INFLUENCES OF POLICY AND VESSEL BEHAVIOR ON THE RISK OF BALLAST-BORNE MARINE SPECIES INVASIONS IN COASTAL ALASKA

A Thesis

Presented to the Faculty of

Alaska Pacific University

In Partial Fulfillment of the Requirements

For the Degree of

Master of Science in Environmental Science

By

Danielle E. Verna

April 2014

____

Danielle Verna

Date________________________________

April 2014

INFLUENCES OF POLICY AND VESSEL BEHAVIOR ON THE RISK OF

BALLAST-BORNE MARINE SPECIES INVASIONS IN COASTAL ALASKA

by

Danielle Verna

THESIS

APPROVED: Thesis Committee

____________________________ ________________
Bradley Harris, Ph.D. Date
Chairperson
Alaska Pacific University

____________________________ ________________
Meagan Krupa, Ph.D. Date
Thesis Committee
Alaska Pacific University

____________________________ ________________
Kimberly Holzer, Ph.D. Date
Thesis Committee
Smithsonian Environmental Research Center

____________________________ ________________
Denny Lassuy, Ph.D. Date
Thesis Committee
North Slope Science Initiative

APPROVED: ____________________________ ________________
Tracy Stewart, Ph.D. Date
Academic Dean

ACKNOWLEDGEMENTS

I am extremely grateful to my advisor, Dr. Brad Harris, for his direction, advice, and insight. While pursuing thesis topics, securing partnerships, and navigating field work opportunities, I appreciated the flexible yet guided support that he provided. I am also very grateful for the advice and guidance of Dr. Meagan Krupa, Dr. Kimberly Holzer, Dr. Denny Lassuy, and Dr. Suresh Sethi, whose experience and expertise greatly strengthened my analysis.

I'd like to thank the Smithsonian Environmental Research Center for field and lab work opportunities, for providing essential data sets, and offering helpful guidance on data analysis, writing, and presentations: particularly Dr. Greg Ruiz, Dr. Mark Minton, Dr. Kimberly Holzer, and Dr. Jenny Carney.

In addition, I'd like to thank the faculty, staff and fellow students of APU for their aid and interest in my project, including all members of the Fisheries, Aquatic Science and Technology Lab for their positive support and morale.

I appreciate the help of my family and friends as well, who supported the notion of graduate school from the beginning and encouraged me throughout.

ABSTRACT

INFLUENCES OF POLICY AND VESSEL BEHAVIOR ON THE RISK OF BALLAST-BORNE MARINE SPECIES INVASIONS IN COASTAL ALASKA

By Danielle Verna

The risk of species invasions in coastal Alaska is increasing due to the continued growth of global shipping and the expansion of trans-arctic trade routes. Coastal Alaska receives about 14 million metric tons of ballast water annually from 49 global ecoregions, including several highly invaded port systems along the west coast of North America. This study reviews the history and drivers of ballast water management policy in the United States and the impacts of policy changes and vessel practices on the risk of ballast-borne species invasions to coastal Alaska. We assessed spatial and temporal trends in ballast water discharge and management practices of vessels arriving to Alaska as reported to the National Ballast Information Clearinghouse from 2005 – 2012. Notably, the Environmental Protection Agency's 2008 Vessel General Permit (VGP) triggered a sharp increase in reporting and an apparent 440% increase in total volume of ballast discharged between 2008 and 2009 by requiring previously exempted management and record keeping practices by crude oil tankers involved in coastwise trade, the dominant vessel type to discharge ballast in the state of Alaska. A vector-based risk assessment of post-VGP ballast water discharge to the top 15 ports of Alaska by volume indicates that the port of Valdez is most at risk of invasion. Klawock and Tolstoi Bay are least at risk. This is the first study to assess the risk of ballast-borne marine invasive species throughout coastal Alaska.

TABLE OF CONTENTS

LIST OF TABLES

Chapter 1

Chapter 2

LIST OF FIGURES

Chapter 1

Chapter 2

GENERAL INTRODUCTION

This study reviews the history and drivers of ballast water management policy in the United States and the impacts of policy changes and vessel practices on the risk of ballast-borne species invasions to coastal Alaska. The objectives are to (1) review the history of ballast water management policy in the United States from its inception to present day, (2) review ballast water discharge and management data reported to the National Ballast Information Clearinghouse for Alaska from 2005 through 2012, (3) assess the implications of policy changes and exemptions on vessel practices and reporting in Alaska, and (4) assess the risk of invasion to coastal Alaska based on environmental characteristics of vessel source and discharge locations, ballast water age, ballast water volume, and donor port species richness. The aim of this study is to provide novel data products and analyses to guide the development and assessment of risk adverse ballast management policy alternatives for coastal Alaska.

Initial ballast water management policy in the United States was developed in response to the invasion of zebra mussels and Eurasian ruffe in the Great Lakes during the 1980’s. Following the National Invasive Species Act of 1996, the first Coast Guard regulations on ballast water management and reporting were voluntary, but proved to be ineffective for tracking vessel behavior. By late 2004, ballast water management and reporting was mandatory, but crude oil tankers involved in coastwise trade, the dominant vessel type arriving in Alaska, were exempted. Regulation of these vessels was eventually included in the Environmental Protection Agency’s 2008 Vessel General Permit (VGP). As a result, there was an apparent 440% increase in ballast water discharge volume to Alaska between 2008 and 2009, which was largely comprised of coastwise ballast to the port of Valdez. Between 2009 and 2012 discharge volume remained stable at nearly 14 million metric tons, indicating that this spike reflects changes in regulation.

As a result of this important change in policy and its clear impacts on vessel reporting effort in Alaska, we developed a risk assessment framework focused on post-VGP data from 2009 through 2012. Our framework builds upon other high-latitude risk assessments in Canada, Norway, and the Baltic Sea and identifies relative hotspots of invasion based upon factors known to influence the likelihood of invasion success. The resulting risk matrix for the top 15 ports of Alaska by ballast discharge volume facilitates modeling current multi-factor invasion risk and considering their practical management implementation.

CHAPTER 1

REVIEW OF UNITED STATES BALLAST WATER MANAGEMENT POLICY AND ASSOCIATED IMPLICATIONS FOR ALASKA

1. INTRODUCTION

Marine species have been transported globally since the days of sailing ships. Organisms were attached to or buried inside wooden hulls or stowed away on dry ballast such as coastal rocks, sand or gravel. As shipping evolved into a prominent means of transportation and exploration, the number, size and speed of vessels transiting the oceans rose dramatically, increasing opportunities for marine hitchhikers. The development of steam technology and steel-hulled vessels signified yet another major turning point in the transport of marine species – seawater as ballast. From a shipping standpoint, ballast water is logistically simple, efficient, and universally available. Yet for its advantages, ballast water quickly became a primary vector for the relocation of marine species (Carlton & Geller, 1993). The introduction of alien marine species via ship ballast has had biological, economic and social consequences on ecosystems worldwide (Ruiz *et al*., 2000, Pimentel *et al*., 2005, Pysek & Richardson, 2010). Unfortunately, although recognized as a problem for at least the past 100 years, the management of ballast water for the prevention of marine invasive species was and continues to be a slow and reactionary process (Firestone & Corbett, 2005, Gollasch *et al*., 2007).

In the United States, ballast water management (BWM) regulations evolved from limited and voluntary to widespread and mandatory (Figure 1.1). As global and national awareness of the hazards associated with marine invasive species rose, in addition to the risks posed by continued invasions, so did the strength and reach of BWM requirements for the shipping industry. However, exemptions to policy allowed specific vessel types and vessel transits to elude these requirements, affecting some port systems more than others.

In particular the state of Alaska has seen firsthand the implications of these policy exemptions. The majority of ballast water discharged in Alaska has historically been unmanaged – compounded by young age and uneven spatial distribution of discharge locations. Ballast reporting data suggest a relationship between policy and vessel practices. However, Alaska-bound vessel traffic patterns and ballast management efforts have not been analyzed since 2004 (McGee *et al*., 2006). Since then, there have been significant improvements in data quality, quantity and continuity allowing for a more thorough assessment of ballast water discharge and management practices in ports and places throughout the state.

The objectives of this paper are to (1) review the history of BWM policy in the United States from its inception to present day, (2) review ballast water discharge and management data for Alaska from 2005 through 2012, and (3) assess the implications of policy changes and exemptions on vessel practices and reporting effort in Alaska. The aim of this study is to provide original data products and analyses to inform ballast water management practices to minimize invasion risks and influence relevant policy actions for coastal Alaska.

2. POLICY REVIEW

2.1. EARLY STAGES

The United States first took action against ballast water transfer of marine invasive species with the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA). Passage of NANPCA was spurred by the introduction and rapid spread of zebra mussels (*Dreissena polymorpha*) and Eurasian ruffe (*Gymnocephalus cernuus*) throughout the Great Lakes and surrounding river systems (NANPCA Sec. 1002(a)(3) and Sec. 1002(a)(10)). Zebra mussels have since altered the ecosystem structure of invaded waters by reducing phytoplankton populations, increasing water clarity, and intensifying fouling (MacIsaac, 1996). Biofouling of drinking water treatment and electric power generation facilities alone was estimated to cost $267 million between 1989 and 2004 (Connelly *et al*., 2007). The Act aimed to stop the spread of aquatic nonindigenous species via ballast water and other vectors, promote research of prevention and control methods, and minimize the impacts of established species, both ecologically and economically (Sec. 1002(b)). The Act focused heavily on implementing programs to study the eradication and control of zebra mussels in the Great Lakes. NANPCA required the establishment of voluntary guidelines and regulations for ballast water exchange by vessels entering the Great Lakes (Sec. 1101(a)), but as originally implemented, the Act did not include ballast water exchange guidelines for coastal areas of the United States other than the Great Lakes region.

NANPCA did, however, take an important step towards national ballast water control by establishing the Aquatic Nuisance Species Task Force (ANSTF) (Sec. 1201). The ANSTF was comprised of the heads of at least six federal agencies with interest in and influence over the spread of invasive species. The purpose of the ANSTF was to design a plan to prevent the introduction and spread of aquatic nuisance species in waters of the United States by investigating the need for a national BWM program (Sec.

1102(a)). Members of the ANSTF were instructed to research and monitor the effects and impacts of these species and subsequent control methods, with emphasis placed upon the zebra mussel (*D. polymorpha*). Education was also a large part of the ANSTF agenda (Sec. 1202(h)). Target audiences included pertinent state entities, businesses, and the general public, such as boaters and anglers. ANSTF goals remain relatively unchanged today, although the breadth of target species and participating agencies has grown as awareness and regulatory influence expanded over time.

At the global scale, initial efforts by the International Maritime Organization (IMO) to combat marine invasive species occurred at roughly the same time as those by the United States. The first attempt at such guidelines began in 1991 with the Marine Environment Protection Committee's (MEPC) voluntary "Guidelines for Preventing the Introduction of Unwanted Organisms and Pathogens from Ships' Ballast Waters and Sediment Discharges" (GloBallast, 2014). The IMO adopted the MEPC's guidelines in 1993. In 1997 these guidelines were updated and re-adopted by the MEPC and IMO as the "Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens." Out of practicality and a realization of the limitations of management options available at the time, between 1993 and 1997 focus shifted from preventing to minimizing species transfer via ballast water (Gollasch *et al.*, 2007). The new guidelines were recommended for use by all maritime nations and included advice on methods of avoiding the transfer and discharge of marine invasive species (Firestone & Corbett, 2005).

2.2. A BROADER REACH

Further aquatic invasion in the United States by the mitten crab (*Eriocher sinensis*), green crab (*Carcinus maenas*) and brown mussel (*Perna perna*) warranted amending and broadening the reach of NANPCA into the National Invasive Species Act (NISA) of 1996 (NISA, 1996). Attention was now drawn to other coasts of the United States, but focus remained largely on the transport of invasive species via ballast water. NISA required the issuance of *voluntary* guidelines "to prevent the introduction and spread of nonindigenous species in waters of the United States by ballast water operations and other operations of vessels equipped with ballast water tanks" (NISA Sec. 1101(c)(1)). These guidelines applied to all vessels operating in waters of the United States containing ballast water tanks. Any vessel that operated outside of the exclusive economic zone[1] (EEZ) was directed to exchange their ballast water or to use an “environmentally sound alternative ballast water management” method (Sec. 1101(c)(2)(D)). The Act required that records be collected from vessels to determine compliance with the voluntary guidelines and include the location and thoroughness of each ballast exchange (Sec. 1101(c)(2)(F)). Within three years and every subsequent three years, the Task Force was required to assess vessel compliance rates and the effectiveness of the guidelines in reducing the “introduction and spread of aquatic nuisance species” (Sec. 1101(e)).

NISA included a number of exemptions to these guidelines. First, a safety exemption to be applied at the Master’s discretion – if the act of exchanging ballast water threatened the safety of the vessel and her crew, exchange was not required and the vessel was not restricted from discharging ballast in the next port of call (Sec. 1101)(k)). Second, passenger vessels containing ballast water treatment systems were exempt, unless ballast water exchange was deemed to be a more effective method of reducing the transfer risk of invasive species (Sec. 1101(c)(2)(K)). Third, an exemption was included in Section 1101(c)(2)(L), wherein the voluntary guidelines did not apply to crude oil tankers engaged in coastwise trade. The Act did not provide an explanation for this exemption. However, the Act did include a subparagraph within the Safety Exemption subsection (Sec. 1101(k)) requiring a Crude Oil Tanker Ballast Facility Study. This study was to be initiated within 60 days of the enactment of NISA and submitted to Congress no later than October 1, 1997. The study aimed to determine the “effectiveness of existing shoreside ballast water facilities used by crude oil tankers in the coastwise trade off Alaska” in the prevention of the introduction of aquatic invasive species (Sec. 1101(k)(3)). The study was also directed to determine the feasibility and cost of improving these facilities to increase their effectiveness if deemed necessary.

Results of the study, dated December 4, 1997, indicated preliminary risk of invasive species from ballast water discharged in Prince William Sound, Alaska. The study focused on the arrival of tankers at Port Valdez during a two-week time period in the spring of 1997. At that time, many tankers carried ballast water in both segregated ballast tanks and cargo tanks. Ballast in segregated tanks was discharged directly into Prince William Sound, while ‘dirty’ ballast from cargo tanks was discharged to the Alyeska Ballast Water Treatment Facility. Unmanaged ballast water discharged from

---

[1] As defined in 33 CFR 151.1504, for the purpose of ballast water management the exclusive economic zone is considered to be the area extending outward 200 nautical miles from the baseline of the United States and the equivalent zone of Canada.

segregated tanks and sourced in domestic ports was found to positively influence the risk of successful invasion. Risk of invasive species from ballast in non-segregated tanks was considered low as species diversity and abundance was found to be nominal in both the tanks and in the treatment facility (Ruiz & Hines, 1997).

As a result of the requirements outlined in NISA, the United States Coast Guard (USCG) initiated voluntary BWM guidelines for any vessel (foreign or domestic) entering United States waters after operating beyond the EEZ. On April 10, 1998, the USCG published Notice of Proposed Rule Making "Implementation of the National Invasive Species Act of 1996" and on May 17, 1999, published an interim rule with an effective date of July 1, 1999. Although the management guidelines were voluntary, vessels subject to this rule were required to submit a ballast water reporting form, regardless of their BWM actions. Reporting was necessary to track vessel participation in the voluntary program and it was made explicitly clear that if participation was insufficient to determine the success of the program, BWM could become mandatory. Data collected from the reports were used to create a database of ballast discharge information in the United Sates, now known as the National Ballast Information Clearinghouse (NBIC). The rule provided an exemption from its mandatory elements, including reporting, for all vessels involved in coastwise trade[2] and for passenger vessels equipped with treatment systems. After addressing public comments, the USCG published its final rule on November 21, 2001, with an effective date of December 21, 2001 (Implementation of the National Invasive Species Act of 1996, 2001).

Concurrent with the USCG's initiation of BWM guidelines, on February 3, 1999, President Clinton signed Executive Order 13112. The Executive Order defined invasive species as "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health", and required all Federal agencies to identify current actions that were or could be related to the status of invasive species and take measures to mitigate these actions and respond to introductions. Agencies were required to research and provide education to the public about invasive species and response efforts. To direct and assist with these requirements, an Invasive Species Council was created and co-chaired by the Secretaries of the Interior, Agriculture, and Commerce. Within 18 months of the issuance of the Executive Order the Council was required to create a National Invasive Species Management Plan recommending

---

[2] As described in 46 USC 551, coastwise trade is the transport of merchandise, passengers, etc. between coastwise points in the United States; see section 55101 for applicability.

specific goals and actions for Federal agencies, taking into account specific measures identified by each agency. The first Management Plan was also required to identify existing and potential vectors for the introduction of invasive species and address means to minimize the risk posed by those vectors.

2.3. EFFORTS TOWARD MANDATORY MANAGEMENT

Following a two-year period, the United States' voluntary BWM program proved to be unsuccessful. A 2002 report to Congress by the USCG and NBIC relayed a reporting compliance rate of only 30.4%; of those reporting vessels discharging ballast water only 51.2% performed ballast water exchange (USCG, 2001). As a result the USCG took two substantial steps towards mandatory BWM by (1) shifting from a voluntary to a mandatory BWM program and requiring all vessels with ballast tanks, rather than solely those vessels entering U.S. water from beyond the EEZ, to submit BWM reports and (2) imposing penalties for noncompliance. On January 6, 2003, the USCG published Notice of Proposed Rulemaking "Penalties for non-submission of Ballast Water Management Reports". The final rule was published on June 14, 2004, with an effective date of August 13, 2004. On July 30, 2003, the USCG published Notice of Proposed Rulemaking "Mandatory Ballast Water Management Program for U.S. Waters." The final rule was published on July 28, 2004, with an effective date of September 27, 2004.

