Chapter 1. Introduction

Anson H. Hines, Smithsonian Environmental Research Center
Gregory M. Ruiz, Smithsonian Environmental Research Center

1A. Project Goals

The overall goal of this project was to assess the risk of biological invasion by nonindigenous species (NIS) introduced into Port Valdez / Prince William Sound, Alaska. Currently, ballast water is the major vector for introductions of NIS in coastal ecosystems, where ballast-mediated biological invasions are causing severe ecological and economic impacts. While the significance of ballast-mediated invasions has focused on temperate zone ports, little consideration has been given to NIS invasions at high latitudes, despite the volume of shipping and critical importance of certain cold-water ports to the world economy and especially US energy interests. Port Valdez is a high latitude-cold water port receiving the third largest annual volume of ballast water in the USA. Moreover, our recent review of NIS invasions at high latitude (Ruiz & Hines 1997) indicates that such cold water ecosystems have been invaded by a diverse array of marine and estuarine species. The specific objectives of the project were:

- To analyze the delivery patterns, biological characteristics, and management practices of ballast water and other ships arriving to Port Valdez from coast-wise versus foreign voyages.
- To assess viability of selected organisms arriving in tanker ballast water to Port Valdez.
- To conduct experiments on the effectiveness of ballast water exchange procedures of tankers.
- To evaluate organisms occurring in entrained sediments at the bottom of ballast tanks of crude oil tankers.
- To evaluate fouling organisms on hulls and in sea chests of tankers as potential sources of NIS.
- To analyze and search for NIS currently invading or already established in coastal waters of south central Alaska, using literature searches, an array of field sampling methods (field collections, fouling plates, and plankton sampling), and examination of existing preserved samples from Prince William Sound.

The purpose of this report is to summarize the research conducted during 1997-1999 to assess the risk of biological invasions in Prince William Sound, especially with regard to oil tankers as a vector for transporting NIS into marine ecosystems. Progress during the project was reported in Ruiz & Hines, 1997 and Hines et al., 1998. Modified elements of the earlier reports are included in the present report, so as to provide a complete overview of the project within one document. Certain limited elements of research will be completed during 2000, including further analysis of existing collections at the University of Alaska Museum and Institute of Marine Sciences, and work-up of sample from ballast water exchange experiments conducted during summer 1999. These last elements will be reported separately upon completion.

1B. Structure & History of Project

This research project has built upon a Pilot Study conducted in 1997 (see Ruiz & Hines, 1997), and includes an expanded scope of work conducted during 1998-1999. The multi-faceted approach to the research required a team of diverse CoPrincipal Investigators and subcontracted taxonomic experts. Drs. Anson Hines and Gregory Ruiz (SERC) have served as over-all project leaders, providing over-all administrative and scientific oversight for the team. In addition, Drs. Ruiz and Hines (SERC) had primary responsibilities for: analysis of ballast water delivery patterns; biological characteristics of ballast water; experimental analysis of initial survival of ballast water organisms; ballast water exchange experiments; analysis of ballast tank sediments and tanker hull fouling; fouling community analysis, and management of most of the focal taxonomic studies; as well many aspects of field surveys of Prince William Sound. To sample and analyze ballast water of tankers arriving to Port Valez, two Biological Technicians (Melissa Frey and George Smith, of SERC) alternately rotated at about four month intervals between SERC's temporary laboratory established in Valdez, Alaska and the SERC Biological Invasions Laboratory in Edgewater, Maryland. Ballast water exchange experiments were conducted with participation by several technicians and students from the SERC Biological Invasions Laboratory (see Acknowledgments). Co-PIs Nora Foster (UAF) and Dr. Howard Feder (UAF) had primary responsibility for analysis of existing samples in museum, reference and voucher collections in the UA Museum and UAF Institute of Marine Science. Nora Foster also participated actively in rapid community assessment surveys of Prince William Sound, and focal taxonomic analysis of molluscs. Dr. Howard Feder provided oversight to subcontracted focal taxonomic analysis of polychaetes. CoPI Dr. John Chapman (OSU) had primary responsibility to conduct rapid community assessment surveys of invertebrates of Prince William Sound, with focal taxonomic analysis of pericaridean crustaceans. CoPI Dr. Gayle Hansen (OSU) had primary responsibility for focal taxonomic field surveys of marine plants (especially macro-algae) of Prince William Sound. Dr. James Carlton (Mystic Seaport, Williams College) had primary responsibility for surveys of fouling communities of Prince William Sound. In addition, an array of systematic experts was subcontracted to analyze several focal taxonomic groups (see Chapter 9 below). Authorship of the chapters and subsections of this report indicate primary responsibilities for each major element.

