or be carried in other compartments unintentionally or intentionally, in both commercial and recreational vessels. Ships have been a vector for transoceanic transport of attached marine organisms for centuries. In addition, there is evidence that fish will accompany heavily fouled vessels (AQIS 1995b). Although shipping traffic has increased markedly, the use of antifouling paints has reduced the intensity of fouling on ships, fishing vessels, and private boats (Carlton 1993). Antifouling paints are not always effective or applied frequently enough to prevent the transport of attached marine organisms, along with associated parasites or microorganisms, as ships travel between ports.

The transport of organisms attached to or associated with the hulls of ships is presumably more effective across similar latitudes and ecological zones. For example, organisms attached to ships traveling from north Asian ports to Washington or British Columbia would be more likely to survive than those coming from South American or Australian ports, which would have to cross the equatorial zone.

PATHWAY ASSESSMENT AND MANAGEMENT IN SHARED WATERS

Following a brief overview of the natural dispersion of marine organisms and of past practices that have led to NIS introductions in the shared waters, a discussion of NIS related regulations, policies, enforcement, and education in Washington and British Columbia is presented for each pathway. Regulatory and educational programs are summarized in Table 2.

Natural Dispersion of Marine Organisms

A brief discussion of natural dispersions is necessary to evaluate the geographic scale on which humanmediated introductions should be considered (Dr. Richard Strathman, Friday Harbor Laboratories, University of Washington, provided the material upon which this summary is based, personal communication, 1995). Marine organisms vary widely in their capacity for dispersal, but many can disperse hundreds to thousands of miles in their planktonic stage, which lasts up to several months for some species, or by the association of nonplanktonic species with floating material. For example, Dungeness crab (Cancer magister) larvae found off Vancouver Island are believed to have originated from as far south as northern California and as far north as southeastern Alaska. This example applies to other species, as well; thus, any particular geographic boundaries that might be imposed on transports within the northeastern Pacific will be relevant to some organisms, but not to others. However, dispersal does not guarantee colonization; certainly, most dispersals do not lead to colonization. El Ni9o events are also a frequent cause of water current and temperature alterations in the northeast Pacific ocean that can bring NIS to the northeast Pacific (Mearns 1988) as well as cause reduced growth, severe population reductions, and mortality of salmon (Oncorhynchus spp.) and herring (Clupea spp.), decreased reproductive success of shorebirds, and other structural changes in the food web (Pearcy and Schoener

Agencies Responsible for Regulation and Education about Pathways for Introduction of Nonindigenous Species to Marine Coastal Waters of Washington and British Columbia

REGULATED ESTABLISHED

EDUCATIONAL PROGRAM PATHWAY

Washington British Columbia Washington-British Columbia

Aquaculture Aquarium Trade and Public Aquariay WDFW

Releases by Individuals WDFW

Research Institutions

Seafood Commodities

Marine Vessels Commercial Marine Vessels Recreational/Military Washington Department of Fish and Wildlife.

U.S. Department of the Interior, Title 50, U.S. Code of Federal Regulations, applies only to specific disease agents of salmonid fishes.

3)MAFF British Columbia Ministry of Agriculture, Fisheries, and Food.

4)DFO Department of Fisheries and Oceans, Canada.

5)MELP British Columbia Ministry of Environment, Land, and Parks pamphlets and school programs.

6)WDA Washington Department of Agriculture, Washington Noxious Weed Control Board (WNWCB)

7)DOT U.S. Department of Transportation; U.S. National Invasive Species Act (October 1996) directs the U.S. Secretary of Transportation to organize a voluntary national program of ballast water exchange with the potential of subsequent implementation of a mandatory program if the voluntary program is not adequate. U.S. Coast Guard implements this program.

8)Canada Shipping Act; regulates shipping industry, including discharge of certain toxic substances, but does not regulate release of NIS or ballast water.

9)USCG U.S. Coast Guard provides a written and video ballast water educational program to shippers.

1987; Schweigert 1995; Mackas 1995). Sightings of species such as California mackerel (Scomber californica), subtropical sunfish (Mola mola), and the colonial hydrozoan, Velella velella, normally rare off Washington and British Columbia, are common in these waters during such events.

Genetic distinction of populations also depends on the particular species considered. Species separated by as little as 10 km of unsuitable habitat may be genetically differentiated, whereas species with planktonic larval stages lasting several weeks can have little or no detectable difference between populations over long stretches of coastline of North America.

An example of the latter is the green sea urchin (Strongylocentrotus droebachiensis), for which similar gene frequencies were measured near Juneau, Alaska, and in the San Juan Islands of Washington.

Past Practices and Nonindigenous Species Introductions

The most apparent NIS introductions in shared waters resulted from past practices that are now prohibited by regulation. Regulations in place, in fact, are a result of the negative effects of these introductions. Some marine plants, including the cordgrasses, a brown alga (Sargassum muticum), and an eelgrass known as Japanese seagrass (Zostera japonica) (Lindstrom 1996), were introduced with shellfish shipments, as were the Japanese oyster drill and the Manila clam (Venerupis philippinarum). Unlike the cordgrasses and the oyster drill, the Manila clam has become a valuable cultured species and is widely considered beneficial.

Japanese seagrass provides improved feeding habitat for dabbling ducks and geese (Baldwin and Lovvorn 1994a, 1994b), but causes other biological and physical changes to the substrate (Posey 1988).

Shipping of live shellfish for outplanting from the east coast of North America or Japan, which resulted in the introduction of some of these deleterious NIS in the shared waters, is now prohibited in both British Columbia and Washington. Such importation has not been carried out for at least 20 years, although the old practice of shellfish seed importation is erroneously cited as an ongoing problem in at least one current publication (Waldichuk et al. 1994). The Pacific oyster industry now produces seed stock in both British Columbia and Washington. Prior to 1975, seed of the Pacific or Japanese oyster (Crassostrea gigas) was commonly imported from Japan, presumably accompanied by the Japanese oyster drill.

Aquaculture

Specific pathways and risks in the shared waters. Most of the major cultured species in the shared marine waters of British Columbia and Washington are NIS. These include the Pacific or Japanese oyster, the Manila clam, and the Atlantic salmon (Salmo salar). Early in this century, and continuing through the 1970s, Pacific oyster seed was repeatedly introduced from Asia. Introductions were necessary, because this oyster only reproduces in a few, limited areas in the shared waters, notably Pendrell Sound in British Columbia and Dabob Bay in Washington. These seed and adult (brood stock) introductions, in particular those early in the century, prior to the development of a seed inspection program, were apparently accompanied by several NIS, notably the Manila clam, the oyster drill, Sargassum muticum, and Japanese seagrass. The Manila clam subsequently has become an important species for aquaculture and recreational shellfish harvests, whereas most of the others are regarded as significant problem species.

The open pathways that allowed the uncontrolled introduction of intentional and accompanying NIS no longer exist in the shared waters for two reasons. The poor reliability and high cost of Asian oyster seed led to the development and commercialization of hatchery technology for oysters, clams, and native bivalve species in Washington state, starting in the 1970s. This has successfully eliminated the need to import seed shellfish, because hatcheries produce a higher quality and more uniform seed product. Additionally, regulatory structures now exist both in British Columbia and Washington that require an extensive review process before NIS of fish, shellfish, or marine plants from other continents or from the east coast of North America, including those that have already become established, can be introduced to the shared waters. Thus, the negative effects of some NIS, such as cordgrass and Japanese oyster drill, associated with aquaculture species in Washington and British Columbia waters are a result of past practices that are now much more stringently controlled.

Atlantic salmon eggs were imported commercially to both British Columbia and Washington starting in about 1985 to support the development of a commercial industry for farming this species. Previously, Atlantic salmon were cultured in pens in Puget Sound by the U.S. National Marine Fisheries Service (NMFS). Unsuccessful attempts were made early in this century by Canadian and United States federal agencies to introduce Atlantic salmon to Pacific waters (e.g., Waldichuk et al. 1994). Recently, the Canadian DFO brought the Japanese scallop (Patinopecten yessoensis) into British Columbia for scientific studies of its aquaculture potential, and after a quarantine and study period of about 4 years, permitted its commercial culture in the province. The bay mussel (Mytilus edulis), resident along the eastern shore of North America, was recently introduced into British Columbia after approval from local shellfish managers and from the federal assistant deputy minister for the DFO, Science. Release of mussels occurred after a twostep evaluation process, modeled along International Council for the Exploration of the Seas (ICES) guidelines.

In both Canada and the United States, ecological, genetic, and animal health/disease issues are considered in evaluating permit requests; the health and disease requirements are far more specific than those for the former two categories. The diseasefree requirements include inspection of source production facilities, health records from these facilities, disinfection procedures, and quarantine and testing of imported eggs. As a result, the risk of introducing infectious diseases with imported aquaculture products is markedly reduced and considered negligible by resource managers. The importance of genetic stock identity and ecological interactions is recognized, but consideration of these factors is not based on specific standards. Continued aquaculture development will likely result in permit requests to introduce new NIS.

There is also a risk of introduction of associated (or nontarget) species with intentional introductions that must be managed if this risk is to be minimized. Such associated species may include nonpathogenic microbial species, microalgae, and a variety of invertebrates that colonize the surfaces of mollucs, crustaceans, and other cultured species.

Washington and United States regulations, policies, and their enforcement for aquaculture introductions. The regulation of intentional introductions for aquaculture is primarily a state, rather than a federal responsibility, and is carried out in Washington by the Department of Fish and Wildlife (WDFW).

The authority of the WDFW is contained in several statutes, including sections of the Revised Code of Washington (RCW): RCW 75.08 regulates the "prevention and suppression of diseases and pests" affecting food fish and shellfish; RCW 75.24 regulates "planting food fish or shellfish," RCW 75.58 applies to "aquaculture disease control," and sections of RCW 77.12 relate to powers and duties of the WDFW. For example, RCW 77.12.030 gives the WDFW "authority to regulate wildlife." These legislative authorities are implemented through the Washington Administrative Code (WAC), promulgated by the WDFW. The relevant WACs include several in Series 22077 on aquaculture disease control that pertain to marine plants, shellfish, fish, predators, and pathogens. All of the administrative codes are specific to listed plants and animals and are therefore not inclusive. However, "deleterious exotic wildlife" can be specifically designated and controlled under wildlife statutes (WAC 323212017). An example is the African clawed frog (Xenopus laevis), a freshwater amphibian specifically excluded from importation to Washington. Such designations have been made by the Washington Fish and Wildlife Commission since July 1, 1996, when it assumed the responsibility for fish and wildlife management formerly held by the director of the WDFW.