The mandatory BWM program applied to all vessels with ballast water tanks that entered United States waters after operating outside the EEZ. Vessels were required to manage their ballast via one of three methods: (1) ballast water exchange in water 200 nautical miles or more from shore, (2) retention of ballast water, or (3) use of an alternative Coast Guard approved BWM method (Mandatory Ballast Water Management Program for U.S. Waters, 2004). Ballast water exchange could be conducted via empty/refill or flow-through methods. Vessels were not required to delay or alter transit course in order to conduct ballast exchange. If the vessel did not transit beyond 200 nautical miles or deemed exchange to be a safety concern the vessel was not restricted from discharging the necessary volume of ballast as required for normal operations (other than in the Great Lakes or Hudson River). This rule was written with the understanding that exchange would be the most viable option for conducting BWM as retention of ballast water would prohibit many vessels from loading cargo and at the time there were no Coast Guard approved alternative BWM methods. The BWM reporting requirements were expanded to include “all vessels operating in United States waters bound for ports or places in the United States…regardless of whether they operated outside of the EEZ” (Penalties for non-submission of Ballast Water Management Reports, 2004). Exemptions from the BWM, reporting, and recordkeeping requirements were again made for crude oil tankers involved in coastwise trade, plus Department of Defense and Coast Guard vessels, and for vessels operating within one USCG Captain of the Port (COTP) Zone (33 CFR 151.2015). Violations to these rules were punishable by a civil penalty of up to $27,500 per violation per day, with knowing violators guilty of a class C felony. The monetary portion of this penalty has since been increased to a maximum of $35,000 (33 CFR 151.2080). The mandatory nature of these rules represents a significant expansion of the United States’ effort to control the transport of marine invasive species via ballast water.

Internationally, initial IMO efforts resulted in a similar outcome as those in the United States. Although an important first step, the voluntary nonbinding Guidelines were insufficient and continued impacts of invasions warranted stronger action. For example, the invasion of the comb jelly (*Mnemiopsis leidyi*) in the Black Sea and the northern Pacific seastar (*Asterias amurensis*) in Australia each had devastating effects on natural biota and wreaked havoc on local economies (Ross *et al*., 2002, Knowler, 2005). On February 13, 2004, the IMO adopted the “International Convention on the Control and Management of Ship’s Ballast Water and Sediments.” The purpose of the Convention was to further minimize and eventually eliminate the risk of marine invasive species transfer via ballast water (Gollasch *et al*., 2007). To achieve this goal the Convention required all vessels to implement a Ballast Water Management Plan and adhere to strict management standards. The Convention established two standards of management: (1) Regulation D-1, the ballast water exchange standard, and (2) Regulation D-2, the ballast water performance standard. D-1 required a minimum ballast water exchange volume of 95%, while the more stringent D-2 established a threshold for the concentration of organisms allowed in ballast water discharge. The D-2 standard required ballast water discharge to contain:

- Less than 10 viable organisms per cubic meter greater than or equal to 50 μm in minimum dimension
- Less than 10 viable organisms per milliliter less than 50 μm in minimum dimension and greater than or equal to 10 μm in minimum dimension

- Less than the following concentrations of indicator microbes, as a human health standard:
  - Toxigenic *Vibrio cholerae* (O1 and O139) with less than 1 colony forming unit (cfu) per 100 milliliters or less than 1 cfu per 1 gram (wet weight) zooplankton samples
  - *Escherichia coli* less than 250 cfu per 100 milliliters
  - Intestinal *Enterococci* less than 100 cfu per 100 milliliters (IMO, 2004)

The Convention, which has yet to enter into force, will do so 12 months after ratification by 30 States representing not less than a combined 35% of the world's merchant shipping gross tonnage. As of November 2013, 38 States and 30.38% of the world's tonnage had ratified the Convention. Once ratified, regulations D-1 and D-2 will be implemented on a phased schedule based on age and ballast water capacity of each vessel, with all vessels eventually required to meet the D-2 standard (GloBallast, 2014).

Around the same time, in an attempt to explore ballast water management systems for use and approval by the United States, the USCG initiated the Shipboard Technology Evaluation Program (STEP) in 2004 (USCG, 2004). STEP is a voluntary program open to any vessel, foreign or domestic, subject to USCG BWM regulations. In order to provide incentive for the development and use of ballast water management systems, the USCG allowed vessels enrolled in STEP to be grandfathered in to any future, potentially more stringent, ballast water discharge standards so long as the experimental treatment system was functioning properly. There are currently four vessels enrolled in STEP, operating four ballast water treatment systems (USCG, 2013). One of these vessels, tanker S/R American Progress, commonly arrived in the port of Valdez, Alaska to export crude oil to refineries on the west coast of the United States.

2.4. INCREASED DOMESTIC REGULATIONS

Regulation of BWM in the United States expanded to include involvement of the Environmental Protection Agency (EPA) in 2008 by the issuance of the Vessel General Permit (VGP). The VGP provided authorization for "discharges incidental to the normal operations of a vessel" under the National Pollutant Discharge Elimination System (NPDES) of the Clean Water Act (CWA), including ballast water (EPA, 2009). The EPA had historically excluded such discharges from permitting, beginning with an initial exclusion in 1973 following the enactment of the CWA. The wording of the exclusion was finalized in 1979 (40 CFR 122.3(a)) and remained unchallenged for the next twenty years (EPA, 2008). In January 1999 a group of environmental organizations, led by the Pacific Environmental Advocacy Center, submitted a petition to repeal 40 CFR 122.3(a) based on its exclusion of ballast water discharge from NPDES permitting, stating that vessels were point sources of discharge and therefore EPA did not have the authority to exclude them (EPA, 2003). The EPA denied the petition in September 2003. As a result of the denial several groups, led by Northwest Environmental Advocates, filed a complaint in the U.S. District Court for the Northern District of California in December 2003. EPA argued that Congress had repeatedly accepted the breadth of the NPDES program as it was written and had subsequently taken several actions (NANPCA 1990, NISA 1996) to combat the spread of invasive species via ballast water without using the CWA as a tool. The responsibility for enforcing these regulations was given to the USCG. Nevertheless, the U.S. District Court ruled in favor of the plaintiffs in March 2005, asserting that EPA had exceeded their authority under the CWA by providing an exclusion for discharges incidental to the normal operations of a vessel from NPDES permitting (EPA, 2008). The Ninth Circuit Court of Appeals upheld this decision in July 2008. In response, Congress passed the Clean Boating Act of 2008 stating that recreational vessels are not subject to NPDES permitting requirements for discharges incidental to the normal operations of a vessel, not including any vessel subject to USCG inspection that “is engaged in commercial use or carries paying passengers” (CBA, 2008). Regardless of Congress’s efforts, the VGP was to have a significant impact on the regulation of ballast water, particularly for coastwise vessels.

The VGP went into effect on December 19, 2008, except for Alaska and Hawaii where it went into effect on February 6, 2009. The VGP required vessels that had taken on ballast water within 200 nautical miles from shore and that would operate outside of the EEZ to exchange their ballast outside of 200 nautical miles (VGP 2.2.3.5, 2008). Similarly, as allowed by the USCG, exemptions from BWM requirements were made for vessels operating within one USCG COTP Zone, vessels using a USCG-approved alternative BWM method, vessels that retained their ballast water, and when the Master of the vessel determined exchange was unsafe (VGP 2.2.3.11, 2008). Again vessels were not required to delay transit or alter course to perform BWM. However, unlike NISA and the USCG no exemption was made for crude oil tankers involved in coastwise trade. The exemption from BWM, recordkeeping and reporting requirements for crude oil tankers involved in coastwise trade was written in NISA 1996, which controlled future regulations by the USCG. The EPA's VGP was not required by NISA and therefore was not mandated to include similar exemptions.

The VGP also contained special requirements for vessels engaged in Pacific nearshore voyages (VGP 2.2.3.6, 2008). These vessels were defined as those involved in the Pacific coastwise trade, those transiting between Pacific coast ports that travelled through multiple COTP Zones, and those from foreign (non-U.S.) ports that did not travel outside of 200 nautical miles from shore that would discharge ballast off the U.S. west coast or Alaska. Vessels meeting this description that took on ballast less than 50 nautical miles from shore were required to exchange their ballast outside of 50 nautical miles in waters more than 200 meters deep. These vessels were required to conduct ballast water exchange outside of 200 nautical miles if their voyage took them to that distance for a sufficient period of time.

The VGP also added an additional requirement for vessels with empty ballast tanks or tanks containing residual ballast water that could not be pumped out (VGP 2.2.3.7, 2008). Vessels were required to seal these tanks so that no water could be taken on or discharged from them or the vessel was required to conduct saltwater flushing. Saltwater flushing is the process of adding ocean water to an empty ballast tank, allowing it to mix with residual water in the tank via the natural roll of the vessel, and discharging the mixed water. Vessels were required to flush their tanks outside of 200 nautical miles, except for vessels engaged in Pacific nearshore voyages where they were required to flush their tanks outside of 50 nautical miles in waters more than 200 meters deep (VGP 2.2.3.8, 2008).

With the exception of requirements for Pacific nearshore voyages and saltwater flushing, VGP BWM requirements were very similar to USCG requirements. Both the USCG and EPA required vessels to be aware of ballast water uptake and discharge location by avoiding such areas as marine sanctuaries, coral reefs, shallow waters, major current boundaries, sewage outfalls, and algal blooms (33 CFR 151.2050, VGP 2.2.3.3, 2008). Record keeping requirements were also duplicative, including ballast water information such as total ballast capacity, total ballast onboard, and BWM location and volume. The VGP differed slightly in that all vessels subject to its authority were required to maintain records.

2.5. CURRENT REGULATIONS

Less than a year after the 2008 VGP, the USCG took BWM regulations in the United States to the next level, following the lead of the 2004 IMO Convention standards. The United States has built regulations parallel to the Convention to include similar discharge standards for vessel ballast water management systems. However, as of December 2013 the United States has yet to ratify the Convention. Although the United States remains involved in the development of the IMO Convention it is unlikely to ever become a signatory due to concerns of potential compromises to national authority and sovereignty (M. Tamburri, Director, Maritime Environmental Resource Center, personal communication, September 11, 2013). The alignment of IMO and USCG regulations allows vessels to prepare for a single discharge standard regardless of Convention status.

On August 28, 2009, the USCG published Notice of Proposed Rulemaking "Standards for Living Organisms in Ships' Ballast Water Discharge in U.S. Waters." This rule would require all vessels operating in waters of the United States "bound for ports or places in the U.S." and equipped with ballast tanks to use a USCG approved ballast water management system, replacing the use of ballast water exchange as the primary means of BWM. Ballast water management system approval would in part be based on the ability to meet a standard for the number of organisms discharged per unit of ballast water. The USCG proposed a two-phase ballast water discharge standard. Phase-one discharge standard matched the IMO D-2 standard (discharge less than 10 organisms per cubic meter of organisms larger than 50 microns; discharge less than 10 organisms per milliliter of organisms 50 microns or smaller but larger than 10 microns, plus additional requirements for bacteria and viruses). Phase-two was 1,000 times more stringent than the phase-one standard (discharge less than 1 organism per 100 cubic meters of organisms larger than 50 microns; discharge less than 1 organism per 100 milliliters of organisms 50 microns or smaller but larger than 10 microns, plus additional requirements for bacteria and viruses). Requirements for the more stringent phase-two standard were targeted at encouraging technological advances in ballast water management systems. Phase-one and phase-two programs were to be implemented over time based on vessel ballast water capacity. The rule would apply to all vessels that discharged ballast water into waters of the United States and, consistent with the language of NISA 1996, provided exemptions for crude oil tankers involved in coastwise trade, Department of Defense and USCG vessels, and vessels operating within one

USCG COTP Zone. Consideration of whether a vessel operated outside of the EEZ was no longer a factor.

On March 23, 2012, the USCG published its final rule on ‘Standards for Living Organisms in Ships’ Ballast Water Discharged in U.S. Waters’ with an effective date of June 21, 2012. In response to public comment, the final rule differed significantly from the proposed rule. Specifically, the final rule removed the phase-two discharge standard, with the caveat that upon additional research, analysis and technological developments the USCG would issue an additional rule establishing a more stringent ballast water discharge standard. The final rule also addressed applicability: all vessels that were previously required to conduct ballast water exchange and also “seagoing vessels that do not operate beyond the U.S. EEZ, that take on and discharge ballast water in more than one COTP Zone, and are greater than 1,600 gross register tons” were required to install and operate an approved ballast water management system (Standards for Living Organisms in Ships’ Ballast Water Discharge in U.S. Waters, 2012). An exemption remained in place for crude oil tankers involved in coastwise trade, Department of Defense and USCG vessels, and vessels operating within one USCG COTP Zone from BWM, reporting and recordkeeping requirements. Although the implementation schedule required all new vessels constructed on or after December 1, 2013, to comply with the ballast water discharge standard and other vessels to comply by future dates based on ballast water capacity, the USCG has yet to type approve any ballast water management systems.

However, in the interim the USCG has allowed vessels to install “alternate management systems” (AMS) – ballast water management systems that are type approved by foreign administrations in accordance with IMO standards. The AMS must be submitted to the USCG for review and approval, but that process is expected to take less time than USCG type approval and should therefore allow vessels to install ballast water management systems in accordance with required implementation dates (Standards for Living Organisms in Ships’ Ballast Water Discharge in U.S. Waters, 2012). If installed prior to the required implementation date, vessels may use the AMS for up to five years from that date (33 CFR 151.2026). During the five years the system will ideally be approved by the United States using testing already conducted by the foreign administration or additional testing as required by the final rule, allowing the vessel to continue to operate the system. As of December 2013 the USCG has approved nearly thirty AMS.

More stringent EPA ballast water management requirements were quick to follow those issued by the USCG. Following a draft permit issued in 2011, the EPA signed the final version of the 2013 VGP on March 23, 2013. The 2013 VGP took effect December 19, 2013, when the 2008 VGP expired, for a period of five years. The EPA matched the IMO D-2 and USCG phase-one ballast water discharge standards by establishing Ballast Water Numeric Discharge Limitations (VGP 2.2.3.5, 2013). To meet this limit, vessels can pursue one of four options: (1) use of a ballast water treatment system (2.2.3.5.1.1), (2) onshore treatment of ballast water (2.2.3.5.1.2), (3) use of a public water supply (U.S. or Canadian) as ballast (2.2.3.5.1.3), or (4) by not discharging ballast water (2.2.3.5.1.4). Vessels on short-distance voyages, e.g. vessels operating within one USCG COTP Zone and vessels not traveling more than 10 nautical miles and not crossing a physical barrier regardless of COTP Zones, were exempt from meeting the discharge limit. Parallel to the USCG requirement, the EPA also provided an exemption for vessels less than 1600 gross registered tons. Once again, as in the 2008 version, the VGP required crude oil tankers involved in coastwise trade to comply with EPA ballast water management requirements.

The VGP requirement for crude oil tankers involved in coastwise trade to manage their ballast water was a major development for Alaska. The State of Alaska relies solely on national standards to manage ballast water discharge within its waters. Although the risk of marine invasive species associated with ballast water discharge was covered in the 2002 Alaska Aquatic Nuisance Species Management Plan, there has yet to be any development of state-specific BWM regulations. Much of the ballast water discharged to Alaska originates on the Pacific coast of North America from California to British Columbia, providing opportunity for the relocation of species from highly invaded marine ports, such as San Francisco Bay (NBIC 2008).

3. IMPLICATIONS FOR ALASKA

A review of ballast water discharge and management data for ports and places in Alaska from 2005 through 2012 from the NBIC reveals dominant source and discharge locations and the impacts of policy changes on vessel reporting over time. 2005 was the first complete year in which ballast water management and discharge reporting was mandatory in the United States for all vessels (with exceptions, see ‘Efforts Toward Mandatory Management’ section above). As defined by NBIC, ballast water was considered ‘overseas’ if it traveled beyond the exclusive economic zone and ‘coastwise’ if it did not. The data were summarized to characterize the number of discharging vessels, the volume and source of discharged ballast water, ballast water age, and ballast water management activities on a per tank level. The behavior of dominant vessels types was also reviewed. Data were summarized per marine ecoregion of Alaska (see Figure 1.2, sensu Spalding *et al*. 2007) and per port (see Figure 1.3).

3.1. VESSELS

3.1.1. Arrivals

A total of 18,638 vessels reported arriving in Alaska from 2005 through 2012. Annual average arrivals fluctuated only slightly (2330 ± 1.2 (SE)). Nearly half (48%) of all arrivals were passenger vessels, followed by tankers (15%), container vessels (11%), others (11%), reefers (6%), roll-on/roll-off vessels (4%), bulkers (4%), general cargo (1%), and one combination vessel. Half of these vessels (50%) arrived in ecoregion 55 (North American Pacific Fjordland) which includes major ports in southeast Alaska such as Ketchikan (3290 arrivals), Juneau (2798 arrivals), Skagway (1753 arrivals), and Sitka (595 arrivals). The second most abundantly visited location (37% of arrivals), was ecoregion 54 (Gulf of Alaska), including ports in southcentral Alaska such as Anchorage (1862 arrivals) and Valdez (1630 arrivals). Ecoregion 53 (Aleutian Islands) received 11% of arrivals, represented largely by the port of Dutch Harbor (2001 arrivals). The last port of call for 82% of these vessels was in the United States, 10% arrived from Canada, 3% arrived from each of Japan and South Korea, 1% arrived from China, and the remaining 1% arrived from a variety of international ports.

3.1.2. Discharging arrivals

Refining the analysis to include only those vessels discharging ballast in Alaskan coastal waters reveals a contrast in dominant vessel type and affected ports. From 2005 through 2012, 3773 unique arrivals reported discharging 7.5 x10^7 metric tons (MT) of ballast water to Alaska. The majority (80.5%) of ballast water discharge was coastwise, while less than one-quarter (19.3%) was overseas. Nearly half of all discharging vessels were tankers (49%), followed by bulkers (15%), others (12%), passenger vessels (11%), reefers (9%), general cargo (2%), container vessels (2%), and one each combination, roll-on/roll-off, and unknown vessel (Figure 1.4).

Tankers (1,844 discharging arrivals) and bulkers (570 discharging arrivals) accounted for 99% of discharged ballast; although the volume attributed to each of these vessel types differed by an order of magnitude. Tankers discharged 6.6 x10^7 MT (88%) while bulkers discharged 8.0 x 10^6 MT (11%). Most of the ballast (92%) was discharged to ecoregion 54 (Gulf of Alaska), largely to Prince William Sound (1.6 x 10^6 MT) and the ports of Valdez (5.8 x 10^7 MT), Nikiski (5.8 x 10^6 MT), and Seward (2.1 x 10^6 MT) but also to Drift River Terminal (6.2 x 10^5 MT), Afognak (5.4 x 10^5 MT), and Anchorage (1.2 x 10^5 MT). Ecoregion 13 (Chukchi Sea) received 4.5% of discharged ballast, primarily to the Red Dog port facility (3.1 x 10^6 MT). Ecoregion 55 (North American Pacific Fjordland) received 2.1% of discharged ballast to locations such as Hawk Inlet (4.7 x 10^5 MT), Hydaburg (3.8 x 10^5 MT), Ketchikan (2.2 x 10^5 MT), and Skagway (1.1 x 10^5 MT) (Figure 1.5).