Throughout the 1997 Pilot Study and the 1998-1999 expanded phase, the project received guidance and comment from the Alaska NIS Working Group, which was organized by the RCAC of Prince William Sound and composed of academic scientists, resource managers from state and federal agencies, representatives of the oil and shipping industries, and concerned citizens of Alaska (see also Acknowledgments).

Initial funding for the Pilot Study was provided by PWS RCAC, US Fish & Wildlife Service, and the US Coast Guard (Ruiz & Hines, 1997). Expanded research for the present project was extended with a proposal submitted in 1997 to the National Sea Grant Program, with co-funding from RCAC, USF&WS, Alyeska Pipeline Service Company, and in-kind support from the oil shipping companies (especially ARCO Marine, BP and SeaRiver Maritime). Funds awarded from the National Sea Grant Program were distributed to the Oregon Sea Grant Program for John Chapman at Hatfield Marine Science Center and to Alaska Sea Grant Program for Nora Foster and Howard Feder at University of Alaska Fairbanks and UA Museum. However, funding from Alaska Sea Grant was delayed for one year, so that funding was actually available beginning in 1999 and will carry through 2000. In 1998 SERC obtained supplemental funding from the American Petroleum Institute, supported by ARCO Marine and SeaRiver Maritime, to conduct ballast water exchange experiments on tankers. SERC also received further funding from USF&WS for these ballast water exchange experiments during 1999 through a proposal submitted to the National Sea Grant Program. The work plan for the ballast water exchange experiments specifies that sample processing and analysis continue into 2000.

SERC's technical staff worked in close coordination with the shipping agents, masters, officers and crews of the oil tankers, and with Alyeska staff of the Valdez Marine Terminal. All of these industry participants provided in-kind contributions and worked actively and cooperatively to assist project operations to sample ballast water and to conduct ballast water exchange experiments (see also Acknowledgments).

Significantly more work than originally proposed was accomplished in nearly all components of the project. Moreover, we have been successful in gaining additional resources to support expanded elements of the project, including contributions in kind, and added external funds for ballast water exchange experiments. Most importantly, a hallmark of the project was the enthusiastic support of the project by the full array of private citizens, scientific institutions, governmental agencies, and industry, which served as cooperative partners.

1C. Background

1C1. Invasive Species & Ballast Water

Aquatic nuisance species have invaded many, perhaps most, freshwater and marine ports around the world. Ballast water from commercial shipping is increasingly recognized as the most significant vector currently for those invasions occurring (Carlton and Geller, 1993). Ballast water consists of water pumped into dedicated tanks or cargo holds/tanks for trim and stability during oceanic voyages, especially when the vessel is empty or only partially full of cargo. Ballast water is usually taken from coastal water containing a rich diversity of planktonic organisms. Ballast water is often discharged into a receiving port prior to loading cargo, inoculating the ecosystem with exotic species. If any of the plankton are viable and become established, these non-indigenous species (NIS) can cause major ecological and economic disruption in the coastal ecosystem, with numerous examples in San Francisco Bay (Cohen and Carlton, 1995), the Great Lakes (Mills et al., 1993), Chesapeake Bay (Ruiz et al.,1999), Hawaii (Coles et al. 1999), and elsewhere (Ruiz et al., 1997). In San Francisco Bay, the rate of invasion has increased to about one new NIS invasion every 16 weeks, probably as a result of increased ballast water discharge (Cohen and Carlton, 1995). Whether the invasion is Eurasian zebra mussels in the Great Lakes, Asian clams in San Francisco Bay, or North American ctenophores in the Black Sea, impacts of ballast introductions have been devastating and irreversible. Despite the profound impact of ballast-mediated invasions, the biological characteristics of ballast water and the factors that regulate invasion success are little studied and poorly understood. In the USA, biological characteristics of ballast water have only been studied in two port systems: Coos Bay (Carlton and Geller, 1993) and Chesapeake Bay (Smith et al., 1996; 1999; Ruiz et al., unpubl. data); and in other countries the biology of ballast water has similarly received little quantitative analysis (Carlton, 1989; however see Williams et al., 1988; Hallegraeff and Bolsch, 1992).