In addition, any importation proposals are subject to a review by all state agencies concerned with natural resource and environmental management, and to a specific review by the WDFW with regard to infectious disease risk. Proposals for importation of exotic species are also subject to the State Environmental Policy Act (SEPA), which requires that they be evaluated with regard to environmental and ecological effects. The SEPA was authorized under RCW 4321.C, and statewide standards for its implementation are promulgated under WAC 19711 and WAC 173802. These implementation standards are triggered by application for the WDFW permits required for importation of fish or shellfish under the statutes cited in the previous paragraph. Thus, a permit application to the WDFW to import an exotic fish for aquaculture would not only require compliance with statutes noted above, but would also require a multiagency review under the SEPA. The SEPA does not contain prohibitions, but rather is a study process under which the lead agency in the state for the application (WDFW for intentional exotic species introductions) must require that a SEPA "checklist" be completed by the applicant and then circulated to all state agencies having authority or responsibility for environmental and natural resource management. These agencies then respond, and based on these responses and other analyses, the lead agency issues either a declaration of nonsignificance (DNS) or alternatively, a declaration of significance indicating that an environmental study (impact statement) is required. In the latter case, the ultimate decision by the agency would be made on the basis of the findings of the environmental study. Such a study would include a consideration of ecological effects and genetic consequences of the introduction.

Within WACs 22077 (aquaculture disease control), proposed aquatic introductions are evaluated in terms of the risk of introducing diseases associated with them. Fish, invertebrates, and plants are treated separately in WAC 22077. As of December 1996, a revised section for invertebrates, which has been under development and review since late 1989, is in final review in the WDFW and is expected to undergo a public hearing process and adoption in the near future. This revision is a considerable improvement over the existing section on invertebrates and provides detailed and rigorous criteria under which invertebrates can be imported into the state. These new policies provide increased and substantial requirements for any proposed importation of a marine invertebrate from outside of the west coast of North America. At the same time, the new policies recognize the historical and economically important transfer of shellfish along the west coast, but contained provisions to ensure that such transports are based on healthy stocks of shellfish. Further, under the revision, a panel with members from the WDFW, the shellfish industry, and other independent experts provides advice to the WDFW regarding proposed aquaculture introductions. The inevertebrate regulations were revised by a committee of representatives from the WDFW, the aquaculture industry, and experts in scientific fields. This committee considered a broad range of issues and input, including the recommendations made by the ICES working groups on this issue. The broad base of input to the development of these revisions, including contributions from a variety of groups, the regulated industry among them, resulted in the drafting of regulations that are widely supported and that will likely be far more effective than those developed solely by government.

For fish, WAC 22077 applies to all species, but is primarily concerned with salmonid fishes, because outside of the aquarium trade, there has been little interest in the importation of other exotic marine fishes. If a permit application were received for importation of nonsalmonid fish, the WDFW would establish protocols and conduct proposal reviews, because the department has the authority and responsibility to regulate all other species besides salmonids. For salmonids, under the existing WACs and their associated protocols, only eggs can be imported from outside of North America, and although invertebrate brood stocks can be imported to a quarantine facility, only the offspring and not the adults can be released into state waters. Fish eggs and live fish can be imported into Washington from sources within North America. If approved for importation, both fish eggs and invertebrate brood stock and their offspring must be held in quarantine facilities with specific effluent treatment requirements and health and disease monitoring requirements before the fish eggs or invertebrate offspring can be released. The adequacy of the quarantine and compliance with these requirements is determined and enforced by officials of the WDFW.

Marine plant introductions for aquaculture are also regulated by the WDFW under WAC 22077. There have been few applications for importation of marine plants, but such applications receive a similar review to that for invertebrates, considering ecological and infectious disease risks under the regulations cited above.

Officials from the Department of Ecology and WDFW were interviewed about the adequacy of the existing regulations (including the draft revised shellfish regulations) for proposed aquaculture introductions, and enforcement thereof, to protect the state's environment. Several officials responsible for managing species introductions expressed concern about unregulated actions of individual members of the public who might carelessly or even intentionally make exotic importations. These officials also indicated that they considered implementation of regulations and enforcement of permit requirements to be",&"0*"T#C"adequate with regard to proposals for international introductions for aquaculture purposes. Further, representatives of the shellfish industry who raised issues leading to the current revision of the invertebrate importation regulations are also concerned about risks of introductions. Their strong opposition to a proposal to import the eastern bay scallop (Argopectin iradiens) in 1989 was the stimulus to begin the process of reviewing and upgrading the marine invertebrate import regulations.

The federal role in aquaculture introduction consists of the following: the federal regulation commonly called Title 50 (50 CFR 5897658981) is enforced by the U.S. Fish and Wildlife Service (USFWS), Department of Interior (DOI). This rule prohibits the importation of certain salmonid pathogens and was applied in conjunction with state regulations to the importation of Atlantic salmon eggs to Washington. The implementation of this regulation requires that foreign sources of salmonid products be certified as free of specific pathogenic agents, that the specific shipments be certified as disease free, and that certain operational precautions be taken to disinfect shipments. This regulation requires a letter of approval from the USFWS director for the importation of live fish or fish eggs into Washington from any foreign source, including British Columbia. Further limited authorities are contained in the Endangered Species Act and Marine Sanctuaries Act, which for the marine environment, provide authority to the NMFS to take regulatory actions to protect endangered species or the biological integrity of marine sanctuaries. Should a proposed NIS introduction impinge upon these responsibilities, the NMFS would have regulatory authority.

British Columbia and Canada regulations, policies, and their enforcement for aquaculture introductions. The regulation of intentional introductions in British Columbia is managed and regulated jointly by the federal DFO and by two provincial ministries, the Ministry of Agriculture, Fisheries, and Food (MAFF) and MELP. The federal authority is contained in the Fisheries Act (General) Regulations Section 55 and 56 and the Pacific Fishery Regulations (PFR), 1993, Section 5. The Fisheries Act states that a person must have a license to release live fish into any fish habitat or to transfer any live fish into any fishrearing facility. This law also pertains to invertebrates, but does not cover plants, as far as introductions and transfers are concerned. The provincial authority is provided by the Provincial Wildlife Act (BC Reg 261/83) and the Provincial Fisheries Act, Section 8, which addresses the transfer of live oysters, freshwater finfish, and lampray eels, but does not cover other invertebrates, tropical fish, ornamental goldfish, or marine fish. Under the authority of these federal and provincial regulations, a federalprovincial Fish Transplant Committee (FTC) considers applications for nonnative and native fish and invertebrate transfers into and within the province of British Columbia. The committee consists of members from the three agencies mentioned above. Federal fish health regulations promulgated under the authority of the Federal Fisheries Act also apply and are supplemented in British Columbia by federal importation policies for Atlantic and Pacific salmon.

Although federal officials stated that these regulations addressed the primary concerns with introductions and transfers, there are several issues that they felt to be insufficiently covered. These are being addressed in a review of the PFR that the FTC is currently conducting. The major concerns regard enforcement of intraprovincial transplants and importations into British Columbia. The lack of provincial border staff to check shipments of live aquatic animals from other provinces was cited as a deficiency. For international imports, inadequate training of Canada Customs staff was cited as a problem. In addition, regulations pertaining to transplants are not a part of Canada Customs existing mandate. To address some of these deficiencies, the FTC is planning to prepare an information booklet for Canada Customs enforcement staff on the potential problems from unauthorized importation of fish and on recognizing species of primary concern. Also noted was the lack of authority of Agriculture Canada to deal with shipments of live fish.

Historical precedent for provincialstate cooperation on aquaculture and fisheries animal transports. There is a precedent for provincialstate cooperation on aquatic animal transports. Under the auspices of the Pacific States Marine Fisheries Commission (PSMFC), a Shellfish Transport Subcommittee, consisting of members representing Canada (DFO) and the five western states bordering the Pacific, initialed an agreement in 1982 to facilitate interjurisdictional communication regarding marine invertebrate movements. Although the Shellfish Transport Subcommittee has not met since 1985, an informal communication network exists among agencies. More recently, when the WDFW began the process of overhauling WAC 220770040 that addresses invertebrate disease control and importations, officials from the British Columbia Ministry of Fisheries and Agriculture and the federal DFO were informed of the process and provided with draft regulations for comments.

Additionally, to promote intergovernmental cooperation, the proposed new Washington state code pertaining to marine invertebrates contains the following wording: "The Department [of Fish and Wildlife] will establish policies on the specific uniform requirements of aquatic invertebrate health management that harmonize, to the maximum extent possible, with the requirements of the member states of the Pacific States Marine Fisheries Commission (namely Alaska, California, Idaho, Oregon, and Washington) and other government entities with interests in north Pacific invertebrate health management (Hawaii and British Columbia, Canada). The Department will participate in and promote intergovernmental information exchange, regarding shellfish diseases and health management, through the Shellfish Transport Subcommittee of the Pacific States Marine Fisheries Commission." With respect to finfish transports between the province and state, officials indicated that communications between responsible resource managers occur on an asneeded basis.

Educational programs related to aquaculture introductions. There are no known formal educational programs that address marine aquaculture introductions, risks, and regulatory requirements in British Columbia or Washington. However as noted above, the Canadian FTC is preparing information for Canada Customs to increase awareness of existing regulations and to assist in recognizing species, the importation of which is prohibited. In addition, the provincial MELP has published several pamphlets aimed at freshwater exotic species control, such as "A Field Guide to Aquatic Exotic Plants and Animals," "Exotics Don't Let Them Ride With You," and "Help! Don't Move Live Fish." WDFW personnel indicated that an informational booklet based on the revised administrative code pertaining to invertebrate introductions is under preparation.

Analysis of aquaculture regulations, policies, and educational programs. The aquaculture industry is the most heavily regulated pathway of NIS introductions, both in British Columbia and Washington. This is a result both of real risk and the relative ease of regulating it, in contrast to some other pathways. All NIS pathways should receive continuing and periodic review, but risks from aquaculture activities appear adequately addressed by current regulation. The approach in Washington, which is to provide rigorous regulatory control over the importation of exotics from outside the west coast region, while continuing a surveillance and control program over west coast commercial transfers of shellfish, matches the relative risk to the region of exotic species introductions. The risk from west coast transfers is very limited as a result of culture practices and regulatory requirements, whereas larger, more difficulttoassess risks accompany transfers from outside the region. Although some concern has been raised in regard to the transfer of associated species, this risk is reduced by the practice of monocultural cultivation for shellfish seed and by the small volumes transferred. Further, west coast historical practices of this shellfish trade provides some assurance that future undesirable effects of such transfers are not likely. For single introductions of exotic species from outside of the region, the risk of associated species is reduced by quarantine, generation of offspring for release, and examination of the target species for introduction.

Based on this analysis and interviews with agency personnel, no significant gaps were found in regulation or enforcement with respect to aquacultures NIS introductions in Washington. As noted above, federal officials in Canada believe that improvements need to be made in terms of enforcement, education of customs officials, and harmonization of federal and provincial regulations. The Canadian FTC should complete its review of the PFR, followed by implementation of the recommended changes. The review and any recommended changes may apply to research, aquarium, and seafood pathways as well as to aquaculture. The existing regulatory framework in Washington would benefit from the completion of the informational booklet proposed by the WDFW concerning invertebrate introductions. A discussion of fish and plant species would broaden the utility of this effort. This booklet would be provided to inform permit applicants and others of NIS risks and regulations.