3.2. BALLAST WATER

3.2.1. Source

Most of the ballast water discharged to Alaska originated on the west coast of North America. The dominant source was ecoregion 56 (Puget Trough/Georgia Basin; 38%), followed by ecoregion 58 (Northern California; 23%), ecoregion 59 (Southern California Bight; 8%), and ecoregion 57 (Oregon, Washington, Vancouver Coast and Shelf; 3%). Ballast water was also transported within Alaska; 6% of discharged ballast originated in ecoregion 54 (Gulf of Alaska). The largest contributions of ballast water from trans-Pacific voyages originated in ecoregion 51 (Central Kuroshio Current; 10%), followed by ecoregion 50 (Yellow Sea; 2%), ecoregion 52 (East China Sea; 2%), and ecoregion 49 (Sea of Japan; 1%).

Of the total 6.9 x 10^7 MT of ballast water discharged to ecoregion 54 (Gulf of Alaska), 78% was sourced from 4 ecoregions on the west coast of North America: 56 (2.8 x 10^7 MT), 57 (2.1 x 10^6 MT), 58 (1.7 x 10^7 MT), and 59 (6.1 x 10^6 MT). Ecoregion 51 was the source for 7.4% of ballast water discharge to ecoregion 54 (5.1 x 10^6 MT). Within ecoregion transport of ballast was also noticeable, as 6.5% of ballast discharged in ecoregion 54 was also sourced there (4.5 x 10^6 MT).

Major sources of ballast water for tankers were ecoregions 56 (43%), 58 (27%), 59 (9%) and 54 (7%). The proximity of these ecoregions to Alaska resulted in 90% coastwise ballast water discharge from tankers. These coastwise vessels mostly called on the port of Valdez, the largest recipient of ballast in Alaska (Figure 1.6). In contrast, 96% of bulker ballast water discharge originated overseas and was sourced primarily in ecoregions 51 (25%), 50 (23%), 52 (18%), 49 (8%), and 48 (6%). For example, the port of Red Dog receives primarily overseas ballast from bulkers (Figure 1.7). In comparison, Dutch Harbor received ballast from a variety of source locations, mostly throughout the North Pacific Ocean (Figure 1.8).

4.2.2. Age

The average age of discharged ballast water was 10.7 (± 0.1 SE) days, ranging from zero to 427 days. Tankers and passenger vessels had on average the youngest ballast water at 7.6 and 7.7 days respectively, while the age of ballast discharged by bulkers averaged 16.8 days. Ecoregion 54 received the youngest ballast water, 8.7 days on average, followed by ecoregion 13 (13.3 days), 55 (17.8 days), 14 (31.8 days), 53 (35.2 days), and 12 (96 days) (Figure 1.9).

3.2.3. Management

By volume only 33% of ballast water discharged in Alaska from 2005 through 2012 was reported to be managed. Coastwise vessels reported managing only 27% of their ballast water, while overseas vessels reported managing 62%. Over half (66%) of managed ballast was exchanged via empty-refill, followed by 27% via flow-through, and 7% via an alternate method. Only 26% of ballast water discharged by tankers was reported to be managed, compared to 90% of ballast discharged by bulkers.

3.3. INFLUENCE OF THE VGP

Regulatory changes were reflected by fluctuations in reported ballast water discharge volumes and management practices. The volume of reported ballast discharge decreased between 2005 and 2008, rose dramatically in 2009 (440%), and remained relatively steady through 2012 (Figure 1.10). The increase in ballast discharge between 2008 and 2009 was largely coastwise ballast water, from 9.6×10^5 MT in 2008 to 1.2×10^7 MT in 2009 (1095%), as compared to overseas ballast which saw only a 17% increase. Most of this ballast water was discharged to ecoregion 54, which saw an “increase” of 1.9×10^6 MT to 1.3×10^7 MT (92% increase in coastwise ballast, 13% increase in overseas ballast). At the same time, the number of reporting tankers increased from 85 to 295 vessels (347%). Most of these vessels arrived to Valdez, which saw an increase from 47 to 258 (549%) discharging tankers. This suggests that by requiring crude oil tankers involved in coastwise trade to manage and keep records of their ballast water, the EPA’s VGP triggered a sharp increase in reporting and thus an apparent 440% increase in total volume of ballast between 2008 and 2009. This also calls into question the degree to which reporting data prior to 2009 reflect actual fleet behavior. Interestingly, ballast management rates showed the largest growth prior to the implementation of the VGP, increasing from 19% managed ballast water in 2007 to 38% in 2008. Rates peaked at 41% during 2009 and remained relatively steady through 2012 (Figure 1.11).

4. DISCUSSION

The management of ballast water to reduce introductions of marine invasive species has progressed substantially since efforts first began nearly 25 years ago. The severe economic and biological impacts of species introductions in the Black Sea, Great Lakes, and waters of Australia triggered the implementation of policies that resounded on a global scale. Ballast water exchange has become routine practice, and over time been adopted by nearly all vessels equipped with ballast tanks. Litigation by concerned conservation organizations triggered expanded regulations in the United States and importantly the inclusion of previously exempted vessels. Development of ballast water management systems marked a shift toward quantitative metrics of compliance. Use of these technologies will allow for a global standard of organism densities and prevalence in the discharged ballast water of ships. Unfortunately much of this policy occurred as a reaction to invasion and implementation remains a slow process. Meanwhile, marine invasions continue to occur on a global scale.

The aforementioned issues notwithstanding, ballast water exchange and proposed ballast water management systems greatly reduce the risk associated with transporting ballast water between ports (Gray *et al*., 2007, Mamlook *et al*., 2007). Alignment of international and domestic strategies has allowed vessels to adhere to common standards, making management an obligatory and seemingly straightforward task for vessels equipped with and operating ballast tanks. The challenge lies in tackling exemptions from management, which continue to negate efforts to reduce invasion risk.

The efficacy of future policies may depend on reducing the number of vessel exemptions and implementing localized regulations or guidelines to consider regional ecological attributes and address species-specific concerns. Particularly in the United States, where inclusion of all pertinent vessel types and intra-coastal traffic has the potential to further reduce marine invasions. For example, exemptions for vessels travelling within one COTP Zone are not based on biological or oceanographic traits, but

USCG jurisdictional zones. Despite its large coastline, the State of Alaska contains only three COTP zones which span six ecoregions (North American Pacific Fjordland, Gulf of Alaska, Aleutian Island, Eastern Bering Sea, Chukchi Sea, and Bering Sea – continental coast and shelf) and a very wide range of habitats (see Figure 1.12). The western COTP zone encompasses a significant portion of the state, stretching across multiple degrees of latitude and longitude including all of part of four ecoregions. Although this area currently receives a lower volume of traffic than the Prince William Sound or southeast zones, expected increases in vessel traffic throughout the Arctic may soon result in substantial port development and increases in seasonal arrivals. Rather than rely solely on nationally designated USCG areas of responsibility, the creation of state-specific regulations based on biologically or ecologically meaningful distinctions would be a proactive and valuable step towards managing invasion risk.

Although Alaska currently has relatively fewer marine invasive species than other locations along the Pacific coast of North America (Ruiz *et al*. 2011), the vast extent of Alaska's coastline warrants prioritization in management. A simplistic ranking system based on the number of arrivals and the volume of ballast received on an annual basis or a more robust risk assessment could be used to prioritize locations. Surveys of marine biota conducted in vessel ballast tanks arriving at these ports and in the surrounding waters would serve as an indicator of the effectiveness of ballast water management in Alaskan waters. Furthermore, regular evaluation of risk factors at ballast water source ports, including new species incursions, water quality, dominant vessel type, and local ballast water management regulations would also serve to aid in prioritization of management efforts in arrival ports.

BWM data from Alaska particularly highlight the need to prioritize management strategies. At first it appears that tankers discharge large volumes of coastwise, unmanaged, young ballast water primarily to the Gulf of Alaska region. However, a formal risk assessment of the entire state that incorporates variables such as environmental similarity between source and discharge ports, ballast water volume, and ballast water age would serve to comprehensively identify areas susceptible to marine invasive species. These areas could in turn be labeled as priority locations for monitoring and management action.

Modeling or adapting existing management strategies from other states may be helpful in identifying effective regulations that do not cause unnecessary burden to industry. For example, on the Pacific coast of the United States, the states of California, Oregon and Washington have chosen to impose state-specific BWM regulations (Cordell *et al*. 2009). The regulations of each state are similar in that they apply to vessels greater than 300 gross tons that are capable of carrying ballast water, require ballast water exchange at least 50 nautical miles from shore, require reporting, and impose penalties for noncompliance. Given that the majority of vessels discharging ballast water to Alaska originate from these west coast states, and are presumably participating in these state-specific programs, it would not be implausible for Alaska to develop similar regulations and not further impede industry. This approach, coupled with local and regional support, may allow for quicker approval and implementation of ballast water management regulations in Alaska.

The most dramatic impact of United States BWM regulatory change on industry practices was the shift from voluntary to mandatory management and record keeping requirements for coastwise crude oil tankers via the EPA VGP resulting in a 440% increase in ballast volume reported to Alaska between 2008 and 2009. This example clearly illustrates the consequence of exempting an important sector of the shipping industry and elucidates a tremendous gap in the pre-2009 data that might have had substantial impacts on management decisions. That gap was a direct result of an exemption to crucial BWM policy. This should motivate managers to assess and further fill data gaps (i.e. vessels traveling within one COTP zone) and to ensure that ballast reporting generated data represent real fleet behavior and thus can accurately inform management. Alaska is in a prime position to be proactive in its approach to state ballast water management in an effort to prevent further introduction of marine invasive species. Effective management strategies include establishing state-specific regulations, reducing the number of management exemptions, prioritizing ports, and conducting surveys of marine biota. The need will only increase as climate change facilitates the colonization of previously unsuitable habitat by lower-latitude species and a rise in Arctic vessel traffic leads to port and infrastructure development and vessel arrivals to Alaska via new trade routes.

CHAPTER 2

BALLAST-BORNE MARINE INVASIVE SPECIES:

EXPLORING THE RISK TO COASTAL ALASKA

1. INTRODUCTION

The introduction of marine invasive species via ship ballast causes biological, economic and social consequences to ecosystems worldwide. Invasive species threaten biodiversity by outcompeting native species, affecting ecosystem services (e.g. supply of subsistence harvest), altering food webs, and increasing the susceptibility of an area to further invasion (Molnar *et al.* 2008, Pysek & Richardson 2010). For example, the invasion of comb jelly (*Mnemiopsis leidyi*) in the Black Sea during the 1980's decimated the anchovy fishery, leading to severe economic losses (Knowler 2005); the European green crab (*Carcinus maenas*) is continuing to outcompete native crab species on coasts throughout the world (Grosholz & Ruiz 1996). Reduced environmental quality can adversely affect tourism and aesthetics, algal blooms can lead to paralytic shellfish poisoning in humans, and the disruption of marine industries can reduce efficiency and yield resulting in loss of employment (Bax *et al.* 2003, Pysek & Richardson 2010).

Ballast water from ships is a well-known and significant transport vector of non-native and invasive marine species on regional and global scales (Carlton & Geller 1993, Ruiz *et al.* 2000, McGee *et al.* 2006, Keller *et al.* 2011). Ships use ballast water on both trans-oceanic and intra-coastal voyages; however, intra-coastal voyages which transit relatively short distances (e.g. ~1,000 – 2,000 nautical miles) typically present a heightened risk of successfully transporting invasive species due to environmental similarity between source and discharge ports and shorter voyage duration. Additionally, intra-coastal voyages act to secondarily spread invasive species, as invaded ports become hosts for the transfer of species to other regional, and perhaps less-trafficked, ports (Simkanin *et al.* 2009). As a result, efforts to reduce the transfer of ballast-borne invasive species have been ongoing for decades in the form of internationally, nationally and locally recognized ballast water management practices (Firestone & Corbett 2005, Cordell *et al.* 2009). Nevertheless, the staggering volume of shipping traffic worldwide continues to pose a substantial threat (Drake & Lodge 2004).

The global shipping industry transports more than 90% of world trade, moves approximately 3500 million metric tons (MT) of ballast water annually and is the largest contributor of marine invasive species (Ruiz *et al.* 2000, Endresen *et al.* 2004, International Maritime Organization 2011). Ships travelling between ports exchange exotic mixtures of species with each uptake and discharge of ballast. Carlton & Geller (1993) found a minimum of 367 taxa while assessing the ballast water of 159 cargo ships arriving in Coos Bay, Oregon from 25 Japanese ports.

The expansion of shipping as a result of globalization is implicated as a major contributor to the increasing rate of ballast-borne species invasions. The number of introduced species attributed to ballast water has been on the rise since 1900, particularly during the 1980s and 1990s (Bax *et al.* 2001). Hulme (2009) identified three phases of biological introductions in the world: (1) 1500 AD, when global exploration began, (2) 1800 AD, associated with the Industrial Revolution and mass European emigration, and (3) the present "Era of Globalization." Each phase represents an establishment or increase in global trade and movement of people and commodities – resulting in more opportunities for the intentional or unintentional introduction of non-native species. As new trade routes continue to emerge, previously unaffected areas are exposed to risk of invasion (Seebens *et al.* 2013).

Changing environmental conditions have led to increased opportunities for high-latitude shipping traffic. Arctic travel has the potential to decrease transit times and reduce fuel costs (Somanathan *et al.* 2009) – both attractive qualities for the growing international shipping industry. Reduced seasonal ice cover in the Arctic has made way for new viable vessel traffic routes, such as the Northern Sea Route (NSR) and the Northwest Passage (Stroeve *et al.* 2008, Kohn *et al.* 2010). For example, 41 vessels transited the NSR in 2011, 46 in 2012, and 71 in 2013, representing a 54% increase in the past two years (Northern Sea Route Information Office 2014), and according to data presented by the United States Coast Guard at the February 2013 Bering Strait Maritime Symposium, annual vessel traffic through the Bering Strait has more than doubled between 2008 and 2012 to greater than 480 transits. In response, the United States National Oceanic and Atmospheric Administration is creating new or updating outdated nautical charts in the Bering, Beaufort, and Chukchi Seas for use by mariners. In recent years the United States Coast Guard has gradually increased their presence near Alaska's Arctic coastlines and is preparing for increased vessel traffic and development in the region. Oil and natural gas exploration has begun in the Beaufort and Chukchi Seas, bringing infrastructure to the offshore environment. In preparation for this development, the State of Alaska and the US Army Corps of Engineers conducted a deep draft port site analysis along Alaska's western and northern coastlines (State of Alaska 2013). However progressive, increased shipping also presents an increased risk of transport of marine invasive species.

In addition to allowing for greater volumes of high-latitude shipping, climate change also has the potential to affect the global movement and establishment of invasive species. Changes in ocean temperature and salinity and reduced ice cover alter pathways by adding or removing physical or ecological barriers resulting in shifts in the intensity of species' impacts and allowing for species (native or non-native) to extend their ranges (Hellman *et al.* 2008, Rahel & Olden 2008). Specifically, the projected increases in global temperature could promote the net movement of species toward high latitudes. de Rivera *et al.* (2011) forecasted the potential spread of four species (the barnacle *Amphibalanus improvisus*, the crab *Carcinus maenas*, the snail *Littorina saxatilis*, the tunicate *Styela clava*) into Alaskan waters and above the Arctic Circle as a result of increased sea surface and air temperatures. Assessing risk of high-latitude invasions is therefore critically important, particularly in areas that expect to have increased rates of shipping.

Risk assessments identify the source and degree of potential hazards and are the first step in successful risk management (Pysek & Richardson 2010). Species invasion risk assessments predict the likelihood of introduction and identify potential impacts (Andersen *et al.* 2004), allowing managers to test plausible scenarios and develop proactive methods to mitigate risk. However, assessing risk associated with ballast water discharge is a complex problem influenced by numerous and overlapping variables. At the root of this complexity lie three fundamental categories: environment, ballast journey, and species (Hayes 1998). Ballast water source conditions, voyage duration and volume each have an effect on non-native and invasive species' ability to survive in and colonize a new habitat. The key to a successful vector based risk assessment is to review each of these factors individually before assessing their impacts collectively to reveal unique risk per location (Keller *et al.* 2011).

The aims of this analysis are to: (1) develop a risk assessment framework for ballast-borne marine invasive species in Alaska following other high-latitude risk assessments (e.g. Leppäkoski & Gollasch 2006, Chan *et al.* 2013, Ware *et al.* 2013) and (2) characterize risk throughout coastal Alaska by developing a relative risk matrix for the top 15 ports/discharge locations with the highest ballast discharge volume. At each location ballast water volume, environmental similarity between source and discharge locations, ballast water age, and invasive species richness present in each source ecoregion were assessed for the four year period from 2009 – 2012 (Table 2.1). This is the first assessment of ballast discharge and associated risk for coastal Alaska.

2. METHODS

2.1. DATA

All ballast data were obtained from the National Ballast Information Clearinghouse (NBIC). Vessels report ballast water information upon arrival in ports of the United States via standard NBIC forms. Data are provided per tank and include date and location of ballast source and discharge and ballast management activities including date, location, volume, and method. The NBIC database was created in 1997 as mandated by the National Invasive Species Act of 1996 and is maintained by the Smithsonian Environmental Research Center in conjunction with the United States Coast Guard. Reporting and conducting of ballast water management became mandatory in the United States in August and September 2004, respectively. However, exemptions provided in the regulations allowed for crude oil tankers involved in coastwise trade to forego management and reporting until 2008, when they were then regulated by the Environmental Protection Agency's Vessel General Permit. Ironically, these vessels are the dominant source of ballast water discharge to Alaska. We therefore chose to analyze risk to Alaska using only data reported from 2009 through 2012.

2.2. PROPAGULE SUPPLY

The likelihood of ballast-borne introductions increases with the number and frequency of discharge events (Kolar & Lodge 2001). Although ballast water volume is not a direct measure of propagule pressure, it has been positively correlated with zooplankton abundance (Minton *et al.* 2005) and in lack of vessel-specific data is a suitable alternative (Lo *et al.* 2012, Chan *et al.* 2013). Efforts to characterize the density and diversity of organisms arriving in ballast water to select Alaskan ports are ongoing, but these data do not characterize all ports, or even regions, within the state. Alternatively, ballast water discharge volumes are readily available across time and were used as a proxy for determining risk associated with species abundance. The association between ballast discharge volume and risk was determined from the greatest mean ballast discharge volume received by any port over all years. The data were $\log_{10}$ transformed and divided into three equal categories (low, medium, high) according to the methods of Chan *et al.* (2013). Similarly a correction factor of 0.1 was applied to managed ballast water (at the tank level) prior to transformation to represent the efficacy of ballast water exchange (90%) across multiple vessel types (Ruiz & Reid

2007). Although efficacy of ballast water exchange can depend upon vessel type and exchange method, this implies that there is generally retention of 10% of the high-risk coastal organisms derived from the source port.