1C2. NIS in High Latitude/Cold Water Ecosystems

Although there has been no significant analysis of NIS in polar marine ecosystems, there have been a limited number of NIS surveys in high temperate latitudes between 40^{o} - 60^{o} and a study of the Baltic Sea, which includes a major bay that extends substantially above 60^{o}. These studies include three regions in the northern hemisphere (Baltic Sea, Wadden Sea, and United Kingdom)(Reise et al., 1999, Lepapakoski 1984) and one region in the southern hemisphere (Tasmania/New Zealand)(Hayward 1997, R. Thresher, 1999 pers. comm.). Together, these studies clearly demonstrate that invasions are not limited to lower latitudes. The number of known NIS at these locations ranges between 32 and 80 species. For each region, the species include a broad range of taxonomic groups, and some of the invasions have generated serious concerns about their ecological and economic impacts. As with most invasions, the actual impacts remain unmeasured (e.g., Ruiz et al., 1999). Nonetheless, based upon reported abundances and known ecology, species such as the green crab *Carcinus maenas* (on the North American east and west coasts, Tasmania), the seastar *Asterias amurensis* (in Tasmania), and the laminarian kelp *Undaria sp.* appear likely to cause significant and irreversible changes. Furthermore, the cumulative effects of the entire NIS assemblage may cause many changes in ecosystem function that are not easily identified with any single invasion event (Cohen and Carlton, 1995).

The numbers of NIS at high latitudes may be lower than those for temperate regions, although it is not clear whether low numbers of documented NIS reflect lack of invasion in high latitude ecosystems or lack of research focused on the invasion biology of these areas. At the outset of this study, the number of NIS documented in Alaskan waters appeared to be lower than other high latitude/cold water ecosystems with more extensive analysis, despite the extensive environmental studies associated with the Exxon Valdez oil spill in Prince William Sound and other ecological research throughout the region (Ruiz & Hines, 1997).

We advanced two hypotheses why NIS have not been as evident at high latitude as at mid-latitudes:

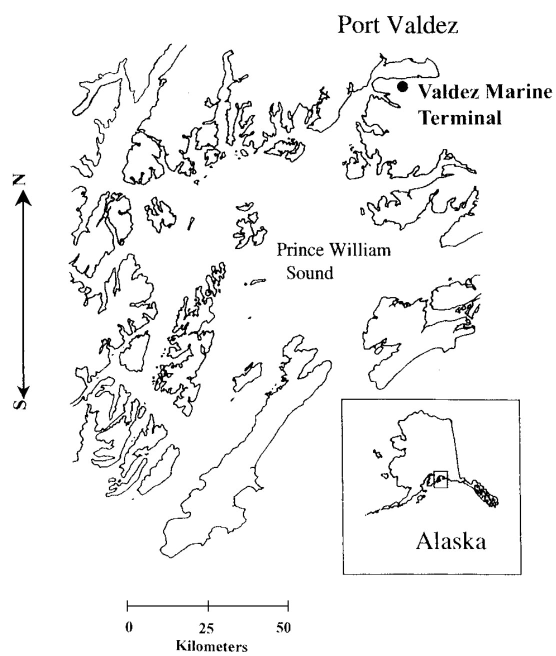
(1) NIS are truly rare at high latitude. High latitude communities may be resistant to invasion (e.g., severe seasonal stress requires specialized evolutionary adaptations not possessed by non-native species). Transport patterns may not have been conducive to inoculation. Shipping/ballast water is major source of rapidly escalating invasions in temperate latitudes, but perhaps neither the relatively recent (20 yrs) surge in tanker traffic to Alaska with very large ballast capacity, nor the current shift in tanker traffic to foreign ports has had time to produce invasions. Note, however, that NIS invasions mediated by ballast water have been common over the past 20 years in some cold temperate ports such as San Francisco Bay (Cohen and Carlton, 1995).