From an evaluation of agency reviews of aquaculture importation permit applications, it is clear that there is some confusion about which species are native and resident in the state, and that this confusion is based, in part, on unclear scientific definition of speciation. The bay mussel complex is an example that points out the need for baseline information on species identity, genetic characteristics, and distribution.

Aquatic animal importation regulations are based largely on infectious disease risk, because infectious diseases are relatively well defined, and because there is general agreement regarding their negative consequences. It would be difficult to base regulations on issues of ecological interactions and genetic effects of proposed NIS ntroduction, because there are no clear standards for unacceptable effects upon which there is wide agreement. Thus, such standards need to be developed.

The mechanism of the Shellfish Transport Subcommittee of the PSMFC as a vehicle to share information between British Columbia and Washington (and other Pacific states) is useful, but it has not formally met since 1985 and should be revitalized.

Aquarium Trade and Public Aquaria

Specific pathways in shared waters. Risk of introduction of NIS exists from potential escapes or releases from public aquaria, from individual citizens who obtain fish, invertebrates, or plants at hobby stores and release them, and from the release of water that contained the plants or animals. Many, if not most of the saltwater species used by hobbyists are considered low risk, because they are tropical species that require higher water temperatures than exist in the shared waters of British Columbia and Washington. WOfficials from the Vancouver Aquarium, the largest public aquarium in British Columbia, indicated that they have no established institutional policies or practices regarding containment of NIS beyond the requirements of the provincial and federal governments, as implemented through the FTC, to which they are subject and by which they abide. They suggested that with their focus on British Columbia, arctic, and tropical environments, the risk is minimal, because animals and plants in their facility are either native to local waters or would not survive release.

Officials at the Seattle Aquarium indicated that effluent from coldwater exotic species displays is chlorinated prior to discharge and that animal carcasses are incinerated or chemically preserved. Effluent from warm water exotic displays is discharged without treatment into Puget Sound. The procedures for disinfection of cold water exotic species displays consist of the specifications from WDFW permitting requirements for aquatic invertebrates.

Washington regulations, policies, and their enforcement for aquarium introductions.

Public aquaria and the aquarium trade are regulated by the WDFW in regard to the importation of live invertebrates, fish, and plants, and by the Washington Department of Agriculture (WDA), Washington Noxious Weed Board (WNWCB) in regard to the sale of prohibited plants. For fish and invertebrates, the same legislative authorities and administrative codes identified for aquaculture introductions and disease control apply, with some exceptions. Public aquarium facilities must be approved by the WDFW, and permits for introductions are required. Invertebrate NIS must be maintained in closed systems with no connection to state waters. Marine aquarium fish, however, are specifically excluded from RCW 7558, RCW 7508080, and WAC 22077, along with indigenous bait fish and game fish, and thus their importation and release is not regulated. Therefore, importation of finfish by public aquaria and marine fish hobbyists is excluded from regulation. Although many imported aquarium fish are tropical and would not survive in Washington state waters, there could be importations of cold water species. For example, sturgeon (Acipenser transmontanus), which is native to Washington state, is a coldwater species that is commonly sold in hobby stores, according to officials of the WDFW. Officials from the WDFW responsible for regulation of imported fish species indicate that they are not aware of any significant problem of individuals importing and releasing NIS of marine fish or invertebrates. However, they believe that public aquaria, which may provide displays of coldwater nonindigenous fishes, shellfish, and algae, are not adequately regulated, and that regulation is needed for the treatment of affluentwaters from such facilities. A review of the administrative code dealing with these issues for fish importations (WAC22077039) is currently underway in the WDFW.

Regulations pertaining to nuisance weed control in Washington state apply to certain aquarium plants. Pet stores selling aquarium plants are required to obtain a nursery license. As a result, such pet stores receive information in regard to prohibited plants, and they can be inspected. The sale of several plants is prohibited in Washington (e.g., parrot feather milfoil, Myriophyllum aquaticum; Brazilian elodea, Elodea densa; and hydrilla, Hydrilla verticillata), but of these, only the cordgrasses are marine plants. The cordgrasses are NIS that are established in Washington and that are in the process of range extension. They are also the subject of recent legislation ("Spartina Bill" Senate Bill 5633) approved by the Washington state legislature in 1995, which establishes a coordinated program for exotic cordgrass control.

British Columbia and Canada regulations, policies, and their enforcement for aquarium introductions. As in Washington, the regulations pertaining to fish and invertebrates imported for public or private aquarium use are the same as those cited above for aquaculture species importations. An area of concern noted by federal officials was the extent of overlaps, discrepancies, and gaps between federal and provincial application of their existing regulations to aquarium species. The provincial regulation (BC Reg. 261/83) specifically excludes all tropical and ornamental fish from permit requirement, but the federal prohibited species list includes tilapia (Tilapia spp.) and all carp (Cyprinus carpio), including the ornamental Koi variety. Further, aquatic plants are not covered by these regulations, because they are not included in the Canadian Fisheries Act. The DFOs prohibited species list is very select; some species excluded from the list are of equal or greater concern than those listed. Currently, the FTC is working with the DFO regulations staff to amend this regulation.

Educational programs related to aquarium introductions. There are no known educational programs in place that address risks of fish or invertebrate introductions related to public or private aquarium practices in British Columbia or Washington. The Vancouver Aquarium has on occasion provided information on threats to the provinces freshwater ecosystems by introduced animals and plants, when particular aquarium displays were appropriate for this instruction.

In Washington, as well as in British Columbia, the planned and existing educational publications mentioned in the section on aquaculture could have applicability to aquarium fish. The WNWCB has produced educational materials focused on aquatic plants for aquarium shops and for the public.

Analysis. In both Canada and the United States, there appears to be limited risk of introduction of marine aquarium fish, invertebrates, and plants, because the private marine aquarium trade deals primarily with tropical species. The types and number of sales of coldwater aquarium species are unknown. Although this is an undefined potential, officials in Washington state do not believe it to be a significant problem. Aquatic plants are regulated in Washington by the WNWCB, but Spartina species, not considered aquarium plants, are the only prohibited marine plants in the state. There is a need to determine what risk, if any, exists from marine aquarium plants sold in Washington. In Canada, aquarium plants are not regulated, but an FTC effort is underway to include them under a federal authority. Inconsistencies between federal and provincial regulations in Canada in regard to aquarium fish and invertebrates are under review by the FTC, and recommendations could be forthcoming.

The following should be considered to provide further definition and management of NIS introduction risks that could result from public aquarium and aquarium trade activities: determination of the species and extent of sales of marine plants, invertebrates, and fishes in aquarium shops in British Columbia and Washington; development of protocols at public aquaria for maintaining and disposing of exotic species used in displays; and protocols and requirements for the treatment of effluent water from facilities that display cold water nonindigenous fishes. The WDFW should determine whether there is need for revision of the Washington administrative code (WAC22077039) that regulates fish (NIS) importations by public aquaria and pet stores.

Research and Teaching Institutions

Specific pathways in shared waters. Government, university, private laboratories, and educational facilities in Washington and British Columbia are often engaged in research using NIS. This might include research on marine invertebrates, toxic marine plankton, animal disease microorganisms, and possibly other marine organisms by university and government laboratories. Private laboratories use NIS in toxicity bioassays. Information on the identity and number of NIS used in research is anecdotal.

Washington regulations, policies, and their enforcement for research introductions. In Washington, the administrative code that applies to aquaculture and public aquaria (WAC 22077) also applies to research institutions. Under these revisions, public and private institutions are required to obtain a permit for invertebrate NIS introductions, and controls are required on effluent release and access to these imported organisms. Invertebrates imported by private or government laboratories for toxicity bioassays must be held in containment facilities with approved effluent treatment and be destroyed after use. Similarly for fish, an import permit is required. Currently, there are some criteria for fish containment and the waste water treatment necessary for such a permit to be issued. Officials at the WDFW indicated that they are in the process of developing new and more detailed criteria for research quarantine facilities (Kevin Amos, WDFW, personal communication, 1996). Staff and administrative personnel at the University of Washington did not know of any universitygenerated protocols for the use of NIS. One private laboratory contacted in Washington indicated that it had detailed procedures in place for research involving NIS.

British Columbia and Canada regulations, policies, and their enforcement for research introductions. Importation of NIS for research in British Columbia is covered by the same regulations as aquaculture. Researchers must have a provincial permit to possess live fish, and they must follow the federal DFO regulations, including PFR for prohibited species. Species listed in the "prohibited category" of PFR 1993 are only permitted to be imported into inspected and approved quarantine facilities. However, the PFR cover only a limited number of listed species; unlisted organisms, such as harmful phytoplankton, could be imported without a license. Because the PFRs species list is limited, the FTC intends to review the adequacy of these regulations. Fish pathogens, which have historically been a subject of fisheries research, are specifically regulated and are only permitted entry under a license from Agriculture Canada.

Educational programs on laboratory use of nonindigenous species. There are no known educational programs pertaining to the use of NIS in laboratories or educational institutions in British Columbia or Washington.

Analysis. In Washington, the research use of marine invertebrate NIS is controlled by the detailed implementation language of WAC 2207740. Indeed, some researchers believe that the language is too restrictive: permits are required for the transport of marine invertebrates from British Columbia to Washington within the shared waters. However, concern about the occurrence in the Strait of Georgia of the parasitic disease of Pacific oysters caused by Mikrocytos mackini (Denman Island disease) has resulted in restrictions on movement of marine invertebrates from British Columbia to Washington, where the disease has not been seen. To more clearly define such risks, additional information is needed on the environmental requirements and transmissibility of this disease. WDFW officials view the lack of explicit and detailed controls on the use of NIS of marine fish and plants in Washington research institutions as a gap in existing WAC implementation policy.

In British Columbia, the FTC is aware of possible inadequacies in regulations that pertain to research importation of NIS and plans a review that will address the species that should be listed in the prohibited category and that would therefore need special handling and containment procedures, if imported for research.

The level of use of NIS by university and government researchers is unknown, but there is believed to be some use of toxic phytoplankton species, animal pathogens, and possibly other organisms. Microorganisms such as these are easily transported in small culture tubes. Researchers may not be aware of the risks or regulations pertaining to NIS use. The Northeast Pacific Culture Collection, which is a research and teaching collection of marine phytoplankton maintained at the University of British Columbia, has holdings from broad geographic sources. Cultures are provided to other research organizations, although there are specific limits on the distribution and use of toxic strains.