2.3. ENVIRONMENTAL SIMILARITY

Environmental similarity between source and discharge ports strongly influences a species' ability to survive once released from a vessel ballast tank and is positively correlated with risk (Paavola *et al.* 2005, Herborg *et al.* 2007, Keller *et al.* 2011). As developed by Spalding *et al.* (2007) in the Marine Ecoregions of the World system, ecoregions are the smallest-scale delineation of marine biogeographic regions characterized by "relatively homogenous species composition…determined by the predominance of a small number of ecosystems and/or a distinct suite of oceanographic or topographic features" (Spalding *et al.* 2007). Given the large scale of this risk assessment and the vast length of Alaska's coastline (33,904 miles) dotted with numerous ports, regional comparisons are the most practical method for an initial risk assessment of marine invasive species throughout the state (Hunsaker *et al.* 1990, Wiegers *et al.* 1998, David *et al.* 2013). Barry *et al.* (2008) warn of masking risk by including additional environmental variables that do not directly influence invasion potential and suggest only temperature and salinity be used as indices of environmental similarity. However, ecological niche models have successfully predicted suitability for species survival using a variety of environmental variables and climate in aquatic and terrestrial ecosystems (Peterson 2003, Thuiller *et al.* 2005, Herborg *et al.* 2007, Zanden & Olden 2008, Kulkanek *et al.* 2011). In addition, the majority of ecoregions relevant to this study lie within the Temperate Northern Pacific realm (the largest spatial unit described by Spalding *et al.* 2007), suggesting basic similarity of higher taxonomic biota and environmental influences. Therefore "environmental similarity" between ballast discharge locations in Alaska and source ports throughout the Pacific was based upon the proximity of ecoregions. Ballast sourced and discharged within the same ecoregion was considered high risk (3), adjacent ecoregions were considered medium risk (2) and ecoregions not adjacent to one another were considered low risk (1). We then calculated a weighted average of assigned risk based on the corrected discharge volume per source ecoregion. Ballast sourced from unknown ecoregions was conservatively considered low risk, and reported ballast discharged to unknown regions was not considered.

2.4. BALLAST WATER AGE

Ballast age is the time elapsed (days) between ballast water uptake and subsequent discharge and is negatively correlated with the survival of ballast-borne organisms. The length of time that organisms can survive in ballast tanks varies, but the largest decrease in abundance typically occurs within the first five days of transit (Gollasch *et al.* 2000, Olenin *et al.* 2000, Cordell *et al.* 2009) and density generally decreases with time (Verling *et al.* 2005). Lavoie *et al.* (1999) found high abundances of organisms survived short voyages (1 – 2 days), while Gollasch *et al.* (2000) and Cordell *et al.* (2009) reported finding organisms alive after long voyages (20 – 30 days). Thus in accordance with these observations, this analysis describes ballast age less than six days as high risk (3), age from 6 to 10 days as medium risk (2), and age greater than 10 days as low risk (1).

2.5. SPECIES RICHNESS

The number of known ballast-borne marine invasive species from each source ecoregion was used to determine the relative risk of arriving species richness per receiving port. Species counts were taken from The Nature Conservancy's Database of Global Marine Invasive Species Threats (Molnar *et al*. 2008). The greatest sum of potential donor species for a single port over all years was divided into three equal categories (low, medium, high) and applied to each port for each year. This is the most recent comprehensive list of global marine invasive species available. We assume that a greater number of non-native species will result in a greater risk to the host environment (sensu Chan *et al.* 2013).

2.6. SITE DESCRIPTIONS

The top 15 ports of Alaska that received the greatest volume of ballast water discharge from 2009 through 2012 are Red Dog (Chukchi Sea ecoregion), Dutch Harbor (Aleutian Island ecoregion), Afognak, Kodiak, Drift River Terminal, Nikiski, Seward, Prince William Sound, Valdez (Gulf of Alaska ecoregion), Skagway, Hawk Inlet, Tolstoi Bay, Klawock, Hydaburg, and Ketchikan (North American Pacific Fjordland ecoregion). The dominant vessel type in the majority of ports (67%) is bulk carriers (bulkers). Bulkers are designed to carry dry bulk cargo, such as exports of timber, minerals and metals from Alaska. Tankers are the dominant vessel type in four of the top 15 ports and are designed to carry liquid bulk cargo, such as crude oil. Lastly, the port of Dutch Harbor receives mostly container and reefer vessels. Container ships transport cargo typically in twenty or forty foot containers while reefers are designed to transport refrigerated cargo, such as seafood (see Table 2.2 for the dominant vessel type and export in each of the top 15 ports).

3. RESULTS

3.1. PORT TRENDS

From 2009 through 2012 a total of 54,018,612 MT of ballast water was discharged at Alaska's top 15 ports/discharge locations from 1,877 arrivals with an average ballast age of 10 days (±0.1 SE; Table 2.3). Corrected for management activity, the volume of ballast water discharge was reduced to 35,551,259 MT (decrease of 34%, Figure 2.1). Valdez was by far the top port for ballast discharge in Alaska, receiving 96% more ballast discharge than the next highest port of Red Dog. Correcting for management activity did not change this but the next highest port shifted to Nikiski. The average ballast water age for all ports ranged from 6 days at Drift River Terminal to 36 days at Dutch Harbor. Only two other ports received ballast less than ten days old (Prince William Sound and Valdez), both approximately 7 days old. Ballast water age at all other ports ranged from 11 – 24 days.

Spatial and temporal variation among discharge ports with respect to Alaska's large coastline is limited with the exception of the Red Dog port facility, located along the Chukchi Sea. Although the second highest discharge location by volume in Alaska, Red Dog is seasonally constricted by ice and receives ballast discharge only between June and October. In comparison, all other discharge locations are located on the southern coast of Alaska or the Aleutian Island chain and are available to vessel traffic year-round.

Temporal changes in ballast discharge volume are most evident in Nikiski, Prince William Sound, Red Dog, and Tolstoi Bay. Prince William Sound saw a 67% reduction in discharge volume between 2009 and 2010, a 63% reduction between 2010 and 2011 and received no ballast discharge during 2012. Conversely, Tolstoi Bay did not receive ballast discharge during 2009 or 2010 but saw a 44% increase in volume between 2011 and 2012. The more established ports of Red Dog and Nikiski also experienced opposite trends in reported ballast discharge volume. Red Dog received a steady increase in ballast discharge across all years (31%, 2009 – 2012) while Nikiski received decreasing volumes between 2010 and 2012 (46%).

3.2. RISK

Risk of species invasion was medium or high across all factors for only Drift River Terminal and Valdez and varied by factor for all other ports (Table 2.4, Figures 2.2, 2.3, 2.4, 2.5).

Risk associated with environmental similarity varied by port. Risk was medium to high for Drift River Terminal throughout all four years, while risk in Ketchikan, Nikiski, Red Dog, Kodiak, Seward, and Valdez was mostly medium. Only Klawock and Tolstoi Bay received low overall risk, although Afognak, Hawk Inlet, Hydaburg, Prince William Sound, and Skagway also had low to medium risk during all years.

Environmental similarity risk based on a weighted average of corrected discharge volumes largely represents the risk posed by the proximity of unmanaged source ballast water. In other words, a high-risk score does not necessarily indicate that the greatest volume of ballast discharge for a port is from the same region, but instead may indicate that the greatest proportion of unmanaged ballast is from the same ecoregion. For example, the dominant sources of ballast water for the port of Ketchikan are three nonadjacent ecoregions (49, 51, 52). However, 100% of ballast received from these ecoregions is managed. Ballast sourced within the same or adjacent ecoregions (55, 54, 56) represents only 5% of ballast discharge to Ketchikan, but the reported management volume is considerably lower (14%, 0%, 0% respectively). Alternatively, the dominant source ecoregion for ballast discharge to Drift River Terminal is within the same ecoregion (54) and 100% of the ballast discharge was reported to be unmanaged.

Risk associated with ballast volume (propagule pressure) was medium or high across all years for 12 of the 15 ports. Valdez was the only port to maintain high risk across all years based on volume. Drift River Terminal received a 43% increase in discharge volume between 2010 and 2011, increasing risk from medium to high. Kodiak, Prince William Sound, and Tolstoi Bay received no ballast discharge or low volume risk during at least one of the four years.

Conversely, risk associated with ballast age was medium or high for only two ports (Drift River Terminal and Valdez). Prince William Sound had medium risk from 2009 to 2011, but did not receive ballast discharge during 2012. Ballast age risk to Nikiski increased to medium in 2010 and 2011 but returned to low risk in 2012. All other ports had low risk associated with ballast water age.

Risk associated with species richness was medium to high for only two ports (Dutch Harbor and Valdez). Drift River Terminal, Hawk Inlet, Nikiski and Prince William

Sound had medium overall risk, but risk varied on an annual basis in each location. The majority of ports had low risk of species richness across all years. However, 43 of the 49 unique source ecoregions contained at least one known ballast-borne marine invasive species and dominant source ecoregions tended to have the highest counts (Figure 2.3).

4. DISCUSSION

Coastal Alaskan waters are at risk from ballast-borne marine invasive species. Ports at greatest risk tend to receive a high volume of relatively young and unmanaged ballast water from source ports with similar environmental conditions known to host invasive species. The source of a vessel's ballast water plays a vital role in determining the risk associated with its discharge, influencing factors such as proximity to discharge location, zooplankton assemblage and environmental similarity. This is particularly important for vessels that do not manage their ballast water and will discharge high-risk coastal organisms rather than low-risk oceanic organisms. Ports that receive large volumes of ballast discharge from source ecoregions that also contain high invasive species richness are at elevated risk of invasion as a result of increased propagule pressure and greater species density. Repeat voyages transporting large volumes of ballast also present a heightened risk of invasion.

Therefore, risk of ballast-borne species invasions is dependent upon the cumulative assessment of multiple risk factors. We do not attempt to combine the factors affecting invasion risk into a "total risk" score, which would assume a proportional impact of each factor is the same across multiple locations. Instead we look at risk relative to ports and from each of the four factors. We infer risk to ports of Alaska based upon evidence of species viability and suitability of habitat (e.g. age and environmental similarity) and relative to what is occurring throughout dominant ballast discharge ports (e.g. volume and species richness). In order to characterize the entire state of Alaska we identified relative hotspots of invasion among the top 15 ports top with the highest ballast discharge volume based upon factors known to influence the likelihood of invasion success.

Our multi-factor vector based risk matrix revealed that Valdez, Drift River Terminal, Nikiski, and Dutch Harbor may be hotspots for potential invasion whereas Klawock and Tolstoi Bay have relatively low risk. Risk to all ports was greatest from environmental similarity and volume, which are arguably the two most influential factors.

Our approach to assessing risk is practical from a management perspective, as ports may be targeted for management based upon one or several of the invasion risk factors. A large volume of ballast discharge or the threat posed by a high number of invasive species in dominant source locations may be enough to prioritize a port for focused risk management strategies. Control measures may also be implemented in a port that receives high volumes of ballast water from closely matched source ports, despite the ballast water discharge lying above the threshold for high age risk. These management decisions may depend upon the assets valuable to that region.

In addition, the risk matrix can be used as a tool to determine where to focus management effort based on trends in risk or based on regional expectations of changes to vessel traffic or development. Decreases in risk to Nikiski but increases to Drift River Terminal, ports located in close proximity to one another, could be a result of a number of economic or resource availability factors, but do not necessarily equate to an overall change in risk to the Cook Inlet region. Expected increases in vessel traffic through the Arctic and Bering Strait may influence management activity in ports such as Dutch Harbor, which already receives ballast water from a variety of sources and has the greatest overall risk of species richness.

A few limitations exist within our methods related to our analysis of environmental matching and the scale of discharge volume. Ecoregion scale environmental matching does not take into consideration port-specific variability or seasonality. For example, a regional risk assessment of the Port Valdez area alone focused on eleven subareas representing eight habitat types (Wiegers *et al.* 1998). Spring snow and glacial run-off in coastal ports of Alaska can add a substantial fresh water lens to marine environments. In addition, the wide range of ballast discharge volumes received in Alaska, even among the top 15 ports by volume, resulted in an initially skewed relative risk scale, controlled by log transformation of the volume. Although Valdez was at greatest risk by volume across all years, the scale fails to adequately portray that port as an outlier, as other ports (Drift River Terminal and Nikiski) also had overall high risk by volume, but receive substantially lower volumes of ballast discharge.

Another area of uncertainly arises within vessel practices and reporting accuracy. In some cases vessels may not discharge all ballast tanks at berth, but instead may begin to discharge ballast water while still approaching a port, particularly if inside protected waters. This practice may reduce time in port by allowing a vessel to load cargo immediately upon arrival without needing to wait while de-ballasting, thus reducing costs and delivering product more efficiently. However, reporting the location of ballast water discharge is often at the discretion of the vessel. The decreasing trend in ballast discharge to Prince William Sound suggests that either vessels no longer discharge ballast at large throughout the sound or instead choose to report all ballast discharge at the arrival port (i.e. Valdez). This represents a level of uncertainty that may have implications for where risk of invasion is likely to occur. Considering other risk factors in addition to volume may aid in determining where to focus management or survey effort.

We make a few explicit assumptions in our risk assessment that also warrant attention. First, we assume that the proximity of ecoregions is positively correlated with risk. Although Leppakoski & Gollasch (2006) use a similar approach with global temperature bands in their risk assessment of the Baltic Sea (i.e. a relatively small region), the approach lacks the necessary specificity for global scale comparisons. For example, ballast water sourced in the southern hemisphere and discharged at an equivalent latitude in the northern hemisphere would be considered low risk on our scale, despite the potential for similar environmental conditions. Although this scenario is unlikely for ballast water discharged in Alaska, as most ballast is sourced from California to British Columbia on the west coast of North America, a more refined environmental similarity index would alleviate this uncertainty.

Second, we assume that propagule pressure is solely a function of ballast discharge volume, rather than an additive parameter of volume and frequency of ballast discharge as suggested by Minton *et al.* (2005). Depending upon the frequency considered (e.g. monthly, seasonally, or annually) the risk in each port may be different than currently expected. For example, arrivals to the Red Dog port facility may be consistent but are seasonal (lower risk), while arrivals to Valdez are fairly consistent year-round (higher risk). A review of one plant and eight bird studies by Kolar and Lodge (2001) shows a positive relationship between the number of introduction attempts and invasion success. However, success as a result of frequent introductions may also be species-dependent. Wonham *et al*. (2000) showed that behavioral traits common to specific fish families (Gobiidae and Blenniidae) may increase their invasion success by positively influencing rates of both introduction and establishment. We suggest a similar study to address this relationship for marine invertebrates.

Although not the goal of this study, it is also possible to use a similar risk framework to analyze the risk posed by specific high impact species known to be located in source ecoregions. This approach may be valuable when targeting monitoring and control efforts at corresponding receiving ports. These species-based risk assessments have the management appeal of using early detection/rapid response techniques to mitigate known harmful impacts (e.g. European green crabs, *Carcinus maenas*, impacting shellfish and habitat in southeast Alaska). Analysis of additional vectors and species' life-history traits could also be incorporated into the risk assessment.

Whether vector-based or species-based, risk assessment for invasive species is a valuable pre-management tool. Global-scale vectors such as shipping present a variety of biotic and abiotic influences on invasion potential and are particularly well suited for risk assessment analyses. Our study summarizes the risk of ballast-borne marine invasive species to coastal Alaska, an area that is currently relatively uninvaded but that receives the majority of its ballast water from highly invaded regions. Compounded by expected increases in vessel traffic and potential influences of climate change, a preliminary analysis of risk is vital to proactive management effort in the state. In addition to portraying relative risk to dominant ports of Alaska, we also suggest that the risk matrix be used to detect areas for final-scale risk analysis or review of vessel traffic patterns and ballast water management activity.

GENERAL DISCUSSION

Marine invasive species have the potential to cause significant harm worldwide, but are a particular concern to coastal Alaska, which has remained relatively un-invaded. The management of ballast water to reduce introductions of marine invasive species has progressed substantially since efforts first began nearly 25 years ago, but exemptions from management and reporting practices for crude oil tankers involved in coastwise trade allowed for unnecessary risk to Alaska. To effectively manage this risk we (1) reviewed the history and drivers of ballast water management policy, (2) assessed how changes to policy in turn influenced vessel behavior, and (3) analyzed how vessel behavior influenced risk of invasion.

An analysis of vessel traffic patterns and ballast water management and discharge data for Alaska from 2005 through 2012 describes the tremendous impact that the Environmental Protection Agency's Vessel General Permit had on tanker reporting effort between 2008 and 2009. Refining the analysis to post-VGP data (2009 through 2012) reveals general trends of vessel types, source locations and management rates that influence the risk of species invasions to Alaska. Tankers, the dominant vessel type discharging ballast water in Alaska, tend to discharge relatively young, unmanaged ballast sourced from locations on the west coast of North America with high ballast-borne invasive species richness. Bulkers, the second most dominant vessel type to discharge ballast water in Alaska, tend to discharge relatively older, managed ballast water sourced from overseas locations with relatively low invasive species richness.

A specific look at the top 15 ports with the highest ballast discharge volume of Alaska shows that ports at greatest risk of ballast-borne species invasions tend to receive a high volume of relatively young and unmanaged ballast water from source ports with similar environmental conditions known to host invasive species. Our multi-factor vector based risk matrix revealed that Valdez, Drift River Terminal, Nikiski, and Dutch Harbor may be hotspots for potential invasion whereas Klawock and Tolstoi Bay have relatively low risk. Our risk assessment of coastal Alaska has identified those ports in greatest need of management attention. Compounded by expected increases in vessel traffic and potential influences of climate change, managing this risk is vital to reducing the potential impacts of marine invasive species in the state.

REFERENCES

46 U.S. Code Chapter 551. 2009. Coastwise Trade. <http://www.gpo.gov> 11 Aug 2013.

Andersen, M. C., Adams, H., Hope, B., Powell, M. 2004. Risk assessment for invasive species. Risk Analysis 24: 787 – 793.