(2) NIS are actually common at high latitude, but have not yet received concentrated study by experts of invasion biology. For example, Carlton (1979) identified some 160 NIS in San Francisco Bay and Pacific northwest coast, but as of 1995 the number of NIS documented in San Francisco Bay was 212 species (Cohen & Carlton, 1995) and is now nearly 250 species (J.T. Carlton, personal communication). Three years ago, the number of NIS in Chesapeake Bay was considered to be only about 25 species; yet pursuant to our on-going literature search of the historical records, we have documented >140 NIS, and the list is still growing with continuing research. Despite extensive biological/ecological assessments of coastal ecosystems associated with oil spills in Alaska, NIS probably remain inadequately studied. The existing and on-going surveys from oil spill work and other studies in Prince William Sound are probably not adequate because those surveys were designed for purposes other than detecting introduced species. Also, they mainly focused on rocky shores rather than on soft-bottom and fouling communities that are most invaded in other regions (e.g., Cohen & Carlton, 1995). Most introduced species have been discovered by taxonomic experts systematically examining specimens previously identified by non-specialists or conducting field surveys of their own.

1C3. Risk Factors for Prince William Sound

Prince William Sound is a relatively pristine, cold water ecosystem at high latitude. Approximately 20% of US domestic oil production is shipped from Port Valdez at the head of the Sound (Fig. 1.1). Tankers arriving to Port Valdez come primarily from domestic source ports of the west coast of North America and Hawaii; but in the past three years tankers also have been traveling from foreign ports, especially in eastern Asia and rarely other locations (Fig. 1.2). Tankers arriving to Prince William Sound discharge two types of ballast water: (1) Segregated ballast water from tanks dedicated solely to ballast water and (2) non-segregated ballast water from tanks which are used to carry petroleum products. Approximately 20 million metric tons of segregated ballast water are discharged annually by tankers into the port and sound, a quantity of domestic ballast water that greatly exceeds the volumes of foreign ballast water released in other U.S. West Coast ports and is the third largest volume for all U.S. ports (behind port systems of New Orleans and Chesapeake Bay). All non-segregated, oily water (about 50% of total) discharged by tankers in Port Valdez must pass through the Ballast Water Treatment Facility located on shore at the Valdez Marine Terminal. Effects of the treatment plant on NIS were unknown prior to our Pilot Study (Ruiz & Hines, 1997). The Pilot Study showed that non-segregated ballast water contained few live planktonic organisms upon leaving tankers and entering the treatment plant, and that there is little risk of NIS in the discharge of water from the treatment plant (Hines et. al., in press). Accordingly, all of our analyses in subsequent research presented in this report focus on segregated ballast water.

Figure 1.1.Map of Prince William Sound, Alaska, showing location of Valdez Marine Terminal.



Segregated ballast water from tankers is discharged directly into the Sound/Port without treatment. This volume is many orders of magnitude greater than the ballast water released by other types of ships traveling to Prince William Sound. Release of ballast water into Prince William Sound increased markedly with the opening of the trans-Alaska Pipeline in 1977. Tankers have made more than 15,000 voyages through Prince William Sound to Port Valdez since the startup of the terminal in 1977. From 1987-1994, tanker arrivals to Valdez averaged