To evaluate and manage the risks of NIS introductions from research activities, the following actions would be useful. The FTC should complete its review of PFR as it applies to research. NIS that are being used in research in the region of shared water need to be determined and documented, and research institutions should develop protocols and standard guidelines for researchers working with NIS. Agencies in British Columbia and Washington should evaluate regulations and make modifications to ensure that they are applied uniformly to the research institutions, as they are applied to other pathways, including specific regulation of nonindigenous marine plants and fish in Washington. The WDFW should complete its specifications on marine quarantine.

Live Seafood

Pathways, policies, regulation, and enforcement. Live seafood products (primarily shellfish) can be easily found in markets in Washington and British Columbia. Many of these shellfish are native or established in the shared waters, but others, such as the eastern lobster (Homarus gammarus), are not. Bivalve shellfish in markets may be kept live in tanks, or for a more limited time, on ice. In addition, Dungeness crabs are transported alive in tanks from Alaskan waters to holding tanks in Washington state. Shellfish, fish, and plants in tanks are subject to WDFW regulation, whereas those on ice are not. Officials at the WDFW reported that they receive occasional tips on possible illegal holding of live seafood, but that instances of this are rare. WDFW personnel occasionally check seafood markets for the presence of NIS, but report that they rarely find such NIS. Due to the increasing trade in live Dungeness crabs from Alaska, WDFW officials recognize a need to educate this industry about compliance with transport regulations.

Miller (1969) reported that lobsters shipped to California were packed in a brown marine alga, Ascophyllum nodosum, and that this alga was carrying populations of invertebrates and other algae, most of which were inhabitants of the upper to midintertidal zone. Further, Miller reported that many of these organisms were alive when the Ascophyllum was discarded into San Francisco Bay.

In British Columbia, importers of live fish and shellfish are requested to have a license issued by the FTC that is of 6 to 12month duration. However, species imported on ice intended for direct market sales and those that have a long history of importation (e.g., the eastern lobster) have been exempted from permit requirements. Live foodfish import requirements are currently under review. In Washington, live aquatic products intended for direct human consumption that are not held in aquaria with connection to state waters do not require a permit from the WDFW.

Analysis. The presence of live NIS in food markets does not itself present a risk unless holding tanks drain directly to seawater or species are released. However, consumers can easily release these shellfish, thus providing the opportunity for establishment. There seems to be little risk of establishing the eastern lobster in the shared waters of Washington and British Columbia, based on the apparent failure of all previous intentional attempts, some implemented by government agencies, although occasional captures of eastern lobster are reported according to DFO personnel. Further, the high price of lobster is a disincentive to purchase and release. Species of live bivalve shellfish are more likely to be released, because their cost is less and larger numbers are sold. If live nonindigenous bivalve shellfish were sold in markets, there would be a risk of their introduction to the shared waters.

In Washington, WAC 2207740 prohibits the release of shellfish or their holding waters, and the WDFW inspects holding areas for edible shellfish. The primary risk appears to be that consumers could release live exotic fish or shellfish if they can purchase them. Although no information on the extent of such shellfish sales was found, interviews with WDFW personnel indicated that the instances were rare and that the agency staff is adequate to investigate them. The distribution of informational pamphlets that describe the risks of NIS introductions should be encouraged at live retail seafood markets.

Shipping Industry

Ballast water: specific pathways and risks in the shared waters. The major ports in the shared waters are Seattle, Tacoma, and Vancouver, but there are other smaller ports in both British Columbia and Washington. Data were obtained on commercial vessel arrivals, but none were available on military or research vessels. There were 3314 ship calls in Puget Sound in 1995, according to the Puget Sound Steamship Operators Association (PSSOA), which provided the only information available from the Marine Exchange of Seattle, Washington, about that years shipping (Harry Hutchins, PSSOA, personal communication, 1996). Gauthier and Steel (1995) reported 3117 vessel entries to the Port of Vancouver in 1991, but Canadian Coast Guard data (Table 3; unpublished data, Rod Forbes, DFO, Canada), recorded only 1863 vessel arrivals at the Port of Vancouver in 1995.

According to the Canadian Coast Guard data, 1266 of 1863 (68%) of the ships arriving at the Port of Vancouver had a last port of call in East Asia, whereas 472 (25%) had a last port of call along the west coast of North America. The data did not indicate which ships arrived in ballast. Levings and Piercey (1996) provided preliminary results of a survey of ships arriving at British Columbia ports in 1995 and 1996. They sampled and enumerated marine invertebrates found in ballast water, but reported that ballast water samples were not obtained from the majority of ships approached for various reasons: disposal of ballast water before arrival in the harbor; midocean exchange of ballast water; insufficient ballast water levels for sampling in ballast tanks; and other unspecified reasons. Thus, these authors suggest that significant amounts of ballast water may be dumped before arrival in harbors. They further cite the opinion of the deputy harbormaster in Vancouver that some ships masters may be voluntarily following an Australian protocol for ballast water exchange.

Table #3 [Table not formatted]

Last Port of Call Region of 1863 Ships
Arriving at Vancouver Ports in 1995

REGION OF LPOC2BK Number of Ships East Asia3#[1,266 IndoPacific4# bt17 AustraliaNew Zealand5#wbt16 North America (west)6#G Central/South America7#bt47G Africa#bt17 Uncertain8#bt284 A TOTAL SHIPS# 1,863

Data supplied by Rod Forbes, Department of Fisheries and Oceans, Canada, based on Canadian Coast Guard data.

LPOC Last port of call.

East Asian ports include those in Japan, Korea, the Peoples Republic of China, Taiwan, and Hong Kong.(#

IndoPacific are southeast Asian ports, including those in Singapore, the Philippines, Thailand, and Vietnam.

All ports in Australia and New Zealand.

California, Oregon, Washington, British Columbia, Alaska, and Hawaii.

Central and South American ports from Mexico to Peru and including one ship that called from Jamaica.

Location uncertain due to ambiguous identification or to other causes.

In comparison with the Canadian Coast Guard data, Gauthier and Steel (1995) reported that a higher proportion (3023 of 3117, or 97%) of Vancouver bound ships originated from ports outside of the northeast Pacific in 1991, and that 78% of vessels had a last port of call bordering the northwest Pacific and westcentral PacificIndonesia. They also reported an estimated ballast water discharge of 33.5 million tonnes for the Port of Vancouver in 1991 (based on a personal communication). However, according to calculations provided by the Port of Vancouver (Rod Forbes, DFO, personal communication) an estimate of 20 million tonnes is more accurate. The latter estimate is based on 21 million tonnes of coal exported from Vancouver, which would account for about 10 million tonnes of incoming ballast water. Coal is the major commodity handled in the Port of Vancouver that requires incoming ballast waterladen ships. Other types of cargo are estimated to account for a total of an additional 10 million tonnes of ballast water, for an estimated annual total of about 20 million tonnes. Ships originating in North America also carry risk of NIS introduction, as noted by Carlton et al. (1995). Whereas few ships arrived in Puget Sound or Vancouver with LPOC on the Atlantic coast of North America, many originated in various ports on the west coast of the continent. The pattern of LPOCs of ships arriving in Puget Sound is similar to that of vessels landing at Vancouver ports. Based on the 1995 data from the Marine Exchange of Seattle (provided by Hutchins, PSSOA, op. cit.), the LPOC of the largest proportion of ships arriving in Puget Sound ports laden with ballast water from continents other than North America was in east Asia, in waters north of the Tropic of Cancer (Table 4).

Table 4. Region of Last Port of Call of 3314 Ships by Vessel Type Arriving at Puget Sound Ports in 1995

REGION

```
Number of Ships from LPOC2 Region by Type
RORO
Container
Refrigerator
Tanker
LG
Bulk Cargo
Atlantic
Europe
Mediterranean
East Asia
IndoPacific
Australia
N. Z.
America
(west)
N. America (east)
Central America
South America
Uncertain
TOTAL SHIPS
Percentage
```

Data from Marine Exchange, Seattle, Washington (Harry Hutchins, PSSOA, personal communication, 1996).

LPOC Last port of call.
Types of ships and deballasting requirements explained in text.
RORO Roll on, roll off vessels.
LG Liquified gas carrier.
East Asia ports north of the Tropic of Cancer.
Southeast Asia ports south of the Tropic of Cancer, and IndoPacific ports.
All ports in Australia and New Zealand.
Ports in California, Oregon, Washington, British Columbia, Alaska, and Hawaii.
Atlantic seaboard of United States, Canada, and Bermuda.
Central and South American ports north of Tropic of Capricorn and south of Tropic of Cancer.

South American ports south of Tropic of Capricorn.
Location uncertain due to ambiguous identification or to other causes.

According to the PSSOA, only certain types of ships arrive with ballast water; an estimated 60% of bulk cargo vessels arrive without cargo and have ballast water discharge requirements:

The types of ships and whether they arrive in ballast or cargoladen, as well as the last port of call needs to be considered in assessing the risk of NIS introductions with ballast water. Generally, ships that arrive with no cargo and take on cargo in Puget Sound are the major contributors of foreign ballast water. These would include ships carrying grain, other agricultural products, logs, and other forest products in bulk, and a very few tankers carrying product from the refineries. Other vessels which typically do not deballast are container ships, tankers carrying crude oils or refinery additives, gypsum, salt, ore, and other carriers of imported bulk cargoes. Most of the vessel traffic is comprised of crude tankers and container ships. The traffic trends have been fairly static in the past few years with the exception of bulk log carriers which experienced a sharp and deep decline in 1993 resulting from logging harvest restrictions and export prohibitions (provided by Hutchins, PSSOA, op. cit.).

The Marine Exchanges listing of 1995 arrivals by LPOC and by vessel type (provided by Hutchins, PSSOA, op. cit.) is shown in Table 4. Information from the Port of Vancouver confirmed that bulk carriers are the only type of ship that undertake total deballasting. Other cargo vessels are considered relatively minor contributors to ballast water discharge.

However, cruise ships take on ballast water regularly during their voyages as fuel and freshwater are consumed. This ballast water is discharged at the sites where these ships refuel.

About 33% of ships (1111 vessels) arriving at Puget Sound ports in 1995 were believed to carry ballast water (Table 4). For these ships, the predominant regions of LPOC were east Asia (544 ships or 49% of ballast waterladen vessels) and the west coast of North America (370 ships or 33% of ballast waterladen vessels). Ballast waterladen vessels with LPOC on the west coast originated primarily in Washington, California, British Columbia, and Oregon.