Barry, S., Hayes, K., Hewitt, C., Behrens, H., Dragsund, E., Bakke, S. 2008. Ballast water risk assessment: principle, processes, and methods. ICES Journal of Marine Science 65: 121 – 131.

Bax, N., Carlton, J. T., Matthews-Amos, A., Haedrich, R. L., Howarth, F. G., Purcell, J. E., Rieser, A., Gray, A. 2001. The Control of Biological Invasions in the World's Oceans. Conservation Biology 15: 1234 - 1246.

Bax, N., Williamson, A., Aguero, M., Gonzalez, E., Geeves, W. 2003. Marine invasive alien species: a threat to global biodiversity. Marine Policy 27: 313 - 323.

Carlton, J. T., Geller, J. B. 1993. Ecological Roulette: The Global Transport of Nonindigenous Marine Organisms. Science 261: 78 – 82.

Chan, F., Bailey, S., Wiley, C., MacIsaac, H. 2013. Relative risk assessment for ballast-mediated invasions at Canadian Arctic ports. Biological Invasions 15: 295 – 308.

Clean Boating Act of 2008. 2008. PL 110-288. 110th Congress. <http://www.gpo.gov/fdsys/pkg/BILLS-110s2766enr/pdf/BILLS-110s2766enr.pdf> 13 Aug 2013.

Connelly, N. A., O'Neill Jr., C. R., Knuth, B. A., Brown, T. L. 2007. Economic Impacts of Zebra Mussels on Drinking Water Treatment and Electric Power Generation Facilities. Environmental Management 40: 105 – 112.

Cordell, J. R., Lawrence, D. J., Ferm, N. C., Tear, L. M., Smith, S. S., Herwig, R. P. 2009. Factors influencing densities of non-indigenous species in the ballast water of ships arriving at ports in Puget Sound, Washington, United States. Aquatic Conservation: Marine and Freshwater Ecosystems: 19: 322 – 343.

David, M., Gollasch, S., Leppakoski, E. 2013. Risk assessment for exemptions from ballast water management – the Baltic Sea case study. Marine Pollution Bulletin 75: 205 – 217.

de Rivera, C. E., Steves, B. P., Fofonoff, P. W., Hines, A. H., Ruiz, G. M. 2011. Potential for high-latitude marine invasions along western North America. Diversity and Distributions 17: 1198-1209.

Drake, J. M., Lodge, D. M. 2004. Global hot spots of biological invasions: evaluating options for ballast water management. Proceedings of the Royal Society B 271: 575 – 580.

Endresen, O., Behrens, H. L., Brynestad, S., Andersen, A. B., Skjong, R. 2004. Challenges in global ballast water management. Marine Pollution Bulletin 48: 615 – 623.

Environmental Protection Agency. 2003. Decision on Petition for Rulemaking to Repeal 40 CFR 122.3(a). <http://water.epa.gov/type/oceb/habitat/ballast_water.cfm> 9 Sep 2013.

Environmental Protection Agency. 2008. Final Issuance of National Pollutant Discharge Elimination System (NPDES) Vessel General Permit (VGP) for Discharges Incidental to the Normal Operation of Vessels Fact Sheet. 1 – 119.

Environmental Protection Agency. 2009. Vessel General Permit for Discharges Incidental to the Normal Operation of Vessels. 1 – 158.

Environmental Protection Agency. 2013. Vessel General Permit for Discharges Incidental to the Normal Operation of Vessels. 1 – 194.

Executive Order 13112. 1999. Invasive Species. Federal Register 64 (25): 6183 – 6186.

Firestone, J., Corbett, J. 2005. Coastal and Port Environments: International Legal and Policy Responses to Reduce Ballast Water Introductions of Potentially Invasive Species. Ocean Development & International Law 36: 291 - 316.

GloBallast. 2014. The IMO Ballast Water Management Convention. <http://globallast.imo.org/index.asp> 6 April 2014.

Gollasch, S., David, M., Voigt, M., Dragsund, E., Hewitt, C., Fukuyo, Y. 2007. Critical review of the IMO international convention on the management of ships' ballast water and sediments. Harmful Algae 6: 585 – 600.

Gollasch, S., Rosenthal, H., Botnen, H., Hamer, J., Laing, I., Leppakoski, E., Macdonald, E., Minchin, D., Nauke, M., Olenin, S., Utting, S., Voight, M., Wallentinus, I. 2000. Fluctuations of zooplankton taxa in ballast water during short-term and long-term ocean-going voyages. International Review of Hydrobiology 85: 597 – 608.

Gray, D. K., Johengen, T. H., Reid, D. F., MacIsaac, H. J. 2007. Efficacy of open-ocean ballast water exchange as a means of preventing invertebrate invasions between freshwater ports. Limnology and Oceanography 52: 2386 – 2397.

Grosholz, E. D., Ruiz, G. M. 1996. Predicting the impact of introduced marine species: lessons learned from the multiple invasions of the European green crab *Carcinus maenas*. Biological Conservation 78: 59 – 66.

Hayes, K. 1998. Ecological risk assessment for ballast water introductions: A suggested approach. ICES Journal of Marine Science 55: 201 – 212.

Hellmann, J. J., Byers, J. E., Bierwagen B. G., Dukes, J. S. 2008. Five potential consequences of climate change for invasive species. Conservation Biology 22: 534 – 543.

Herborg, L., Jerde, C., Lodge, D., Ruiz, G., MacIsaac. 2007. Predicting invasion risk using measures of introduction effort and environmental niche models. Ecological Applications 17: 663 – 674.

Hulme, P. E. 2009. Trade, transport and trouble: managing invasive species pathways in an era of globalization. Journal of Applied Ecology 46: 10 - 18.

Hunsaker, C., Graham, R., Suter II, G., O'Neill, R., Barnthouse, L., Gardner, R. 1990. Assessing ecological risk on a regional scale. Environmental Management 14: 325 – 332.

Implementation of the National Invasive Species Act of 1996. 1998. Federal Register 63: 17782 – 17792.

Implementation of the National Invasive Species Act of 1996. 2001. Federal Register 66: 58381 – 58393.

International Maritime Organization. 2004. International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM). <http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships%27-Ballast-Water-and-Sediments-(BWM).aspx> 12 Aug 2013.

International Maritime Organization. 2011. Ballast Water Management. <http://www.imo.org/ourwork/environment/ballastwatermanagement/Pages/Default.aspx#5> 11 Dec 2012.

Keller, R. P., Drake, J. M., Drew, M. B., Lodge, D. M. 2011. Linking environmental conditions and ship movements to estimate invasive species transport across the global shipping network. Diversity and Distributions 17: 93 – 102.

Khon, V., Mokhov, I., Latif, M., Semenov, V., Park, W. 2010. Perspectives of Northern Sea Route and Northwest Passage in the twenty-first century. Climatic Change 100: 757 – 768.

Knowler, D. 2005. Reassessing the costs of biological invasion: *Mnemiopsis leidyi* in the Black sea. Ecological Economics 52: 187 – 199.

Kolar, C. S., Lodge, D. M. 2001. Progress in invasion biology: predicting invaders. Ecology & Evolution 16: 199 – 204.

Kulhanek, S., Leung, B., Ricciardi, A. 2011. Using ecological niche models to predict the abundance and impact of invasive species: application to the common carp. Ecological Applications 21: 203 – 213.

Lavoie, D. M., Smith, L. D., Ruiz, G. M. 1999. The Potential for Intracoastal Transfer of Non-indigenous Species in the Ballast Water of Ships. Estuarine, Coastal and Shelf Science 48: 551 – 564.

Leppakoski, E., Gollasch, S. 2006. Risk Assessment of Ballast Water Mediated Species Introductions – a Baltic Sea Approach. 1 – 111.

Lo, V., Levings, C., Chan, K. 2012. Quantifying potential propagule pressure of aquatic invasive species from the commercial shipping industry in Canada. Marine Pollution Bulletin 64: 295 – 302.

MacIsaac, H. J. 1996. Potential Abiotic and Biotic Impacts of Zebra Mussels on the Inland Water of North America. American Zoologist 36: 287 – 299.

Mamlook, R., Badran, O., Abu-Khader, M., Holdo, A., Dales, J. 2008. Fuzzy sets analysis for ballast water treatment systems: best available control technology. Clean Technologies and Environmental Policy 10: 397 – 407.

Mandatory Ballast Water Management Program for U.S. Waters. 2003. Federal Register 68: 44691 – 44696.

Mandatory Ballast Water Management Program for U.S. Waters. 2004. Federal Register 69: 44952 – 44961.

McGee, S., Piorkowski, R., Ruiz, G. 2006. Analysis of recent vessel arrivals and ballast water discharge in Alaska: Toward assessing ship-mediated invasion risk. Marine Pollution Bulletin 52: 1634 – 1645.

Minton, M. S., Verling, E., Miller, A. W., Ruiz, G. M. 2005. Reducing propagule supply and coastal invasions via ships: effects of emerging strategies. Frontier in Ecology and the Environment 3: 304 – 308.

Molnar, J. L., Gamboa, R. L., Revenga, C., Spalding M. D. 2008. Assessing the global threat of invasive species to marine biodiversity. Frontiers in Ecology and the Environment 6: 485 – 492.

National Ballast Information Clearinghouse. 2008. NBIC Online Database. Electronic publication, Smithsonian Environmental Research Center & United States Coast Guard. <http://invasions.si.edu/nbic/search.html> 10 Sep 2012.

National Invasive Species Act of 1996. 1996. PL 104-332. 104th Congress. <http://thomas.loc.gov/cgi-bin/query/z?c104:H.R.4283.ENR::> 18 Aug 2012.

Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990. 2000. PL 106-580. <http://www.anstaskforce.gov/Documents/nanpca90.pdf> 13 Aug 2013.

Northern Sea Route Information Office. 2014. Transit Statistics. <http://www.arctic-lio.com/nsr_transits#>

Olenin, S., Gollasch, S., Jonusas, S., Rimkute, I. 2000. En-route investigations of plankton in ballast water on a ship's voyage from the Baltic Sea to the Open Atlantic coast of Europe. International Review of Hydrobiology 85: 577 – 596.

Paavola, M., Olenin, S., Leppakoski, E. 2005. Are invasive species most successful in habitats of low native species richness across European brackish water seas? Estuarine, Coastal and Shelf Science 64: 738 – 750.

Penalties for non-submission of Ballast Water Management Reports. 2003. Federal Register 68: 523 – 530.

Penalties for non-submission of Ballast Water Management Reports. 2004. Federal Register 69: 32864 – 32871.

Peterson, A. T. 2003. Predicting the geography of species' invasions via ecological niche modeling. The Quarterly Review of Biology 78: 419 – 433.

Pimentel, D., Zuniga, R., Morrison, D. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52: 273 – 288.

Pysek, P., Richardson, D. M. 2010. Invasive Species, Environmental Change and Management, and Health. Annual Review of Environment and Resources 35: 25 - 55.

Rahel, F. J., Olden, J. D. 2008. Assessing the Effects of Climate Change on Aquatic Invasive Species. Conservation Biology 22: 521 - 533.

Roberts, L. 1990. Zebra Mussel Invasion Threatens U.S. Waters. Science 249: 1370 – 1372.

Ross, D. J., Johnson, C. R., Hewitt, C. L. Impact of introduced seastars *Asterias amurensis* on survivorship of juvenile commercial bivalves *Fulvia tenuicostata*. Marine Ecology Progress Series 241: 99 – 112.

Ruiz, G. M., Fofonoff, P. W., Carlton, J. T., Wonham, M. J., Hines, A. H. 2000. Invasion of Coastal Marine Communities in North America: Apparent Patterns, Processes, and Biases. Annual Review of Ecology and Systematics 31: 481 – 531.

Ruiz, G. M., Hines, A. H. 1997. The risk of nonindigenous species invasion in Prince William Sound associated with oil tanker traffic and ballast water management: Presented to Regional Citizens' Advisory Council of Prince William Sound. 1 – 47.

Ruiz, G., M., Smith, G. E., Verling, E., Santagata, S. 2007. Efficacy of ballast water exchange. NOAA Technical Memorandum GLERL-142 Current State of Understanding about the Effectiveness of Ballast Water Exchange (BWE) in Reducing Aquatic Nonindigenous Species (ANS) Introductions to the Great Lakes Basin and Chesapeake Bay, USA: Synthesis and Analysis of Existing Information. G. Ruiz, D. Ried (Eds.) 27 – 44.

Seebens, H., Gastner, M. T., Blasius, B. 2013. The risk of marine bioinvasion caused by global shipping. Ecology Letters 1 – 9.

Simkanin, C., Davidson, I., Falkner, M., Sytsma, M., Ruiz, G. 2009. Intra-coastal ballast water flux and the potential for secondary spread of non-native species on the US West Coast. Marine Pollution Bulletin 58: 366 – 374.

Somanathan, S., Flynn, P., Szymanski, J. 2009. The Northwest Passage: A simulation. Transportation Research Part A 43: 127 – 135.

Spalding, M. D., Fox, H. E., Allen, G. R., Davidson, N., Ferdana, Z. A., Finlayson, M., Halpern, B. S., Jorge, M. A., Lombana, A., Lourie, S. A., Martin, K. D., McManus, E., Molnar, J., Recchia, C. A., Robertson, J. 2007. Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas. BioScience 57: 573 – 583.

Standards for Living Organisms in Ships' Ballast Water Discharge in U.S. Waters. 2009. Federal Register 74: 44632 – 44672.

Standards for Living Organisms in Ships' Ballast Water Discharge in U.S. Waters. 2012. Federal Register 77: 17254 – 17320.

State of Alaska, United States Army Corps of Engineers. 2013. Alaska Deep-Draft Arctic Port System Study. 1 – 68.

Stroeve, J., Serreze, M., Drobot, S., Gearhead, S., Holland, M., Maslanik, J., Meier, W., Scambos, T. 2008. Arctic Sea Ice Extent Plummets in 2007. Eos 89: 13 – 22.

Thuiller, W., Richardson, D. M., Pysek, P., Midgley, G. F., Hughes, G. O., Rouget, M. 2005. Niche-based modeling as a tool for predicting the risk of alien plant invasions at a global scale. Global Change Biology 11: 2234 – 2250.

United States Coast Guard. 2001. Report to Congress on the Voluntary National Guidelines for Ballast Water Management. <http://aapa.files.cms-plus.com/PDFs/Report_to_Congress-Revised_5-8-02.pdf> Sep 2013.

United States Coast Guard. 2004. Navigation and Vessel Inspection Circular No. 01-04. Shipboard Technology Evaluation Program (STEP): Experimental Ballast Water Treatment Systems. Commandant Publication P16700.4.

United States Coast Guard. 2013. Nome Maritime Symposium. Presented at the Bering Strait Maritime Symposium, Nome, Alaska. <http://seagrant.uaf.edu/conferences/2013/bering-strait-maritime/presentations/houck-cg-overview-traffic-spill-response-web.pdf>

United States Coast Guard. 2013. Shipboard Technology Evaluation Program (STEP). Homeport. <https://homeport.uscg.mil/> 11 Aug 2013.

Verling, E., Ruiz, G. M., Smith, L. D., Galil, B., Miller, A. W., Murphy, K. R. 2005. Supply-side invasion ecology: characterizing propagule pressure in coastal ecosystems. Proceedings of the Royal Society B 272: 1249 – 1257.

Vessels Carrying Oil, Noxious Liquid Substances, Garbage, Municipal or Commercial Waste, and Ballast Water. Title 33 Code of Federal Regulations Part 151. 1 Aug 2013.

Ware, C., Berge, J., Sundet, J., Kirkpatrick, J., Coutts, A., Jelmert, A., Olsen, S., Floerl, O., Wisz, M., Alsos, I. 2013. Climate change, non-indigenous species and shipping: assessing the risk of species introduction to a high-Arctic archipelago. Diversity and Distributions 1 – 10.

Wiegers, J., Feder, H., Mortensen, Shaw, D., Wilson, V., Landis W. 1998. A regional multiple-stressor rank-based ecological risk assessment for the fjord of Port Valdez, Alaska. Human and Ecological Risk Assessment 4: 1125 – 1173.

Wonham, M., Carlton, J., Ruiz, G., Smith, L. 2000. Fish and ships: relating dispersal frequency to success in biological invasions. Marine Biology 136: 1111 – 1121.

Zanden, M., Olden, J. 2008. A management framework for preventing the secondary spread of aquatic invasive species. Canadian Journal of Fisheries and Aquatic Science 65: 1512 – 1522.

TABLES

Chapter 1

Table 1.1. Characteristics of ballast water discharge to ecoregions of Alaska, 2005 through 2012.

Ecoregion	Volume (MT)	Discharging arrivals	Dominant vessel type	Average age (days)	Managed ballast discharge (%)
12	7.2E+02	2	Other	96.0	0.0
13	3.3E+06	149	Bulker	13.3	86.1
14	2.2E+04	110	Bulker	31.8	75.9
53	2.0E+05	362	Container & Reefer	35.2	70.6
54	6.9E+07	2556	Tanker	8.7	29.7
55	1.6E+06	582	Bulker	17.8	92.1

Table 1.2. Characteristics of ballast water discharge to Alaska, 2005 through 2012.