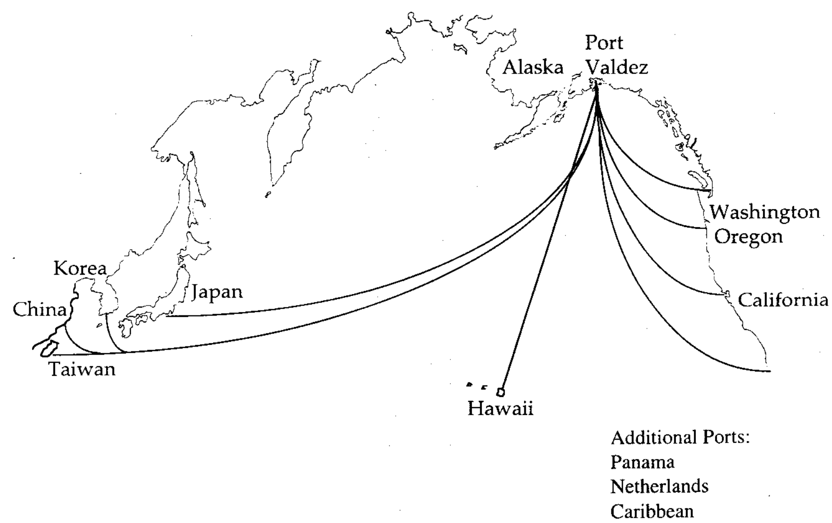
799 per year but have declined to less than 600 per year currently. Since 1996, oil shipping patterns authorized by the US Congress have changed to allow sale of crude oil on foreign as well as domestic markets. Tankers from foreign ports are required to conduct mid-ocean exchange of their coastal ballast water, which is expected to reduce numbers of organisms transported from foreign coastal ecosystems to Alaskan waters. However, the effectiveness of mid-ocean exchange is poorly measured. Moreover, the greatest volume of ballast water coming to Alaska derives from domestic ports of the west coast of North America, which themselves are highly invaded by NIS. Tankers on these domestic, relatively short coast-wise voyages are not required to exchange ballast water.

To determine whether the known NIS in Alaska provide an accurate indicator of the probability for biological invasions, we considered 6 factors which contribute elements of risk for invasions of Prince William Sound:

1. <u>Huge volume of ballast water.</u> The greatest quantities of ballast water are transported by bulk cargo carriers and tankers (Carlton et al., 1995; Smith et al., 1996). Chesapeake Bay receives 10-fold more ballast water than other ports on the east and west coasts of the U.S. because of the high volume of bulkers arriving to the ports of Baltimore and Norfolk. The tanker traffic to Port Valdez releases the third largest volume of ballast water into a US port. Other things being equal, larger ballast volumes mean larger inoculations of NIS.
2. <u>Short voyage time.</u> Our analysis of biological characteristics of ballast water arriving to Chesapeake Bay shows a marked inverse relationship between densities of organisms and length of voyage, such that ballast water after voyages of 14-24 days had more than 10-fold fewer organisms than voyages of 5-13 days (Smith et al., 1996; 1999). However, these effects may be confounded by differences in the source of ballast, which co-varies with the length of voyage (Smith et al., 1996; 1999). Voyages of tankers delivering ballast water to Prince William Sound average only 3-6 days, quite short compared to most trans-oceanic voyages that average 12-22 days. Short voyages mean that many larvae and other organisms are likely to be in good health when they are discharged (see Chapt 2 and 3 below).
3. <u>Pattern of repeated delivery from same donor locations.</u> Although Chesapeake Bay receives about 10-fold more ballast water than does San Francisco Bay, San Francisco Bay appears to be invaded by many more ballast-mediated NIS. This greater risk could be due to San Francisco Bay receiving repeated ballast inoculations delivered from relatively fewer ports than does Chesapeake Bay. Similarly, Prince William Sound could be at increased risk not only by the large volume of ballast water, but also by the repeated inoculation of ballast from a small set of west coast ports (Fig. 1.2, Chapt 2 below).
4. <u>The match of environmental conditions of source and receiving ports.</u> Environmental conditions in Alaska are often perceived as being harsh and inhospitable to most potential invaders from temperate latitudes where moderate conditions prevail. Obviously, temperature, light and other conditions during winter are indeed more extreme than those in temperate regions of North America and Asia. However, temperature-salinity conditions in Prince William Sound during spring and summer often approximate conditions in source ports of northwest North America, especially during productive periods of cold water up-welling. In fact, many of the native marine/estuarine species in Alaska have geographic ranges which extend to British Columbia, Washington, Oregon, and Northern California. Temperature-salinity conditions in segregated ballast water of tankers arriving from several west coast source ports is shown to be similar to the waters of Port Valdez (see Chapt 4 below). In the fjords of Prince William Sound, such as Port Valdez, heavy loads of

suspended sediment during summer snow/glacial melt also may be a major stress on marine organisms in surface waters.

Figure 1.2. Major tanker routes to Port Valdez, Alaska.