Washington and United States regulations, policies, and their enforcement for ballast water introduction of nonindigenous species. Due to the interstate and international nature of shipping, ballast water governance is regarded as a federal matter in the United States, according to the USCG. The federal programs and authority are described as follows by the USCG:

The "Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990"(Public Law 101646, November 29, 1990) directs the United States Coast Guard to issue voluntary ballast exchange guidelines to ensure ballast water containing exotic species was not discharged into the Great Lakes. On December 30, 1994 (59 FR 67632) the Coast Guard promulgated a final rule modifying 33 CFR part 151 completing implementation of the "Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990" requiring ballast exchange for ships entering the Great Lakes and certain parts of the Hudson River. The Coast Guard has extended a voluntary ballast water exchange program nationally and published the International Maritime Organization ballast water guidelines: "Control of the Discharge of Ballast Water Containing Harmful Marine Organisms (Draft MEPC resolution and Draft international guidelines" 31st Session, Agenda Item 14, April 5, 1991). Currently, the Coast Guard is focused on educating shipping agents. It is my personal opinion that large shipping companies will act responsibly, if for no other reason than to avoid addition federal regulation. The problem may be more substantial for small companies and/or infrequent visitors to U.S. Waters (Lt. Donald T. Noviello, A Summary of U.S. Coast Guard

Programs Relating to Exotic Species Introduction, unpublished report prepared for this document, March 1, 1996).

In October 1996, the National Invasive Species Act became United States law. It requires the implementation of voluntary ballast water exchange for ships arriving in all United States ports and the possibility of mandatory ballast water exchange if the voluntary program is judged inadequate.

British Columbia and Canada policies and their enforcement for ballast water introduction of nonindigenous species. Gauthier and Steel (1995) reported that for the Pacific coast of Canada, there are no regulations or voluntary guidelines for the exchange of ballast water. However, Port of Vancouver officials indicated that a voluntary ballast water exchange program is under development.

Educational and voluntary programs on management of nonindigenous species

introductions from ballast water discharges. Guidelines for the management of ballast water to reduce the chances of NIS introductions have been published by the International Maritime Organization (IMO) of the United Nations. These guidelines describe and encourage the application of general principles of ballast water management, implementation guidelines, ship operational procedures, and strategies for preventing introduction of unwanted organisms and pathogens from ships ballast water and sediment. WThe PSSOA encourages the voluntary exchange of ballast water for ships arriving in Puget Sound, and it conducted a compliance survey in 1995. It reported that 58% of the surveyed vessels are exchanging ballast water offshore, whereas 78% of ships indicate they have or would have little or no difficulty in doing so. According to the PSSOA, this survey was intended as a firstorder estimation of ballast exchange status, and another, more detailed survey is planned for 1996. The PSSOA expects to find more ships conducting water exchanges since its request that arriving ships exchange ballast water offshore. The PSSOA estimates that 95% of the ships will ultimately be able to do open water ballast exchanges.

The USCG has a ballast water education program, which it describes as follows:

The Shipping Agent Ballast Water Education Program is a [USGS] initiative to educate shipping agents about the exotic species introduction problems and preventative measure available. Materials provided to shipping agents include a handbook and video containing information on the need for ballast water exchange at sea and operation of such a program.

The Sea Partners Campaign is funded by the Department of Defense Civil Military Cooperation Action Program and employs over 300 Coast Guard Reserve members as presenters of educational outreach materials that focuses on [the following]:

Protecting the marine environment and preserv[ing] natural resources while promoting national wellbeing and economic prosperity

Rais[ing] public awareness of marine pollution issues and motivat[ing] public conservation of the marine environment

Help[ing to] prevent the discharge of marine pollutants and [to] increase the chances of timely detection, reporting, and cleanup of discharges [that] do occur.

This program focuses on school, civic, and professional groups interested in protecting the marine environment or simply complying with Coast Guard [r]egulations. Oil and [h]azardous materials spills, and MARPOL V (garbage discharges) have been the central subjects,but ballast water management for the prevention of exotic species introduction can be discussed (Noviello, op. cit.).

The recentlyenacted, voluntary ballast water exchange program in the United States will be assessed for adequacy, and if judged inadequate, a mandatory ballast water exchange will be implemented (see Section II, page 16).

Analysis. Based on the information provided by the PSSOA and Marine Exchange (Hutchins, PSSOA op cit.), 1111 or 33% of ships arriving in Puget Sound ports in 1995 were bulk cargo carriers, the only category of ship that often arrives with ballast discharge requirements. The PSSOA estimated that of these, about 60% (667 ships, or 20% of all vessels) arrive without cargo and therefore must discharge ballast water. Using the 58% ballast exchange rate provided by the PSSOA, 279 ships would arrive without exchanging ballast. Assuming that voluntary ballast exchange is proportional to arrival with ballast exchange requirements and LPOC, about 25% of the bulk cargo carriers from each region of LPOC could arrive with deballasting requirements.

Considering risk of introduction of NIS, carriers originating from east Asian ports are prominent by number, and many of these ports are in temperate zones. However, ships with LPOC in west coast ports, for example, those in the San Francisco region, could transfer NIS such as planktonic larvae of the European green crab in ballast water. Therefore, the carriers coming directly from foreign ports are not the only concern. Further, it is important to note that if ballast water and sediments are incompletely discharged or disinfected, ships may carry organisms that originated from ports prior to their LPOC.

The voluntary ballast exchange program developed by the USCG and implemented by the PSSOA may have substantially reduced the risk of NIS introductions through ballast water, because the number of ships arriving with unexchanged ballast was reduced from 667 to 279. Continuing efforts should further reduce this number, and because of the October 1996 passage in the United States of the National Invasive Species Act, there will be greatly increased incentive to further develop voluntary programs as an alternative to mandatory regulation of ballast water exchange. According to the PSSOA, the 95% potential exchange rate would reduce the number of ships arriving with ballast water to 33, based on the 1995 data. Several important features are missing from the existing PSSOA voluntary ballast water management program. Ballast sediments are not addressed, and the completeness of ballast water exchange for individual ships is not known or reported. A formal report is not available for distribution and review.

The following improvements for the future PSSOA surveys of voluntary ballast water compliance are suggested: determination of the LPOC for each ship surveyed; determination of whether ballast sediments are discharged by ships exchanging ballast; assessment of the completeness and adequacy of ballast water exchange and ballast sediment discharge; determination of where open water ballast water exchanges are taking place; and the provision of an annual report of the ballast exchange program and survey.

An assessment of military and passenger ship traffic and its possible contribution to ballast water discharge is also needed.

A voluntary program of ballast exchange may be preferable to a mandated program. There is some credible argument that a higher compliance rate will be achieved under a voluntary program if ship operators understand the need for the program. In addition, a voluntary program avoids the potential inefficiency and costs of the bureaucracy required for its implementation. Because west coast ports are in competition for business, the ability of particular ports to conduct an effective and credible ballast exchange program will provide a competitive cost advantage over ports with mandated exchange programs, at which the added cost of compliance will ultimately be charged to ships calling there. However, a critical requirement for an effective voluntary program is that it have credibility. Credibility can be established by a documented ballast water management plan, records that show compliance with and monitoring of the program, and periodic reports describing the program. Although the existing voluntary program in Puget Sound is a positive and useful first step, the features still missing from it, as discussed above, should be provided in a documentable fashion, if the program is to gain wide acceptance. The development of a voluntary ballast water exchange program and survey for ships entering British Columbias ports would reduce the risk of NIS species introductions.

An evaluation is needed of sites for offshore ballast water exchange that will not allow seeding of inshore waters with organisms contained in the discharge. Such locations could change seasonally, depending on ocean currents. It also would be useful to evaluate the magnitude of risk of NIS transfer by marine vessels, outside of the ballastwater medium.

Although transport via ballast water is considered to be the primary risk, there is secondary risk of transfer by other marine vessel associated means. Further investigation and information will be required before this risk can be determined.

Marine vessels: specific pathways and risks in shared waters. The previous discussion of ballast water risks is applicable to understanding the nature of risk for attached organisms as well (Tables 2 to 4). In 1995, 1230 ships last calling in temperate Asian ports arrived in Puget Sound, and in 1989 (the last year for which data were provided), 914 such ships arrived in Vancouver ports. Seattle and Vancouver are also ports where large numbers of recreational boats are moored, some of which are used for longdistance trips, but there is no readily available information on the number of trips or the destinations. What could be considered raw data on recreational and commercial vessel trips between Canada and the United States may be available from the customs offices of both countries.

The shared waters are also home to commercial fishing fleets. The target fisheries for some of these boats are the north Pacific and Bering Sea. Because the fleet does not fish in the inshore waters of Asia, the presence of fouling organisms from Asia on fishing ship hulls seems unlikely. However, boats from this fleet commonly go to port in Alaska, sometimes for extended periods, and therefore there is an opportunity for attached marine organisms to be transported to the shared waters of Washington and British Columbia. The main foreign ships fishing in British Columbia coastal waters are from Poland and the Russian Federation.

On occasion, these ships berth in Vancouver or other British Columbia ports for repairs. WRecreational boating is also a potential source of NIS introduction. Although the magnitude of risk from this activity is assumed to be low, it is unknown.

Management in place for the risk in shared waters. No regulation, policy, or educational programs regarding transport of organisms on ship hulls has been established in this region.

Analysis. There is clearly a potential for transfer of marine organisms on ship hulls from other regions of the world, but no information was found on the frequency or risk of this pathway of transfer. Wooden hulled boats are considered by Quayle (1992) to have likely been responsible for the introduction of the woodborer, Teredo navalis, from the Atlantic Ocean to California, and later to Washington and British Columbia. Use of antifouling paints on ship hulls has likely reduced such transfers markedly, but has not eliminated them, particularly because many ships go for long periods of time between repainting.

Although this form of transfer of marine organisms is considered secondary in importance to ballast water transfers, more information is needed to assess the risk.

SELECTED HIGHLIGHTS OF NONINDIGENOUS SPECIES MANAGEMENT IN OTHER JURISDICTIONS

The following are summaries of information requested by the British Columbia and Washington work groups on exotic species. These are not comprehensive reviews of NIS management, but provide some perspective on management of NIS elsewhere.

Australia

The Australian Nature Conservation Agency (ANCA) has primary responsibility for regulating introduced species under the Wildlife Protection (Regulation of Exports and Imports) Act 1982, but the Australian Quarantine Inspection Service (AQIS), Department of Primary Industry and Productivity, is responsible for addressing infectious disease concerns.

Information in this section provided by Linda Walker, Kevin Doyle, Dennis Ayliffe, and Ian Hamdorf, Australian Quarantine and Inspection Service, Department of Primary Industry and Productivity, Australia, 1996.

The states and territories each have separate legislation that may have powers useful in controlling exotic marine introductions. In general terms, all have Fisheries Act(s), Wildlife Protection Act(s), and/or Flora and Fauna Protection Act(s) that contain relevant powers. The national approach to quarantine of aquatic animals is currently under review by the National Taskforce on Imported Fish and Fish Products.

Concern about ballast water importation of NIS is prominent in Australia, where research has implicated ballast water in the introduction of toxic algal cysts (Hallegraeff and Bolch 1992; Scholin et al. 1994). Ballast water controls and voluntary guidelines have been developed by AQIS, which operates under the Quarantine Act 1908 and provides the Secretariat for the Australian Ballast Water Advisory Council. AQIS has sponsored shipping ballast water exchange trials (AQIS 1993) and a ballast water symposium (AQIS 1994).