Port	Volume (MT)	Discharging arrivals*	Dominant discharging vessel type by volume	Average age (days)	Managed ballast discharge (%)
Adak Island	2.7E+02	1	Reefer	25.0	100.0
Afognak	5.4E+05	64	Bulker	16.6	91.1
Akutan	1.6E+03	6	Reefer	17.5	71.2
Alaska	3.1E+05	6	Tanker	9.0	0.0
Anchorage	1.2E+05	41	Tanker	22.4	61.2
Angoon	1.6E+02	1	Reefer	62.0	100.0
Atka	8.4E+01	1	General Cargo		0.0
Auke Bay	1.7E+02	1	Other	7.0	1.0
Beaver Inlet	2.5E+03	6	Reefer	13.0	0.0
Bristol Bay	2.6E+02	1	Reefer	35.0	61.9
Captains Bay	5.2E+01	1	General Cargo	7.0	0.0
Chignik	9.9E+01	1	Reefer	19.0	0.0
Cold Bay	9.9E+01	1	Reefer	48.0	0.0
Cook Inlet	6.9E+02	5	Container	45.6	60.9
Cordova	1.3E+03	5	Tanker	6.0	0.0
Drift River Terminal	6.2E+05	75	Tanker	6.0	23.2
Dutch Harbor	1.7E+05	308	Container & reefer	33.6	68.4
Egegik	9.9E+01	2	Other	8.0	0.0
Hagemeister Island	8.4E+02	4	Reefer	19.3	89.3
Haines	2.0E+01	1	Other	4.0	0.0
Hawk Inlet	4.7E+05	88	Bulker	21.7	97.0
Homer	1.9E+04	11	General Cargo	25.1	91.7

Hoonah	6.2E+03	19	Passenger	7.0	31.7
Hydaburg	3.8E+05	55	Bulker	22.7	99.1
Icy Bay	5.5E+04	10	Bulker	15.4	100.0
Icy Strait	9.6E+03	34	Passenger	5.2	0.0
Juneau	5.2E+04	126	Passenger	6.7	20.0
Kake	1.3E+04	3	Bulker	15.0	100.0
Ketchikan	2.2E+05	102	Bulker	16.7	89.7
King Cove	6.7E+02	6	Reefer	48.2	69.5
Kivalina	1.4E+05	6	Bulker	9.9	96.6
Klawock	2.0E+05	33	Bulker	20.7	97.7
Knowles Head Anchorage	2.8E+04	3	Tanker	6.6	27.5
Kodiak	8.1E+04	22	Bulker	16.5	94.2
LAT LON	4.2E+05	475	Other	16.1	35.9
Leask Cove	8.3E+03	1	Bulker	14.2	90.4
Naknek	7.5E+02	2	Reefer	25.0	100.0
Nikiski	5.8E+06	333	Tanker	11.0	24.0
Nome	6.3E+01	2	Passenger	13.5	100.0
Petersburg	1.5E+03	15	Other	7.0	25.1
Point MacKenzie	5.3E+04	15	Bulker	10.1	98.8
Port Bailey	6.1E+01	1	Reefer	10.0	100.0
Port Clarence	4.7E+02	3	Tanker	12.3	0.0
Port Mackenzie	7.4E+04	5	Bulker	42.1	100.0
Port Moller	2.3E+02	4	General Cargo	186.8	100.0
Prince William Sound	1.6E+06	105	Tanker	7.5	9.2
Prince William Sound COTP Zone	2.5E+05	5	Tanker	7.2	0.0
Prudhoe Bay Offshore	7.2E+02	2	Other	96.0	0.0
Red Dog	3.1E+06	138	Bulker	13.5	85.5
Saint George Island	4.4E+01	1	General Cargo	23.0	0.0
Saint Paul	3.0E+02	6	General Cargo	70.6	42.7
Sand Point	9.0E+02	11	Other	19.2	28.7
Seward	2.1E+06	110	Bulker	14.9	92.5
Shumagin Islands	4.4E+01	1	General Cargo	6.0	0.0
Sitka	1.0E+03	4	Passenger	2.3	0.0
Skagway	1.1E+05	54	Bulker	18.6	92.2
Symonds Bay	4.6E+01	1	Other	9.0	0.0
Togiak Bay	4.8E+02	5	Reefer	13.9	0.0
Tolstoi Bay	7.4E+04	11	Bulker	23.9	100.0

Uganik Bay	2.1E+01	1	General Cargo	88.0	100.0
Unimak Pass	1.3E+02	1	Other	35.0	0.0
Valdez	5.8E+07	1414	Tanker	7.2	27.7
Warm Chuck Inlet	2.3E+02	1	Other	19.0	100.0
Western Alaska COTP Zone	3.3E+04	2	Bulker	10.8	75.0
Whitestone	6.2E+01	1	Other	3.0	100.0
Whittier	7.1E+04	143	Other	5.8	0.5
Wrangell	1.0E+02	2	Passenger	6.0	0.0
Yakutat	4.8E+04	7	Bulker	13.3	51.5
All Ports	7.5E+07	3773	Tanker	10.7	33.4

*A single vessel may discharge ballast at multiple locations.

Chapter 2

Table 2.1. Factors to categorize risk of ballast-borne marine invasive species in ports of Alaska.

	Environmental Similarity	Age (days)	Corrected mean volume of ballast water discharge (log_{10}MT)	Species Richness
(1) Low	< 1	> 10	< 2.6	< 110
(2) Medium	1 – 2	6 – 10	2.6 – 5.1	110 – 219
(3) High	> 2	< 6	> 5.1	> 219

Table 2.2. The dominant vessel types discharging ballast water and the primary exports for the top 15 ports in Alaska by ballast discharge volume.

Port	Dominant Vessel Type Discharging Ballast Water	Dominant Vessel (%)	Primary Export
Afognak	Bulker	100%	Timber
Drift River Terminal	Tanker	100%	Crude oil
Dutch Harbor	Container & Reefer	43% & 44%	Seafood
Hawk Inlet	Bulker	90%	Metals
Hydaburg	Bulker	100%	Timber
Ketchikan	Bulker	95%	Timber
Klawock	Bulker	100%	Timber
Kodiak	Bulker	96%	Seafood
Nikiski	Tanker	98%	Crude oil
Prince William Sound	Tanker	100%	Crude oil
Red Dog	Bulker	100%	Zinc & lead
Seward	Bulker	99%	Coal
Skagway	Bulker	82%	Minerals, timber
Tolstoi Bay	Bulker	100%	Timber
Valdez	Tanker	100%	Crude oil

Table 2.3. Average ballast water discharge volume, corrected discharge volume and age in the top 15 ports in Alaska that received the greatest volume of ballast discharge, 2009 through 2012. Discharging arrivals represents the number of vessels that reported discharging ballast at a given location; vessels may discharge ballast in more than one location on a single voyage.

Port	Discharging Arrivals	Volume (SE) (MT)	Corrected Volume (SE) (MT)	Age (SE) (days)
Afognak	38	3.1E+5 (29.3)	3.8E+4 (8.4)	16.9 (0.4)
Drift River Terminal	60	4.9E+5 (34.9)	4.1E+5 (41.2)	5.8 (0.3)
Dutch Harbor	225	1.3E+5 (10.7)	4.7E+4 (7.3)	36.3 (1.5)
Hawk Inlet	47	2.7E+5 (50.4)	3.1E+4 (6.7)	20.4 (0.7)
Hydaburg	37	2.8E+5 (27.6)	3.0E+4 (5.1)	22.9 (0.5)
Ketchikan	57	1.5E+5 (33.1)	2.2E+4 (3.9)	16.6 (0.8)
Klawock	18	1.4E+5 (42.0)	1.4E+4 (4.2)	20.1 (1.0)
Kodiak	16	8.E+4 (29.1)	1.1E+4 (9.7)	17.3 (0.6)
Nikiski	99	1.6E+6 (42.2)	1.3E+6 (41.1)	11.0 (0.4)
Prince William Sound	62	3.4E+5 (171.6)	2.1E+5 (167.9)	7.5 (0.9)
Red Dog	81	1.9E+6 (73.3)	4.9E+5 (60.1)	13.2 (0.1)
Seward	84	1.6E+6 (107.6)	2.8E+5 (44.9)	15.1 (0.4)
Skagway	24	8.3E+4 (68.8)	1.0E+4 (10.1)	20.4 (1.1)
Tolstoi Bay	10	7.4E+4 (42.0)	7.4E+3 (4.2)	23.9 (2.3)
Valdez	1088	4.7E+7 (24.4)	3.3E+7 (24.0)	7.4 (0.1)
Total	1946	5.4E+7 (20.3)	3.6E+7 (19.0)	10.3 (0.1)

Table 2.4. Relative risk on a scale of 1 to 3 (low to high) per factor. Risk scores are shown per year and for the average of all four years. Zeroes indicate that no ballast was received during that year.

Port	**Env Similarity Risk**					**Volume Risk**				
	2009	2010	2011	2012	**All**	2009	2010	2011	2012	**All**
Afognak	2	1	1	2	2	2	2	2	2	2
Drift River Terminal	3	2	3	3	3	2	2	3	3	3
Dutch Harbor	2	2	2	2	2	2	2	2	2	2
Hawk Inlet	1	2	2	2	2	2	2	2	2	2
Hydaburg	2	1	2	2	2	2	2	2	2	2
Ketchikan	2	2	2	2	2	2	2	2	2	2
Kodiak	3	2	2	1	2	1	2	2	2	2
Klawock	1	1	1	1	1	2	2	2	2	2
Nikiski	2	2	2	2	2	3	3	3	2	3
Prince William Sound	1	2	1	0	2	3	2	2	0	3
Red Dog	2	2	2	2	2	2	2	3	3	3
Seward	2	2	2	2	2	2	2	2	2	3
Skagway	2	2	1	2	2	2	2	2	2	2
Tolstoi Bay	0	0	1	1	1	0	0	2	2	2
Valdez	2	2	2	2	2	3	3	3	3	3

Port	**Age Risk**					**Species Richness Risk**				
	2009	2010	2011	2012	**All**	2009	2010	2011	2012	**All**
Afognak	1	1	1	1	1	1	1	1	1	1
Drift River Terminal	2	2	3	3	3	1	2	2	2	2
Dutch Harbor	1	1	1	1	1	2	2	2	2	3
Hawk Inlet	1	1	1	1	1	1	2	1	1	2
Hydaburg	1	1	1	1	1	1	1	1	1	1
Ketchikan	1	1	1	1	1	1	1	1	1	1
Kodiak	3	1	1	1	1	1	1	1	1	1
Klawock	1	1	1	1	1	1	1	1	1	1
Nikiski	1	2	2	1	1	1	1	1	2	2
Prince William Sound	2	2	2	0	2	1	1	1	0	2
Red Dog	1	1	1	1	1	1	1	1	1	1
Seward	1	1	1	1	1	1	1	1	1	1
Skagway	1	1	1	1	1	1	1	1	1	1
Tolstoi Bay	0	0	1	1	1	0	0	1	1	1
Valdez	2	2	2	2	2	2	2	2	2	2

FIGURES

Chapter 1

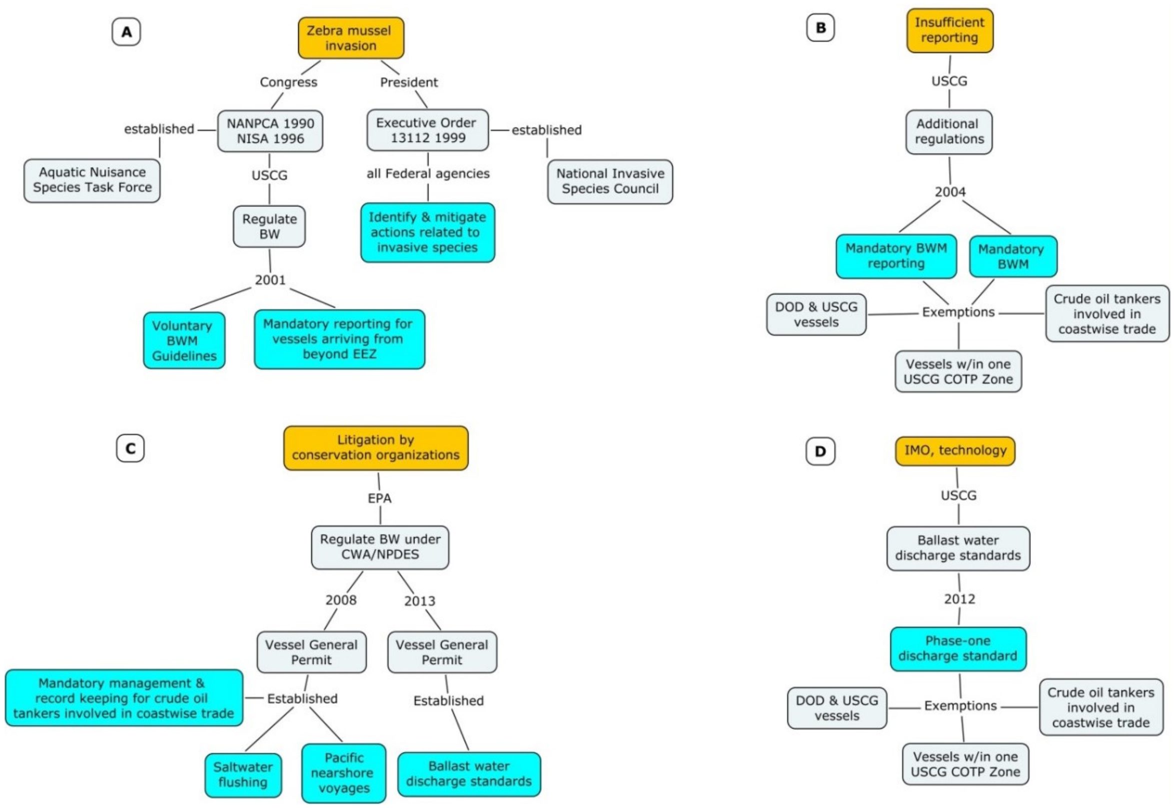

Figure 1.1. A 4-step concept map depicting drivers of ballast water management policy in the United States. Yellow boxes depict drivers of policy and blue boxes depict outcomes or implementation of policy. Map A portrays the foundation of ballast water management policy in the United States as a result of zebra mussel invasion in the Great Lakes. This invasion led to several federal regulatory actions that resulted in the establishment of management and oversight organizations and initial attempts at regulating vessel management practices. Map B portrays the shift to mandatory ballast water management and reporting as a result of insufficient response to voluntary programs. Map C portrays the development of ballast water management policy by the Environmental Protection Agency under the authority of the Clean Water Act as a result of legal pressure. This policy, the Vessel General Permit, regulated previously exempted vessels which in turn had a significant impact on ballast water reporting in Alaska. Finally, Map D portrays the most recent ballast water management policy in the United States. Following standards created by the International Maritime Organization, ballast water discharge standards have been set by both the United States Coast Guard and the Environmental Protection Agency and in the future will become the predominant method of reducing global ballast-borne invasive species risk.

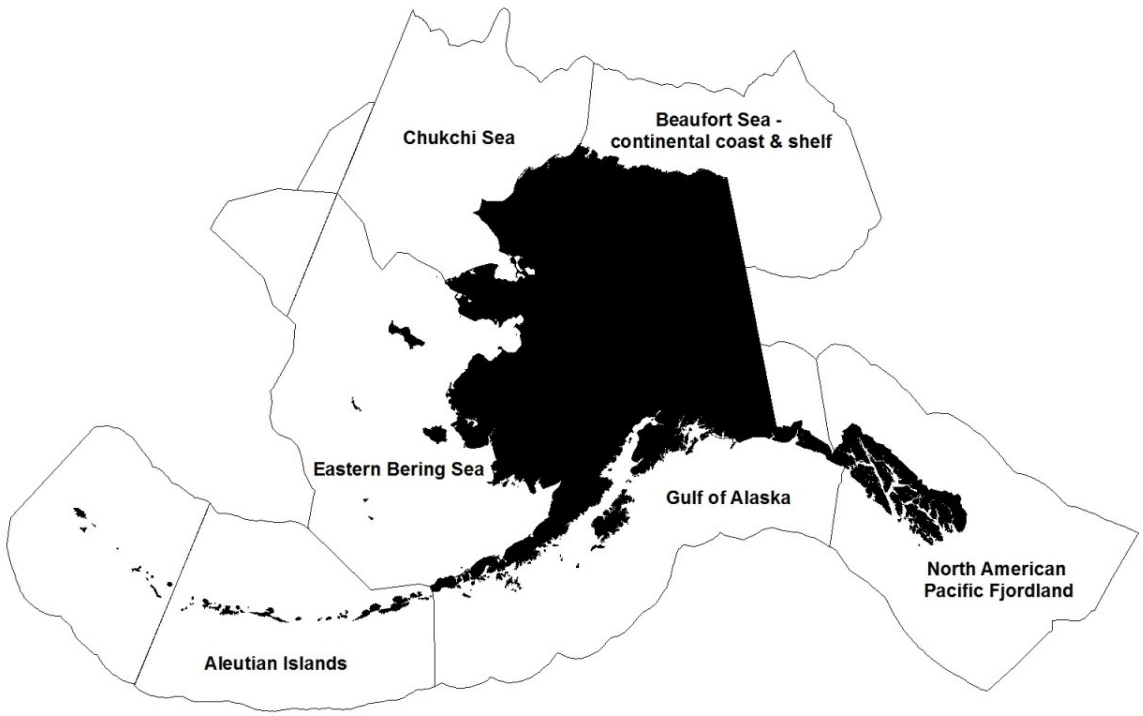

Figure 1.2. Ecoregions of Alaska, as described by Spalding *et al*. 2007 (Marine Ecoregions of the World).

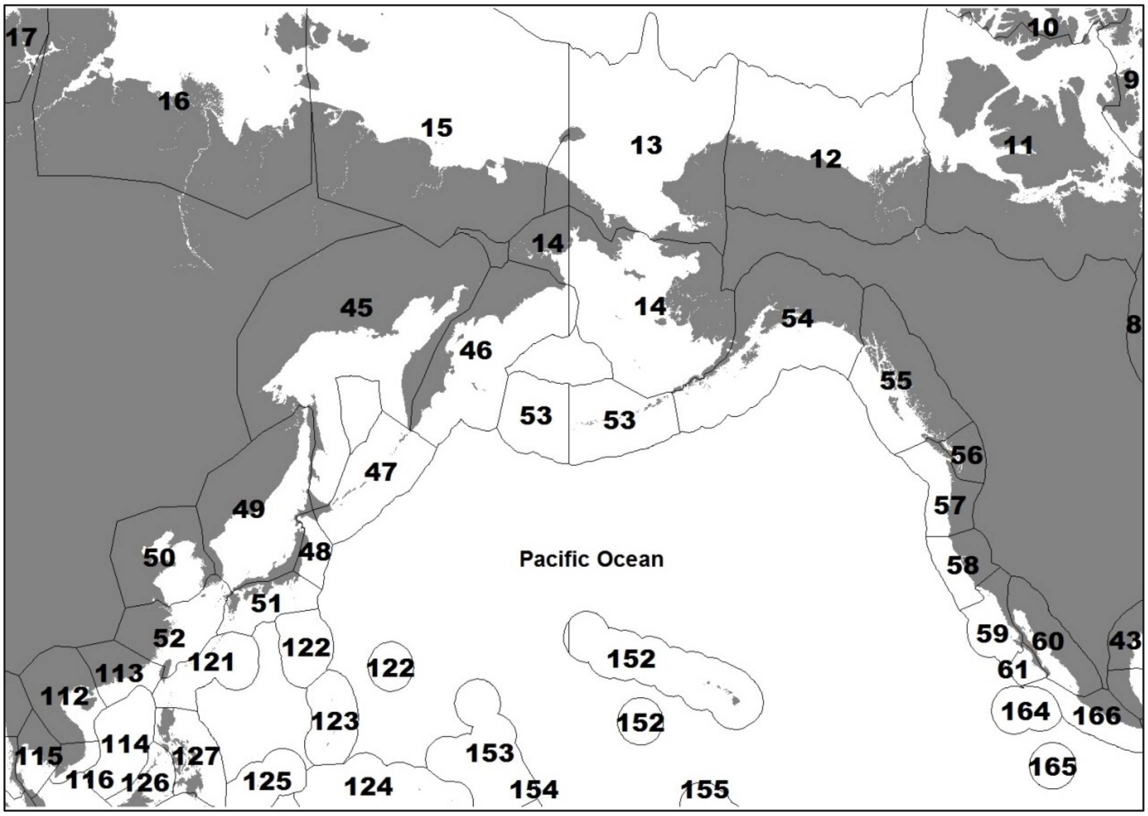

Figure 1.3. Ecoregions of the Pacific Ocean, as described by Spalding *et al*. 2007 (Marine Ecoregions of the World).