5. <u>Lack of mid-ocean exchange of ballast water delivered to Prince William Sound.</u> Mid-ocean exchange of ballast water reduces concentrations of larvae and plankton by 50-90% (Smith et al., 1996). Exchange presumably limits the risk of invasion, as mid-ocean species are generally thought to be incapable of invading near-shore habitats. Delivery of ballast from coastal ports of the U.S. West Coast without oceanic exchange before release into Prince William Sound poses an elevated risk. Further experimental assessment of this role of mid-ocean exchange in reducing plankton abundance and diversity in ballast water is presented below in “Ballast Water Exchange Experiments”. While ballast water exchange is required for tankers from foreign ports, the National Invasive Species Act of 1996 considers tankers from U.S. west coast ports to be domestic, coast-wise traffic that does not require exchange.
6. <u>High frequency of known NIS - especially those transported by ballast water - in source regions of ballast coming to Prince William Sound.</u> Some workers consider that there may be "hotspots" of invasion or donation of NIS. If such hotspots exist, certainly San Francisco Bay and other ports of the U.S. west coast qualify as having among the highest prevalences of documented ballast-mediated invasions. These, in turn, form the sources donating much of the ballast water delivered to Prince William Sound. The 310+ known NIS of the west coast of North America vary considerably in abundance among 6 latitudinally separate regions (southern California, San Francisco Bay, northern California, Coos Bay Oregon, northwest region from the Columbia River estuary to British Columbia, and Alaska) (Ruiz & Hines, 1997). The number of known NIS varies from about 80+ species in southern California to about 40+ species in the northwest region of Washington and British Columbia, with the largest number of nearly 250 species occurring in San Francisco Bay. At each location along the west coast, NIS are common in a diverse array of taxonomic groups, with arthropods, mollusks, and annelids comprising major fractions of NIS at most locations. In several locations (San Francisco Bay, Northern California, Oregon), vascular plants and chordates also comprise major portions of the NIS. Much of the variation in number of NIS

probably reflects the level of study and state of knowledge for each location, especially since the highest numbers occur at two locations (San Francisco Bay and Coos Bay) where J.T. Carlton has focused his past research. Many NIS occur in several locations along the west coast, indicating that invasions by the same species have occurred widely across latitudinally separate sites. The similarity of NIS at less studied sites may be expressed as a percent overlap with NIS in well-studied San Francisco Bay. The overlap of NIS at west coast source ports with those in San Francisco Bay is high, ranging from about 60-75%. For the limited sample known for Alaska, the overlap of NIS with San Francisco Bay is substantially lower at about 25%. However, it is not clear whether this lower overlap reflects reduced compatibility with the Alaskan region or the small sample size, or both.

7. <u>History of other vectors for NIS in Prince William Sound.</u> Although ballast water from tankers is currently a major vector for introductions of NIS in Prince William Sound, several other vectors have been, and continue to be, active in Alaska for long periods of time and in the present. These transport mechanisms include:
   - Ballast water from other types of ships, especially bulk carriers of such products as wood (logs, wood chips), ore, and coal, which come from foreign or domestic ports to Alaska in ballast to load. These may provide inoculations in ports nearby Prince William Sound (e.g., Homer, Seward), that may be spread by coast-wise traffic.
   - Fouling of ship hulls, which was especially important historically in wooden ships and before anti-fouling paints. However, fouling continues to be common, and may be especially important in coast-wise transport to and within Alaskan waters. This vector may include all types of private, recreational and commercial vessels.
   - Intentional and accidental release from aquaculture activities. Both species that are cultured and species that may be coincident with the aquaculture (including disease organisms) may be released. Oyster culture, salmon culture, and cultured herring roe on kelp are especially common and potential sources of NIS in Prince William Sound. Mussel culture may be initiated in the area.
   - Fishery release has occurred commonly in the past through efforts of state and federal agencies to improve stocks.
   - Aquarium and pet trades have resulted in NIS invasions at many places around the world.
   - Large-scale changes in current patterns may transport NIS into Alaskan waters. During 1998 the very strong El Niño along the eastern Pacific may have brought warm-water species much further north than their typical distribution. These shifts may also allow species transported by human activities to become established.

In many ecosystems, NIS invade over time as a series of vectors shift in importance, and this accumulation of NIS can result in major changes in the diversity and function of coastal ecosystems (Cohen & Carlton 1995).