Ballast water management in Australia consists of voluntary guidelines, in conformance with the IMO recommendations. According to literature published by AQIS (1992, 1995a), the emphasis is on guidelines to minimize the discharge of ballast water and sediment. Measures enroute include reballasting at sea or inhold water treatment (currently only carried out on one or two ships, on an experimental basis). Measures on arrival include a commitment not to discharge ballast, onshore ballast water treatment, and discharge of sediments only to approved areas. Other recommended measures for ships' masters are to ensure that wherever possible, ballast taken on is free of sediment; to ensure that ballast tanks are kept clean; to avoid or minimize taking on ballast in shallow waters; and to avoid ballasting when toxic dinoflagellate blooms are occurring.

California Ballast Water Control and San Francisco Estuary Project

An attempt to control ballast water at the state level was made by California Assembly Bill 3207 Campbell (Chapter 840, Statutes of 1992, amending the Fish and Game Code), which declared "that the people of the state have a primary interest in the regulation of the dumping of ballast water originating in foreign ports in any river estuary, bay or coastal area of the state." The bill also made it the policy of the state to "prevent the introduction and spread of aquatic nuisance species into any river, estuary, bay or coastal area through the exchange of ballast water of vessels prior to entering those waters." Compliance would be monitored by a ballast water control report required from ships masters (CBC 1995).

However, these regulations were not implemented, because the USCG advised California that it did not have the authority to interfere with interstate or foreign commerce (CBC 1995).

The San Francisco Estuary Project is a part the EPAs National Estuary Program and is developing a management plan for San Francisco Bay. The Estuary Project supports implementation of stringent regulations to control discharge of ships ballast water within the estuary, and prohibition of the intentional introduction of aquatic exotic species in the estuary.

Chesapeake Bay Program

The Chesapeake Bay Program, a multijurisdictional association, adopted a policy for the introduction of aquatic NIS in December 1993. The program's executive council statement (Anonymous 1994) described the essence of the program:

It shall be the policy of the Jurisdictions in the Chesapeake Bay basin to oppose the firsttime introduction of any nonindigenous aquatic species into the unconfined waters of the Chesapeake Bay and its tributaries for any reason unless environmental and economic evaluations are conducted and reviewed in order to ensure that risks associated with the firsttime introduction are acceptably low. The signatories to the Adoption Statement are committed to sharing information and to carefully assessing through a joint review process all firsttime introductions of nonindigenous aquatic species in the Chesapeake Bay basin.

The signatories to the Adoption Statement are also committed to working together to prevent unintentional introductions of nonindigenous aquatic species and to minimize the negative effects of undesired aquatic species within the Chesapeake Bay ecosystem.

The Chesapeake Bay Program published a draft in February 1996 of the Implementation Plan for the Introduction of Nonindigenous Species (Chesapeake Bay Program 1996). The program includes sections on public and private aquaculture stocking, introduction of NIS for research, monitoring for NIS, controls on NIS, and education, as well as summaries for existing regulations and protocols for intentional introductions.

Hawaii

Intentional importation of all living organisms, including marine species, to Hawaii is regulated by the Plant Quarantine Branch of the State Department of Agriculture, which maintains lists of approved, restricted, or prohibited species (Olin 1993). New NIS may be intentionally imported to Hawaii, subject to a review of risks and benefits of introduction. Such proposals are reviewed by a technical advisory committee on the basis of biological and ecological interactions, diseases, life cycle analysis, control and eradication measures, and other specific criteria (Olin 1993).

New Zealand

New Zealand has adopted a conservative stance for the intentional introduction of NIS, according to officials from the Department of Primary Industries (Barbara Hayden and Mike Hine, Department of

Primary Industries, New Zealand, personal communication, 1996). This is largely because the country is composed of islands over 800 miles from other continents, which consequently allows New Zealand to police introductions. The officials indicated that other reasons for an increasingly conservative stance were (1) a growing awareness of past mistakes that have resulted in adverse ecological impacts, (2) a perception that public opinion is increasingly opposed to NIS introductions, and (3) the difficulty in competing economically in the production of NIS aquaculture species due to the remoteness of the country (Hine and Hayden, New Zealand, op. cit.). A high level of public awareness of the risks of moving live animals internationally was also cited by officials. If a proposed intentional introduction appeared attractive after a review, it would be subjected to a risk analysis.

A national policy paper on NIS introduction by the various shipping associated pathways to New Zealand is currently being drafted. Controls on ballast water discharge are now voluntary and are likely to remain so, according to officials, until more effective and safe management options are identified. New Zealand is in the process of adopting management policies similar to those in Australia, due to the large volume of vessel and commodity exchange between the two countries, and the view that they share a common risk.

NONINDIGENOUS SPECIES EXISTING IN OR NEAR SHARED WATERS

Some of the betterknown NIS in the waters of the Strait of Georgia and Puget Sound are summarized in this chapter. The purpose of this section is to provide a historical perspective on these introductions and their consequences, as well as to highlight management and regulation where it exists or is needed. The European shore crab (Carcinus maenus) is included, because it is found in California and is a potential nonindigenous invader of the shared waters. A comprehensive list of shared waters northwest marine NIS does not exist, but a list of some Pacific coast NIS published by Environment Canada is included as an appendix to this report.

Asian copepod, Pseudodiaptomus inopinus

The following information was provided by Dr. Jeff Cordell of the School of Fisheries, University of Washington.

Source of nonindigenous species to the shared waters. Copepods are small crustaceans that are ubiquitous in marine, estuarine, and freshwater habitats. They occur from the deepest ocean trenches to temporary pools and are abundant in bottom sediments, on aquatic plants, and in the water column. Because of their abundance and availability, they form a fundamental link in aquatic food chains by providing forage for a variety of other invertebrates and small fish. For example, copepods are a major food resource for many species of commercially important fishes that spend their early life in estuaries, including Pacific salmon, striped bass (Roccus saxatilis), and many species of flatfish. In 1990, we found that an important Pacific Northwest estuary, the lower Columbia River, had been invaded by a species of Asian calanoid copepod, Pseudodiaptomus inopinus (Cordell et al. 1992). Subsequent rapid biological surveys in Oregon, Washington, and British Columbia revealed that P. inopinus had invaded at least seven other coastal United States estuaries and perhaps had started to make its way into the inland marine waters of Puget Sound, but it had not yet reached British Columbia estuaries (Cordell and Morrison 1996). The continued expansion of the range of this copepod into new estuaries is expected, but has not been examined since these original surveys in 1991-1992.

Beneficial uses of the nonindigenous species. None reported or known.

Negative effects of the nonindigenous species. The impact of this introduced copepod on commercially and politically important resources such as Pacific salmon is potentially large. For example, an invasive estuarine zooplankter may compete with and depress prey species of juvenile salmon, but not be a good substitute prey because it is adept at evading predators or its patterns of production do not coincide with periods of fish presence or feeding in the estuary. In fact, this phenomenon has been recently suggested in California, where two other Asian copepods have been implicated in recruitment failure of striped bass in the Sacramento San Joaquin estuary. Conversely, it is possible that this species may form substantial prey resources for small fish. Because little is known about the biology and ecology of P. inopinus in either its native or invaded habitats, answers to questions such as these await further indepth study of this species.

Management of the nonindigenous species. None reported or known.

Atlantic salmon, Salmo salar

Source of nonindigenous species to the shared waters. In British Columbia, Atlantic salmon introductions were made relatively recently. The FTC evaluated the proposed introduction of Atlantic salmon into British Columbia in the mid1980s and recommended against its introduction. At that time, there was opposition from steelhead (Oncorhynchus mykiss) advocates, and the FTC believed that there was merit to concerns about displacement of native salmonids, competition for habitat, and the possibility of hybridization of steelhead and Atlantic salmon. This recommendation was not accepted by the federal government, which allowed the importation of Atlantic salmon eggs based on its view of the development of a fish farming industry as a needed economic opportunity. Importation of eggs was permitted from 1985 to 1989 and again in 1991. Atlantic salmon eggs were imported into Washington in the 1980s, and continued importation may be made, subject to the federal and state requirements noted in a previous section of this report. Attempts were made to establish Atlantic salmon runs on the Pacific coast by intentional introductions by federal agencies during this century. However, none of these attempts resulted in the establishment of the species.

Beneficial uses of the nonindigenous species. An Atlantic salmon production industry has been established in both British Columbia and Washington. According to the British Columbia Salmon Farmers Association, 14,468 tonnes of Atlantic salmon was produced in British Columbia in 1995. The value of total salmon production (22,259 tonnes, including chinook [O. tschawytscha] and coho salmon [O. kisutch] from 100 aquacultural operation sites) was CAN$ 165,000,000 and represented British Columbia's largest agricultural export. According to the Washington Farmed Salmon Commission, 4983 tonnes of Atlantic salmon was produced at seven aquaculture sites in Washington in 1995, with a farm sales value of US$ 30,000,000. Estimated direct employment for this industry is 230 people.

Negative effects of the nonindigenous species. Concerns have been raised regarding Atlantic salmons potential competition with Pacific salmon for habitat, introduction of diseases, and degradation of the marine environment around salmon aquaculture sites. These issues have been addressed in a number of studies both in Washington and British Columbia and in an ongoing study in British Columbia (Salmon Aquaculture Review) sponsored by the British Columbia MELP. The MAFF seeks to further evaluate these issues. The competition among uses of the marine environment, specifically for residential development, has focused attention on this issue. Even though disease concerns and impacts on marine sediments appear to be well managed and of limited or no consequence to native species, the primary concern today is the effect of escapement from net pens and competition with native salmonid species for freshwater habitat. From June 1988 to 1993, 21,200 Atlantic salmon were reported to have escaped from British Columbia aquaculture facilities in seven reported incidents. In another seven occurrences, 64,229 were reported to have escaped in 1994, most from the Johnstone Strait region (Thomson and McKinnell

1995). In 1994, 1068 Atlantic salmon were either returned or reported to DFO from the British Columbia fishery, and of these, 31 were found in freshwater. In the same year, 29 Atlantic salmon were reported from the Alaska commercial fisheries and 363 in Washington (Thomson and McKinnell 1995).

Management of the nonindigenous species. The Atlantic salmon industry in Washington is regulated by the state Department of Ecology (sediment standards), Department of Natural Resources (DNR, site permitting) and WDFW (health management). In British Columbia, fisheriesrelated aspects of the Atlantic salmon industry are regulated by the agencies cited earlier in this report.

Brown Alga, Sargassum muticum

The following summary was provided by Dr. Annette Olson and Ellie Linen of the University of Washington.

The following references were use to prepare this summary: Carlton (1992); Seagal (1956); and Rueness (1989).