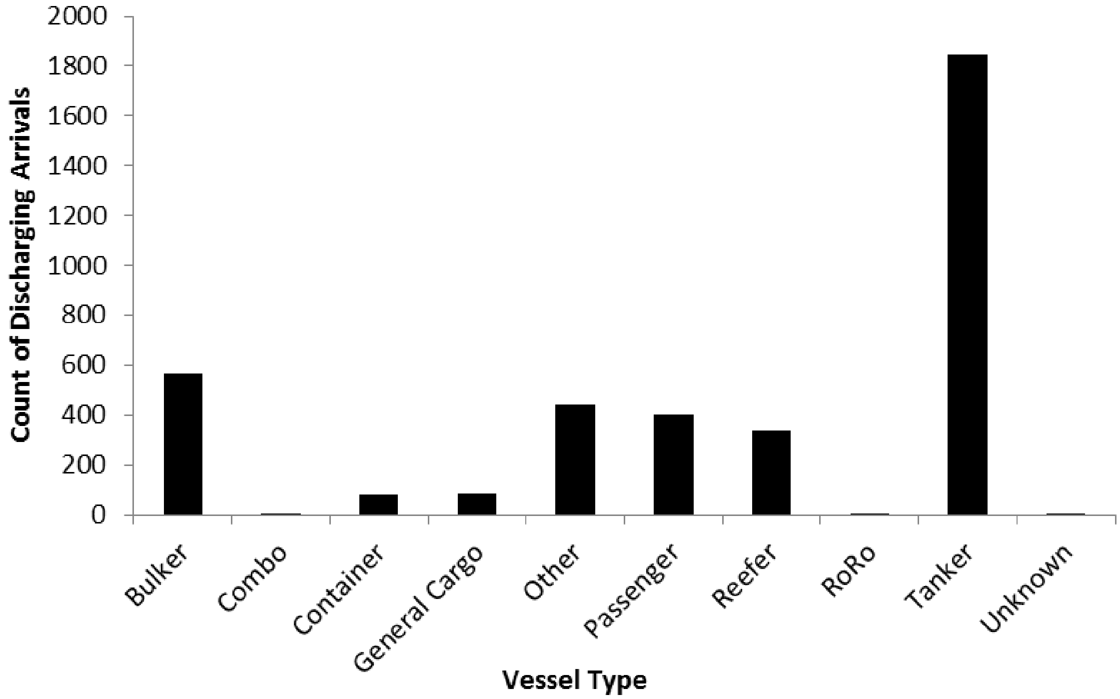

Figure 1.4. Count of vessels that reported discharging ballast water to Alaska per type, 2005 through 2012.

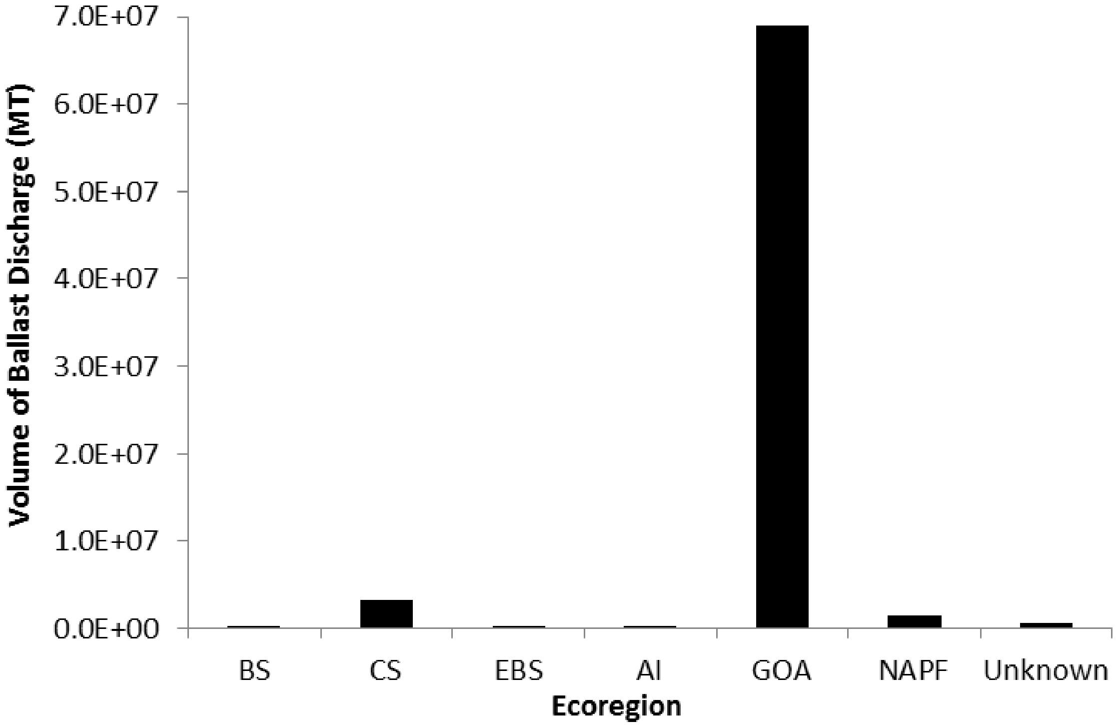

Figure 1.5. Reported volume (metric tons) of ballast water discharged to ecoregions along Alaska's coastline, 2005 through 2012. BS = Beaufort Sea – continental coast and shelf (12), CS = Chukchi Sea (13), EBS = Eastern Bering Sea (14), AI = Aleutian Islands (53), GOA = Gulf of Alaska (54), NAPF = North American Pacific Fjordland (55).

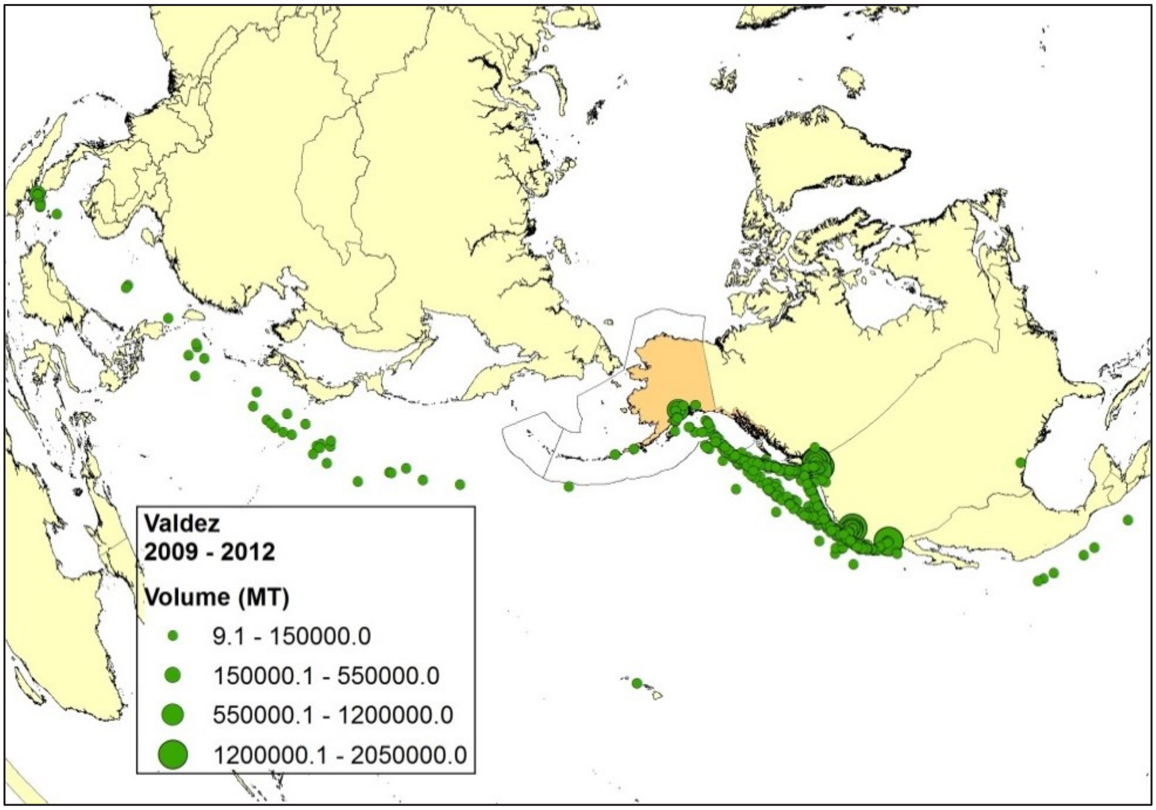

Figure 1.6. Ballast water source locations by reported volume for the Port of Valdez, Alaska, 2009 through 2012.

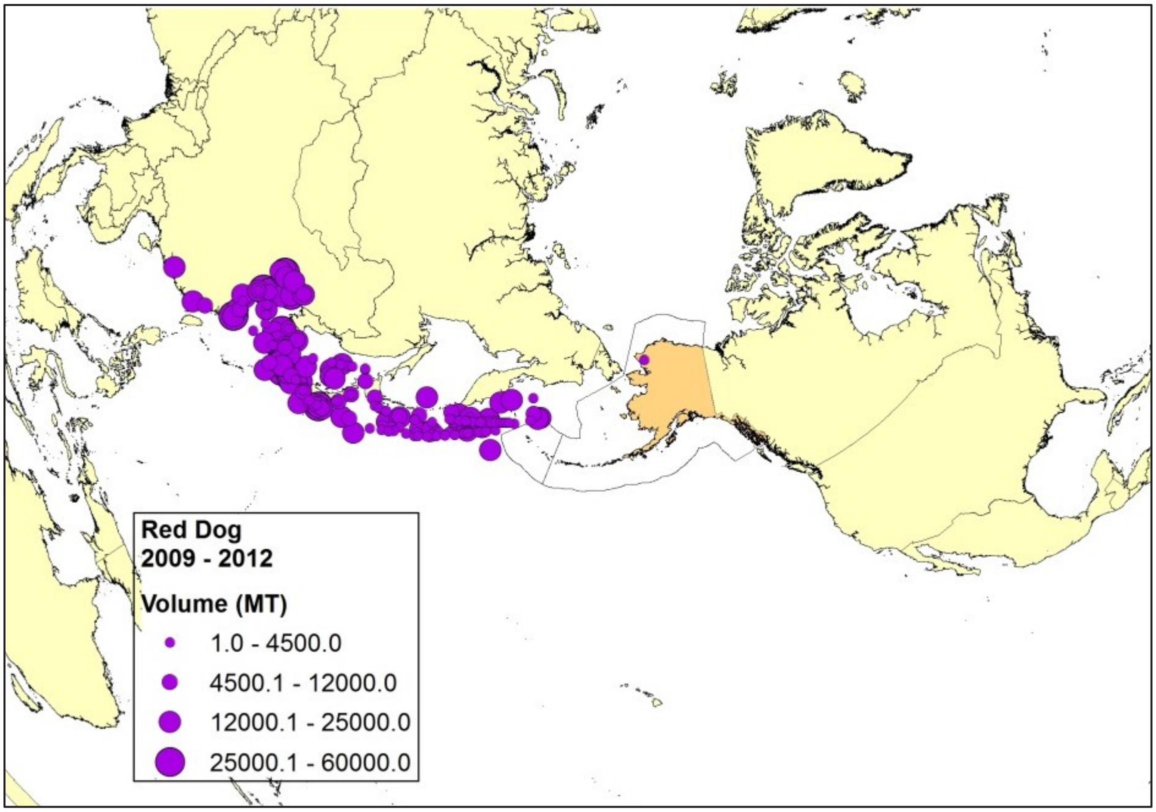

Figure 1.7. Ballast water source locations by reported volume for the Port of Red Dog, Alaska, 2009 through 2012.

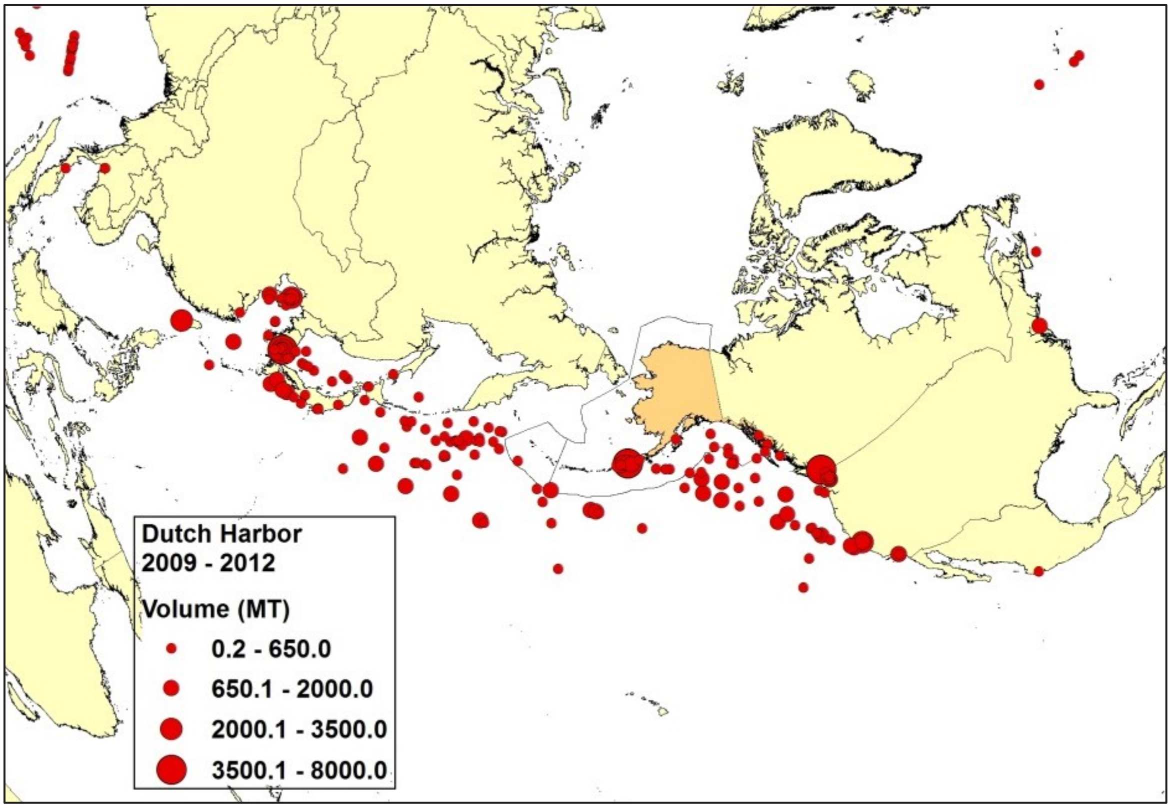

Figure 1.8. Ballast water source locations by reported volume for the Port of Dutch Harbor, Alaska, 2009 through 2012.

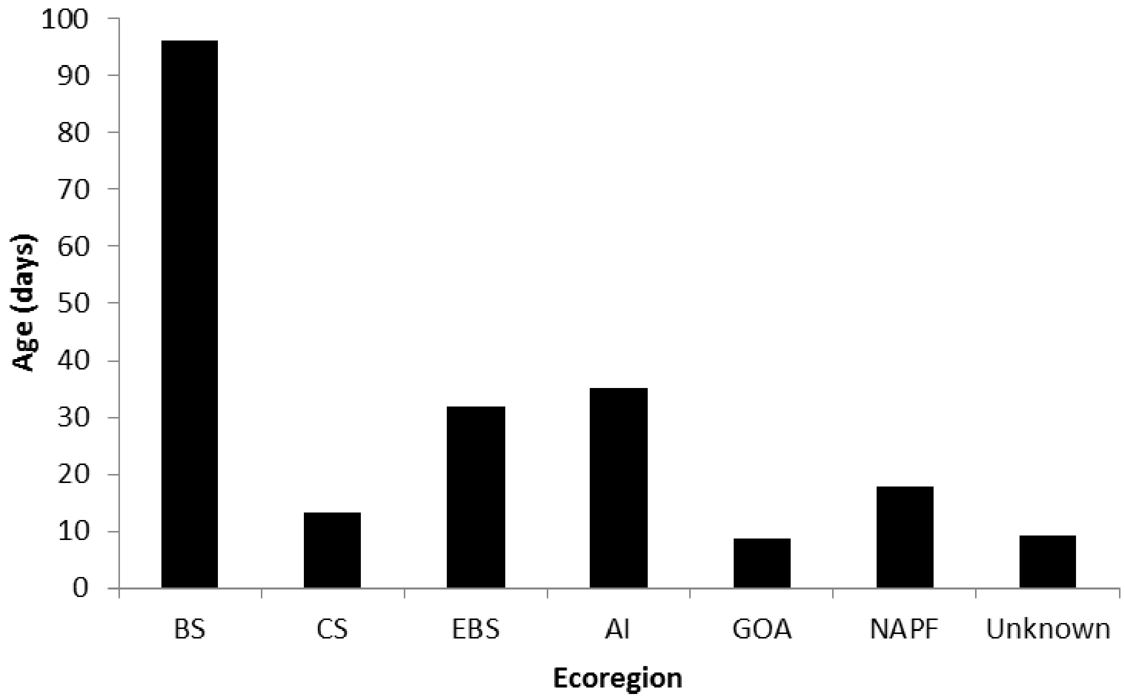

Figure 1.9. Average age of reported ballast water discharged to ecoregions along Alaska’s coastline, 2005 through 2012. BS = Beaufort Sea – continental coast and shelf (12), CS = Chukchi Sea (13), EBS = Eastern Bering Sea (14), AI = Aleutian Islands (53), GOA = Gulf of Alaska (54), NAPF = North American Pacific Fjordland (55).