1D. References

Carlton, J.T. 1979. History, biogeography, and ecology of the introduced marine and estuarine invertebrates of the Pacific coast of North America. Ph.D. Thesis, Univ. Calif., Davis. 904 pp.

Carlton, J.T. 1989. Man's role in changing the face of the ocean: biological invasions and the implications for conservation of near-shore environments. Conserv. Biol. 3(3): 265-273.

Carlton, J.T. and J. B. Geller. 1993. Ecological roulette: the global transport of nonindigenous marine organisms. Science 261: 78-82.

Carlton, J.T., D. Reid and H. van Leeuwen. 1995. The role of shipping in the introduction of nonindigenous aquatic organisms to the coastal waters of the United States (other than the Great Lakes) and an analysis of control options. Report to U.S. Coast Guard, Marine Environment Protection Division, Washington, DC. 215 pp.

Cohen, A.N. and J.T. Carlton. 1995. Nonindigenous aquatic species in a United States estuary: a case study of the biological invasion of San Francisco Bay and delta. Report to U.S. Fish & Wildlife Service, Washington, DC and National Sea Grant College Program, Connecticut Sea Grant. 246 pp.

Coles, S. L., R.C. DeFelice, L.G. Eldredge and J.T. Carlton. 1999. Historical and recent introductions of non-indigenous marine species into Pearl Harbor, Oahu, Hawaiian Islands. Mar. Biol. 135(1): 147-158.

Hallegraeff, G.M. and C.J. Bolch. 1992. Transport of diatom and dinoflagellate resting spores in ships' ballast water: implications for plankton biogeography and aquaculture. J. Plankton Res. 14: 1067-1084.

Hayward, B.W. 1997. Introduced marine organisms in New Zealand and their impact in the Waitemata Harbour, Auckland. Tane 36:197-223.

Hines, A.H., G.M. Ruiz, J. Chapman, J. Carlton and N. Foster. 1998. Biological invasions in cold-water coastal ecosystems: Ballast-mediated introductions in Port Valdez/Prince William Sound, Alaska. Progress Report to the Regional Citizens' Advisory Council of Prince William Sound.

Leppakoski, E. 1984. Introduced species in the Baltic Sea and its coastal ecosystems. Ophelia, suppl 3: 123-135.

Mills, E.L., J.H. Leach, J.T. Carlton and C.L. Secor. 1993. Exotic species in the Great Lakes: A history of biotic crises and anthropogenic introductions. J. Gt. Lakes Res. 19(1): 1-54.

Reise, K., S. Gollasch and W.J. Wolff. 1999. Introduced marine species of the North Sea coasts. Helgol. Meeresunters. 52: 219-234.

Ruiz, G.M., J.T. Carlton, A. H. Hines and E.D. Grosholz. 1997(a). Global invasions of marine and estuarine habitats by non-indigenous species: Mechanisms, extent, and consequences. Am. Zool. 37: 621-632

Ruiz, G.M. and A.H. Hines. 1997. Patterns of nonindigenous species transfer and invasion in Prince William Sound, Alaska: Pilot Study. Report Submitted to the Prince William Sound Citizens' Advisory Council. 80pp.

Ruiz, G.M., P. Fofonoff and A.H. Hines. 1999. Non-indigenous species as stressors in estuarine and marine communities: Assessing invasion impacts and interactions. Limnol. Oceanogr. 44(3, part 2): 950-972

Smith, L.D., M.J. Wonham, L.D. MCann, D.M. Reid, G.M. Ruiz and J.T. Carlton. 1996. Biological invasions by nonindigenous species in United States waters: Quantifying the role of ballast water and sediments. Parts I and II. Final Report to the U.S. Coast Guard and the U.S. Department of Transportation. 246 pp.

Smith, L.D., M.J. Wonham, L.D. McCann, G.M. Ruiz, A.H. Hines and J.T. Carlton. 1999. Invasion pressure to a ballast-flooded estuary and an assessment of inoculant survival. Biol. Invasions 1: 67-87.

Williams, R.J., F.B. Griffiths, E.J. Van der Wal and J. Kelly. 1988. Cargo vessel ballast water as a vector for the transport of non-indigenous marine species. Est. Coast. Shelf Sci. 26: 409-420.