Source of the nonindigenous species to the shared waters. The brown alga (Sargassum muticum) was inadvertently introduced as packing material with shipments of Japanese oysters, and perhaps also was carried accidentally as spores, sporelings, or fragments of reproductive adult plants. Subsequent secondary dispersal is by spores and drifting fragments of adult plants, which have numerous floats. Although these fragments cannot reattach, they can survive and become reproductive.

S. muticum was first found in Washington's Willapa Bay in 1953, although it may have been present before that time, and it is now common in coastal areas throughout the Pacific Northwest. It was first found in Europe in 1973 on the Isle of Wight. The subsequent rapid expansion of the alga has resulted in many permanent populations along the European Atlantic coast and in the western Mediterranean.

Beneficial uses of the nonindigenous species. None is known in the shared waters.

Negative impacts of the nonindigenous species. S. muticum exhibits many features of an invasive weed, combining fast growth (up to 4 cm per day) and tolerance of a wide range of environmental conditions with easy dispersal. It is a large canopyforming species, which potentially affects entire ecological communities. S. muticum probably permanently displaces some native algae, and it has been documented to suppress the natural of recovery of kelp beds disturbed by an El Ni9o event in California.

As pest in commercial oyster beds, S. muticum was first observed in the Pacific Northwest by oyster growers concerned about its ability to invade commercial shellfish beds and potentially to inhibit shellfish growth.

Management of the nonindigenous species. There may be some removal of S. modicum from commercial oyster beds, but the extent of this practice is unknown.

Cordgrasses: Spartina alterniflora, S. anglica, and S. patens

The following information was provided by Lisa Lantz of the WNWCB.

Source of nonindigenous species to the shared waters. All three cordgrass species are established on Washington tidelands. Spartina alterniflora has in particular has been the focus of control efforts, due to its spread in Willapa Bay and its range extension in the Puget

Sound region. S. alterniflora was inadvertently introduced into Willapa Bay in the 1890s and was intentionally planted in Puget Sound (Padilla Bay) in the 1940s in an effort to stabilize an island. The establishment in Willapa Bay is believed to have resulted from the eastern coast of the United States, when the species was used as a packing material for imported eastern oysters. S. anglica was intentionally planted in Port Susan Bay in 1961 in an attempt to convert tidelands to pasture. The only known established site of S. patens is at the mouth of the Dosewallips River. More details regarding the introduction of these species to Washington can be found in Aberle (1993) and Hitchcock and Cronquist (1973).

Beneficial uses of the nonindigenous species. No beneficial economic uses of significance are known or reported. There are anecdotal reports of the production of paper or beer from cordgrasses, but no developed technology or market is known for such uses.

Because Spartina species are palatable to livestock, their continued spread could increase pasture lands. Research has also been conducted on using S. alterniflora in paper production (Ebasco Environmental 1993).

Because of their ability to trap sediment, Spartina species have been planted in many parts of the world for estuary reclamation (Partridge 1987). Although S. anglica has been used more commonly for this purpose, S. alterniflora has been planted for estuary reclamation in New Zealand. In estuaries of British Columbia and Washington, species that are able to use Spartina marshes could benefit from the expansion of this species. For example, juvenile chinook salmon have an affinity for salt marsh habitat and might therefore benefit from the spread of salt marsh vegetation (Simenstad and Thom 1995).

Negative effects of the nonindigenous species. Cordgrasses are capable of major tideland modification. The species colonize mudflats like those in Willapa Bay, where dense growths of the vegetation increase silt deposition, displace mudflat dwelling organisms and plants, alter tidal exchange, and reduce capacity of estuaries to buffer freshwater input during flood riskperiods. The Spartina species can reduce rearing habitat for some salmon species, lingcod (Ophiodon elongatus), English sole (Parophyrys vetulus), clams, oysters, and hardshell crabs. They have the potential to displace the beneficial use of oyster culture in Willapa Bay and other marine waters. Cordgrasses can result in raising the ground level through siltation and produce narrow, deep channels bordered by heavy growths of the grasses. S. anglica colonizes a wide variety of substrates, including mudflat, sand, and gravel/cobble, and Spartina species may extend up rivers for considerable distances.

Table 5. Potential Impacts of Spartina alterniflora spread in Washington state

[Table not formatted.] Possible Impact Cause Competitive replacement of native plants Higher seed production and germination: higher vegetative production Effects of sedimentation Greater stem densities, larger and more rigid stems Changes in available detritus Differences in quantity and quality of detritus Decreased bottom dwelling algae production Lower light levels beneath Spartina canopy Increased wrack deposition and disturbance to upper marsh Greater stem production and subsequent deposition in high

marsh Changes in habitats for native wetland animals Greater stem densities Changes in bottom dwelling invertebrate populations Higher shoot densities and lower intertidal distribution Loss of shorebird and wading bird foraging areas Lower intertidal distribution
Adapted from Callaway and Josselyn (1992).

Management of the nonindigenous species. Cordgrasses are prominent in Willapa Bay, and they are spreading in areas of Puget Sound. Apparently, they also occur to a limited degree in British Columbia (Lorne Clayton, British Columbia Shellfish Growers Association, personal communication, 1996). Control of Spartina in some areas of Washington is mandated by state law and is the responsibility of the landowner. In Washington, control and eradication of Spartina spp. are practiced by mowing, uprooting young plants, and using glyphosphate herbicide. The combination of mowing and herbicide application is reported by state agency officials to be effective. In 1995, a state law was approved in Washington (Washington State Laws 1995, Chapter 255) mandating that the WDA be responsible for a unified effort to eliminate Spartina cordgrasses and purple loosestrife (Lythrum salicaria). As a result, a control coordinator was appointed in the WDA, and during 1996, the appointee has developed Spartina management plans for areas of the state. The cordgrasses are the only marine plants currently controlled in Washington. All noxious weeds in the state are regulated through authority of the WNWCB and county noxious weed control boards that may be activated at the discretion of the counties.

Volunteer efforts in cordgrass control in Washington are run through AdoptABeach, a nonprofit environmental stewardship organization, and Washington Water Trails, a nonprofit organization dedicated to preserving Washington's marine environment. The goal of the volunteer program supported by these two groups is to identify Spartina growing sites and to work with shoreline residents for the careful removal of plants. The project is coordinated by the Spartina Technical Advisory Committee, which consists of a county weed board representative and representatives of the DNR, the WDA, and the state secretary of the WNWCB.

European shore crab: Carcinus maenus

Source of nonindigenous species to the shared waters. The European shore crab has not been reported in the Straight of Georgia or Puget Sound, but based on environmental tolerances and rate of propagation up the coast from San Francisco Bay, it could reach Washington's coastal estuaries in the near future. The European shore crab was first reported in San Francisco Bay around 1989, and as of the summer of 1995, had extended its range northward approximately 470 km to Humboldt Bay, California. It may have reached California initially in seaweed packing materials (Ascophyllum nodosum) used to ship lobsters and bait worms from the east coast (Miller 1969).

Beneficial uses of the nonindigenous species. The European shore crab is eaten in some areas, but its small size (only about 60 mm maximum carapace width) would make it an unlikely fishery item in an area with much larger and more desirable crab species.

Negative effects of the nonindigenous species. This crab is originally from Europe, and its introduction to the east coast of North America is believed to have markedly decreased the softshell clam fishery in the northeast in the late 1940s and early 1950s through predation on the clams (Glude 1955). As a voracious predator on mollusks, it could have similar effects on oyster and clam culture in Washington, particularly in Willapa Bay and Grays Harbor. It could also have a significant impact on Dungeness crab in the shared waters of Washington and British Columbia, because it readily preys on other crab species and would be resident in the intertidal shell habitats used by newlysettled Dungeness.

Management of the nonindigenous species. The European shore crab does not now reside in the shared waters, and therefore, no management program exists. There is also no known management or educational program to reduce the chances of its introduction to the shared waters. Attempts to control this shore crab on the east coast, using fences to exclude it and traps to catch and remove it, did not prevent the negative effects on the clam fishery. Existing culture practices in the shared waters may have to be modified (e.g., putting oysters out at a larger size) if the European shore crab spreads to this region, becomes established, and proves to be as voracious a predator on regionally cultured shellfish as on New England softshell clam (Mya arenaria).

Japanese oyster drill, Ceratostoma inornatum

Source of nonindigenous species to the shared waters. The Japanese oyster drill was introduced when Pacific oysters were imported from Japan during the early 1900s.

Beneficial uses of the nonindigenous species. None are known.

Negative effects of the nonindigenous species. The Japanese oyster drill is among the most damaging of pests found in oyster beds. In drillinfested areas of Washington, up to 25% mortality occurs in outplanted oyster seed, production costs increase by nearly 20%, and net profits decrease by as much as 55% due to drill predation (Bob Sizemore, WDFW, personal communication, 1996).

Management of the nonindigenous species. State waters are classified by WDFW as restricted with respect to diseases, pests, or predators that can threaten aquaculture stocks and native flora and fauna. Currently, a permit process is in place to monitor shellfish movements between designated areas. In the future, the permit process could be replaced with an information pamphlet that includes the shellfish transfer conditions.

Japanese eelgrass or seagrass, Zostera japonica

The following information was provided by Dr. Annette Olson, University of Washington.

Source of nonindigenous species to the shared waters. Japanese eelgrass or seagrass is thought to have been introduced as live packing material for Pacific oysters. Although it is no longer allowed under Washington state statute, seed oysters were imported from Asia to Washington until the mid 1970s.

Beneficial uses of the nonindigenous species. Some wildlife managers consider Japanese seagrass to have beneficial uses. It is consumed by herbivorous birds (dabbling ducks and brant), and because it occurs at higher elevations in the intertidal, it is more accessible than native seagrass; for some species, it constitutes a majority of esophageal contents (Baldwin and Lovvorn 1994a). Japanese seagrass could provide food chain support and shelter for fisheries species, although direct experimental evidence that either Japanese or native seagrass production benefits fisheries is presently lacking. It provides habitat and food for herbivorous invertebrates, and increases the diversity of macroepifauna and infauna, as well as species density in some cases (Posey 1988). Rates of feeding on Japanese seagrass and its epiphytes have not been documented in the field, nor have mechanisms for enhancement of invertebrate populations been investigated. In particular, the possibility that it provides shelter from predation has not been tested. Invertebrates may be less available to fisheries species in Japanese seagrass beds than on mudflat habitats.

Negative effects of the nonindigenous species. Japanese seagrass inhibited leaf growth and vegetative expansion of native seagrass in experiments at the Padilla Bay National Estuarine Research Reserve, but it has been associated with increases in cover of native seagrass in observational studies at Boundary Bay. The interactions of native and Japanese seagrasses and patterns of natural or anthropogenic disturbance have not been studied. The relative habitat value of Japanese and native seagrass and mudflat communities is not known. It is likely that Japanese seagrass invasion of mudflats benefits some native species and harms others. In particular, feeding by visual predators, such as shorebirds, may be inhibited by vegetation (as has been observed in other aquatic and marine systems). If Zostera japonica can replace the native Z. marina under some circumstances, associated species composition may also change. Anecdotal evidence suggests that Z. japonica may facilitate invasion by Spartina spp., and it may interfere with oyster ground culture operations at some locations.

Management of the nonindigenous species. In Washington, Z. japonica is managed as habitat" under the same regulatory process as the native Z. marina, and therefore, mitigation for its destruction is required. Although managers are mindful of potential differences between the species, and they occur at different elevations on the shore, there is no formal policy that differentiates between them. Because aerial inventories cannot distinguish the two species, groundtruthing is necessary. Consequently, estimates of the rates of conversion of native mudflat and seagrass habitats by Japanese seagrasses are not presently available. Pawlak and Olson (1995) recommended the development of a clearly documented and formalized seagrass policy, consideration of a watershed approach to management, evaluation of differing functional values of native and Japanese seagrass, and an inventory of seagrass resources.

Mahogany clam, Nuttalia obscurata

The following information on the mahogany clam was provided by Glen Jamieson of the DFO, Canada.

Source of nonindigenous species to the shared waters. Nuttalia obscurata is locally called the varnish clam, but primary known as the dark mahogany clam. It is native to Korea and Japan, and was first noticed in Strait of Georgia waters in 1994. Based on the relatively large size of the clams, the introduction probably occurred, presumably by ballast water, sometime two or more years earlier. The clams have been found from Quadra Island to Saanich Inlet; therefore, they most likely dispersed rapidly from some initial source, probably one of the nearby ports, and it may now be distributed throughout the Strait of Georgia and on the southern aspect of Vancouver Island on the Strait of Juan de Fuca. There is no reported occurrence of this species in Puget Sound or in the San Juan Islands, but there is sufficient ambiguity of identification and naming of related clam species that it could be present, but as yet unrecognized.

For a discussion of the problem of clam systematics as it relates to the study of biodiversity and NIS introductions, see Vecchione et al. (1996, pp. 4849).

Beneficial uses of the nonindigenous species. There are currently no fisheries for the mahogany clam; however, it is an edible species, so there may be interest in developing a fishery in the future. Specimens grow to in excess of 50 mm wide, but the curvature of the valves is flatter than that in Manila clams; consequently, the meat yield is less.

Negative effects of the nonindigenous species. It occurs in the intertidal zone at an elevation similar to that occupied by the Manila clam, and seems perhaps more tolerant of freshwater than the latter, based on its greater abundance around stream and river mouths. The nature of its competition with other bivalves is unknown.

Management of the nonindigenous species. None.

Manila clam, Venerupis philippinarum

Source of nonindigenous species to the shared waters. The Manila clam was apparently imported with shipments of Japanese oysters, when such importations were allowed.

Beneficial uses of the nonindigenous species. Subsequent to its introduction, the Manila clam has become an important aquaculture species in Washington state. It is also a major component of the commercial and recreational shellfish harvest in British Columbia. It is a product of higher value than the native littleneck clam, Prototheca staminea, which is also harvested, but not augmented by propagation of hatchery stocks. The WDFW indicated that the farm sales value of the Manila clam industry in Washington was US$ 11,100,000 in 1993.

Negative effects of the nonindigenous species. No specific negative effects of the Manila clam were found. Although it generally occupies a higher tidal range than the native littleneck clam, it could compete with that species.

Management of the nonindigenous species. Cultured populations of Manila clams are managed by private companies and are harvested by native American tribes and recreational shellfishers.

Pacific or Japanese oyster, Crassostrea gigas

Source of nonindigenous species to the shared waters. Pacific oyster, Crassostrea gigas, was imported to Washington during the early part of the 1900s, following intensive harvest and dramatic reduction in populations of the native oyster, Ostrea conchaphila. Until the mid 1970s, seed oysters (spat) were imported from Japan into Washington state to support continued production of the Pacific oyster, because it reproduces naturally only in very limited areas of the Pacific coast of North America. Since the advent of new hatchery technology that supplies the seed oyster industry, Asian oyster spat is no longer imported to Washington. In North America, the range of the Pacific oyster is from southeast Alaska to Baja California.

Beneficial uses of the nonindigenous species. According to the WDFW, Pacific oyster production in Washington in 1993 had a farm sales value of about US$ 16,900,000. The farmed shellfish industry employs about 3500 people in Washington in combined direct and indirect jobs, according to the Pacific Coast Oyster Growers Association. Washington state is a world leader in oyster production and production technology, and the highquality oysters are sought in various world markets. British Columbia, oyster production in 1993 was 250 tonnes, valued at CAN$4,200,000, accounting for approximately 75% of farmed shellfish production.

Negative effects of the nonindigenous species. The principal negative effects associated with Pacific oyster aquaculture are a result of past practices that are no longer in existence. The main impact is from the introduction of the Japanese oyster drill. Japanese seagrass was also apparently introduced with Japanese oysters, but whether its introduction has been beneficial or deleterious is not clear.

Management of the nonindigenous species. Japanese oyster culture is managed in Washington by the WDFW, and in British Columbia by the British Columbia MAFF.

VI.RECOMMENDATIONS

Recommendations regarding specific NIS pathway management are contained in the analysis section at the conclusion of each pathway discussion. In addition, the following, more general recommendations are made.

Need for baseline information and assessment methods

Information is limited on indigenous (and previously introduced NIS) species distribution, and in some cases, on the identity of indigenous species. The bay mussel complex is a good example.

The so called Mediterranean mussel (Mytilus galloprovincialis) is widely cultured in Washington and has been resident in the state for at least 20 years (Brooks 1991). It was introduced into Washington from California for aquaculture, because the resident bay mussel, M. trossulus, is subject to a severe leukemialike disease and high losses during the summer. M. galloprovincialis was previously believed to be a European native species; however, there is strong evidence that it is native to the west coast. Morphologically similar mussels were reported from 5000yearold middens in southern California (Sarver and Loudenslager 1991), and Kenchington et al. (1995) used genetic sequence data to study this species, and found that Washington state M. galloprovincialis shares 99.5% of the genetic sequence data with other Mytilinae, and thus "appears incorrectly named." Nonetheless, federal agencies (USFWS and NMFS), commenting on an application to import California mussels to Washington in 1995, considered it an exotic species. In contrast to these findings, Heath et al. (1995) reported the presence of "alien alleles" in blue mussel populations from the west coast of Canada, resulting from the introduction of M. edulis from the east coast of North America and the importation of M. galloprovincialis.

In order to address the shortage of needed information on species distribution and identity, there is a need to assess in detail the knowledge gaps and develop a consolidated inventory regarding presence and distribution of native and nonindigenous marine species on the west coast of North America. Approaches such as that of the U.S. National Research Councils (NRC) Committee on Biological Diversity in Marine Systems (NRC 1995) and that of the Nature Conservancys (TNC) Natural Heritage project in the shared waters of the Great Lakes region (TNC 1995) could be useful. In regard to a specific risk, there is a need to assemble detailed information on the risk of European shore crab introduction from California waters and a means to reduce this risk or manage the species, should it be introduced. A more systematic approach, standards, or guidelines are needed regarding genetic effects and ecological interactions for the intentional movement of NIS into shared waters, which are not based on zero risk, but rather on reduction of relative risk.

Education

Educational materials can help reduce the risks of unintentional NIS introductions. Completion of the educational materials planned by the WDFW that address risks from introductions of marine invertebrates, and expansion of the subject matter to include aquatic fish and plants is needed. These educational materials should address risks from aquaculture, individual releases, the aquarium industry, and research activities. In addition, informational materials to educate consumers about the risks from the release of living marine organisms sold as seafood would be useful. The existing educational materials developed by the British Columbia MELP and the WNWCB may be useful models for other, similar materials.

Communication

Fisheries agencies in Washington and British Columbia should support the enhanced use of the PSMFC Shellfish Transport Subcommittee to facilitate information exchange and to promote uniformity of biological criteria used to regulate invertebrate species movement.

Regulation

Voluntary programs are preferable to mandatory programs, if they are credible and functional. Clearly, the voluntary program for ballast water exchange, now required in the United States in order to avoid a mandatory program, will be a test case regarding the feasibility of the voluntary nature of the program. Functional voluntary programs require that the industry have a stake in the success of the program. Due to the many pathways of NIS entry and the enormous cost that would be required to effectively regulate and police all of the pathways uniformly, it seems clear that education and voluntary programs will play a large role in the future reduction of risks from nonintentional NIS introductions.

Natural dispersion, commercial and recreational boat traffic, and many established, other pathways contribute to the movement of species along the west coast of North America. The focus of limitation of species movements should be the exclusion of recognizable NIS from other continents. Risks from NIS, such as the European shore crab, from other continents introduced to other areas of the west coast of North America present a special challenge for management of the shared waters.

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Nonindigenous Species in the Shared Inland Marine Waters British Columbia and Washington

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APPENDIX A.

Nonindigenous Species in the Shared Inland Marine Waters of British Columbia and Washington (not a comprehensive list)

APPENDIX B. Canadian List of Prohibited Species

Table from M. Waldichuk, P. Lambert, and B. Smiley, 1994, Exotic Introductions in B.C. Marine Waters, pp. 220223, in Biodiversity in British Columbia: Our Changing Environment, eds. L.E. Harding and E. McCullum, Environment Canada, Canadian Wildlife Service, Ministry of Supply and Services, British Columbia.

APPENDIX C. List of Abbreviations, Initialisms, and Acronyms

ANCA Australian Nature Conservation Agency
AQUIS Australian Quarantine Inspection Service
CBC Chesapeake Bay Commission
CFR U.S. Code of Federal Regulations
DFO Department of Fisheries and Oceans, Canada
DNR Washington Department of Natural Resources
DNS declaration of nonsignificance
DOC U.S. Department of Commerce
DOI U.S. Department of the Interior
EPA U.S. Environmental Protection Agency
FR U.S. Federal Register
FTC Fish Transplant Committee (British Columbia)
ICES International Council for the Exploration of the Seas
IMO International Maritime Organization
LG liquified gas carrier
LPOC last port of call
MAFF Ministry of Agriculture, Fisheries, and Food.
MELP British Columbia Ministry of Environment, Lands, and Parks
NIS Nonindigenous species
NMFS National Marine Fisheries Service
NRC National Research Council
OTA U.S. Office of Technology Assessment
PFR Pacific Fishery Regulation
PSMFC Pacific States Marine Fisheries Commission
PSSOA Puget Sound Steamship Operators Association
RCW Revised Code of Washington
RORO roll on, roll off (vessels that arrive with cargo, no ballast water requirements
SEPA State Environmental Policy Act
TNC The Nature Conservancy
USCG U.S. Coast Guard
USFWS U.S. Fish and Wildlife Service
WAC Washington Administrative Code
WDA Washington Department of Agriculture
WDFW Washington Department of Fish and Wildlife
WNWCB Washington Noxious Weed Control Board