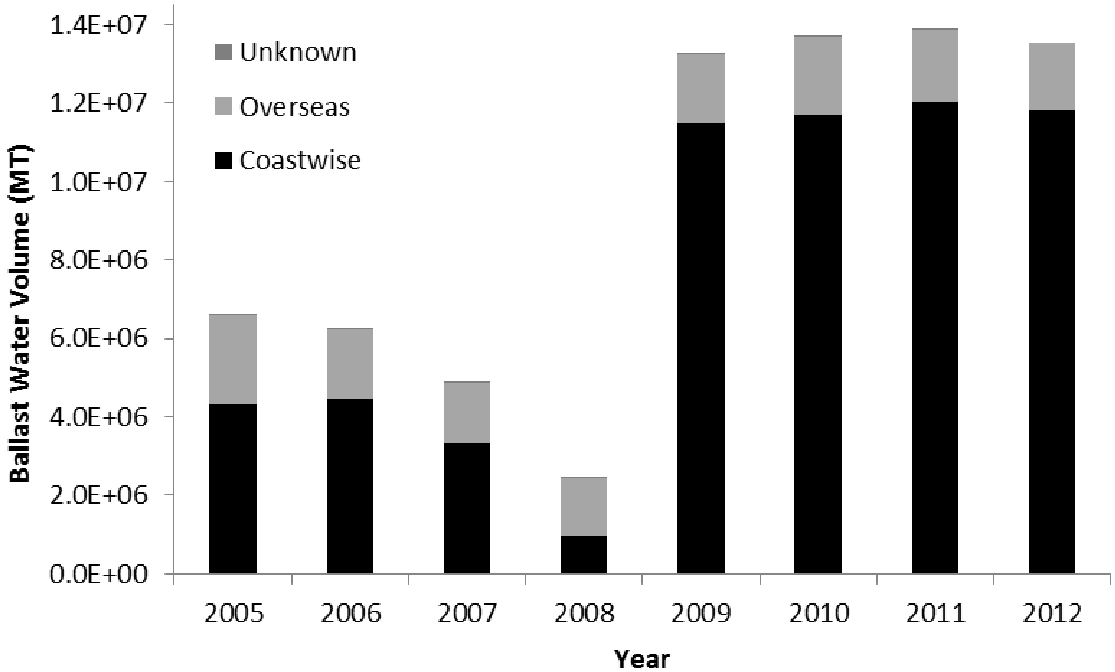

Figure 1.10. Reported volume (metric tons) of ballast water discharged to Alaska, 2005 through 2012.

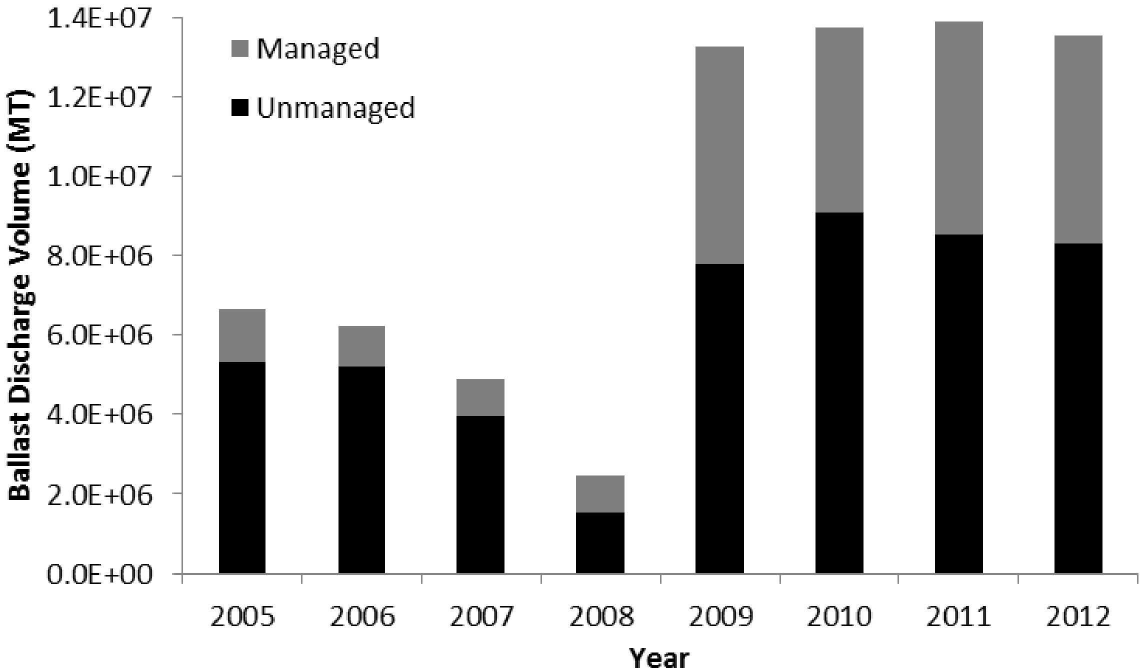

Figure 1.11. Reported volume (metric tons) of managed and unmanaged ballast water discharged to Alaska, 2005 through 2012.

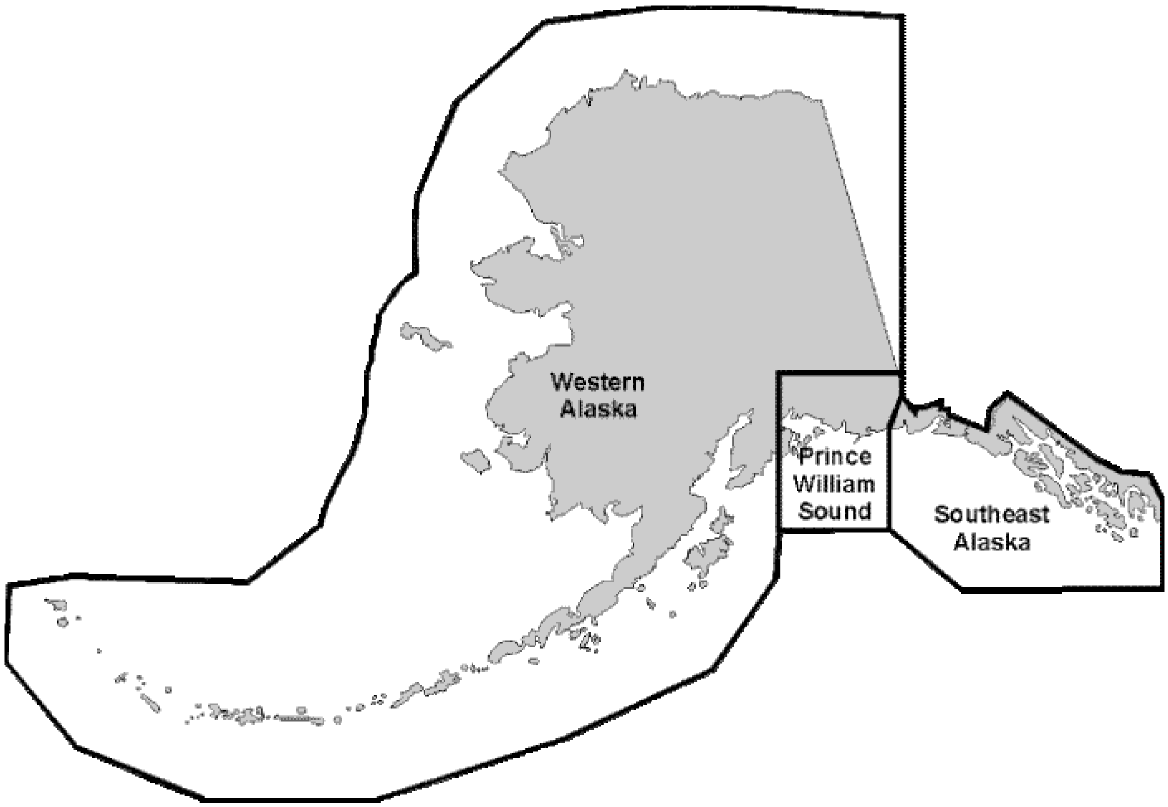

Figure 1.12. Designated United States Coast Guard Captain of the Port Zones in Alaska
<http://www.mxak.org/uscg/cotp_areas.html>

Chapter 2

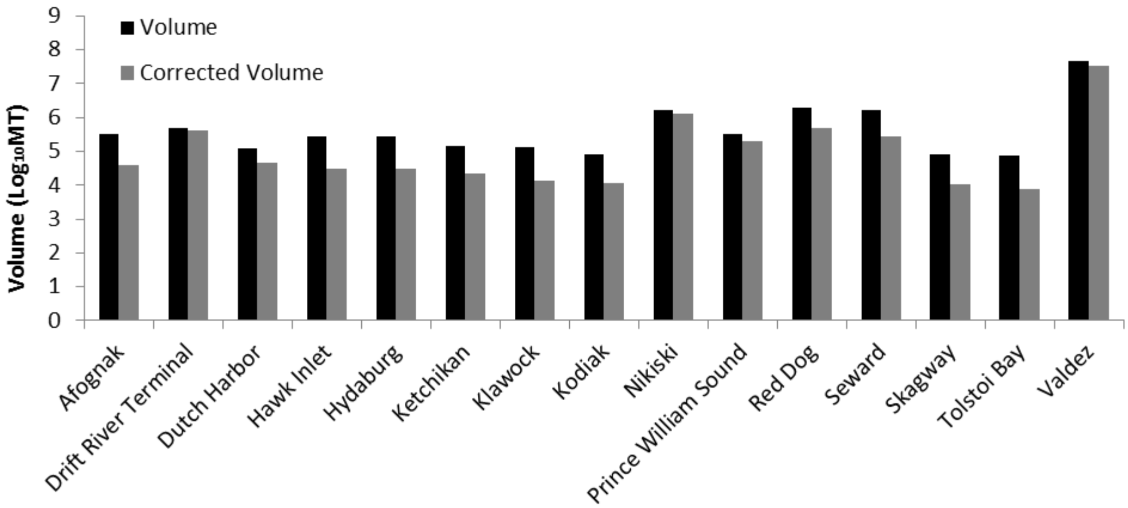

Figure 2.1. Actual and corrected reported ballast water discharge volumes for the top 15 ports of Alaska by volume, 2009 through 2012.

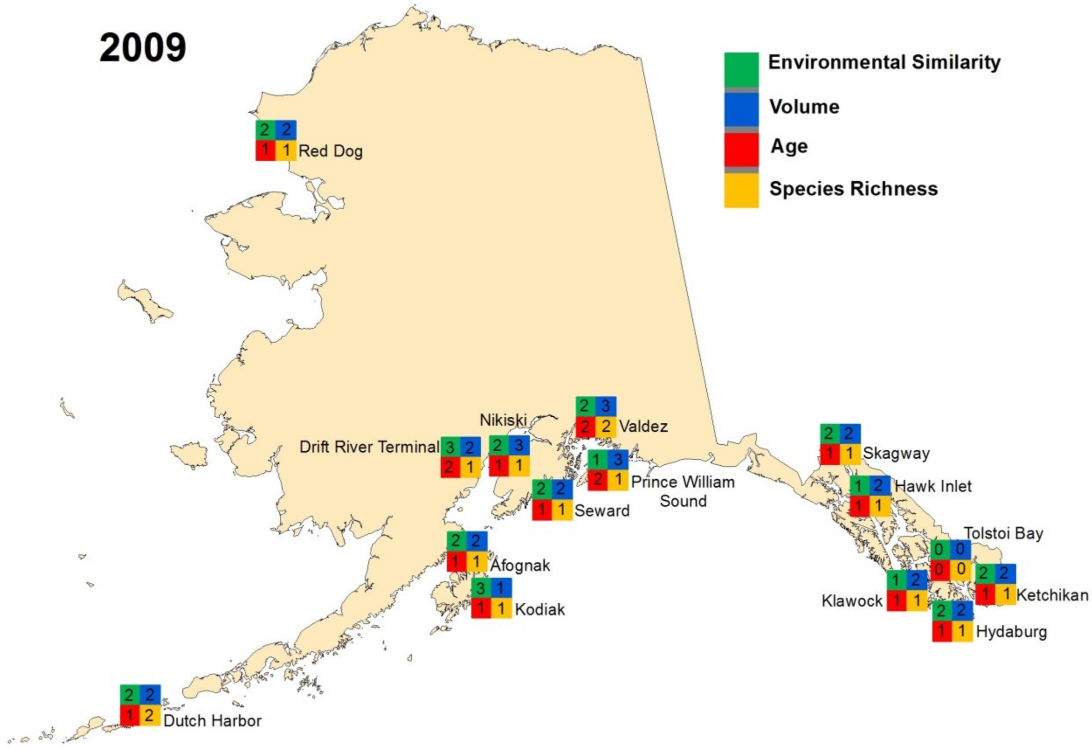

Figure 2.2. Relative risk of ballast-borne species invasions in 15 ports of Alaska during 2009.

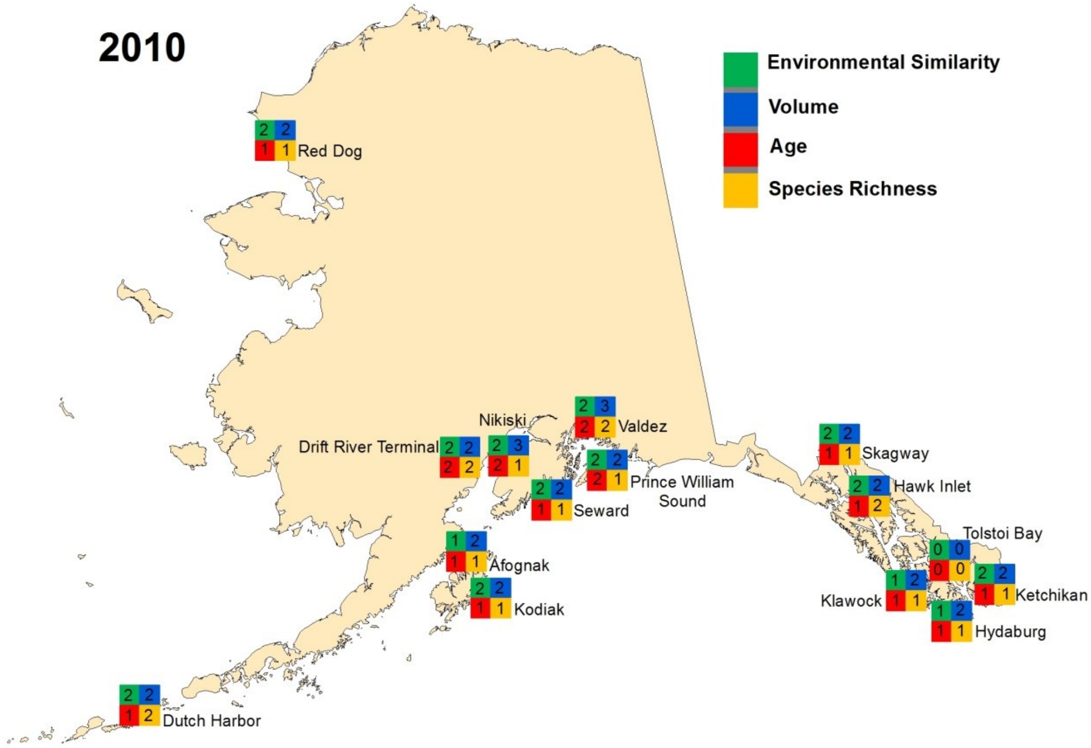

Figure 2.3. Relative risk of ballast-borne species invasions in 15 ports of Alaska during 2010.

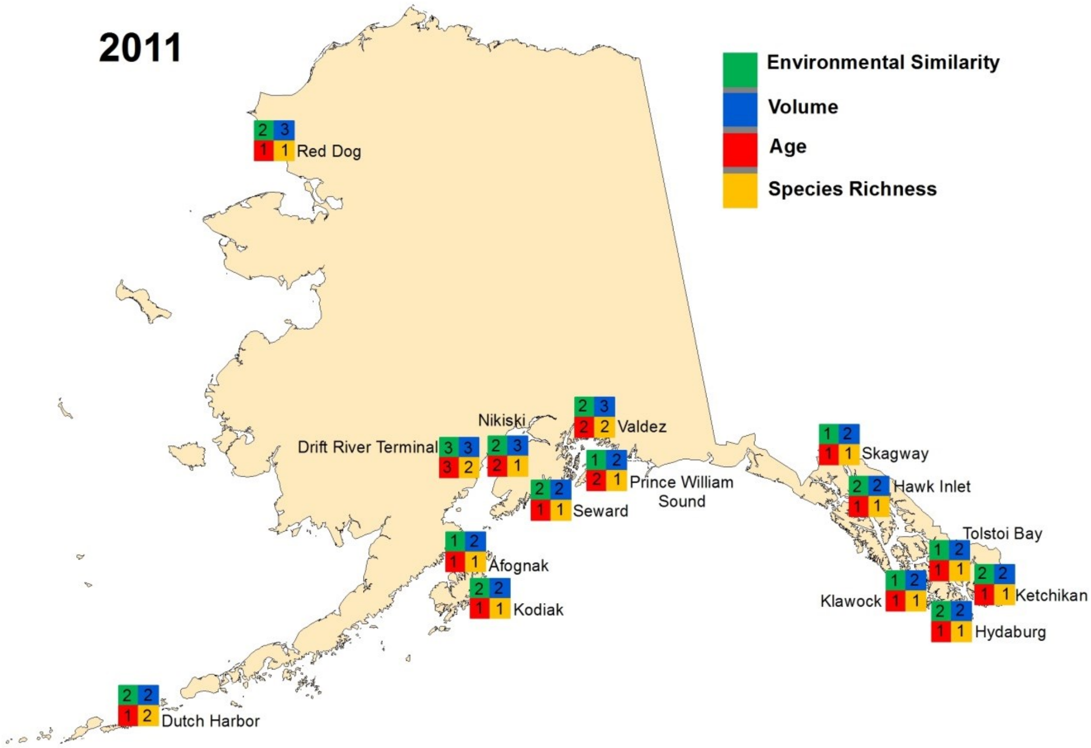

Figure 2.4. Relative risk of ballast-borne species invasions in 15 ports of Alaska during 2011.

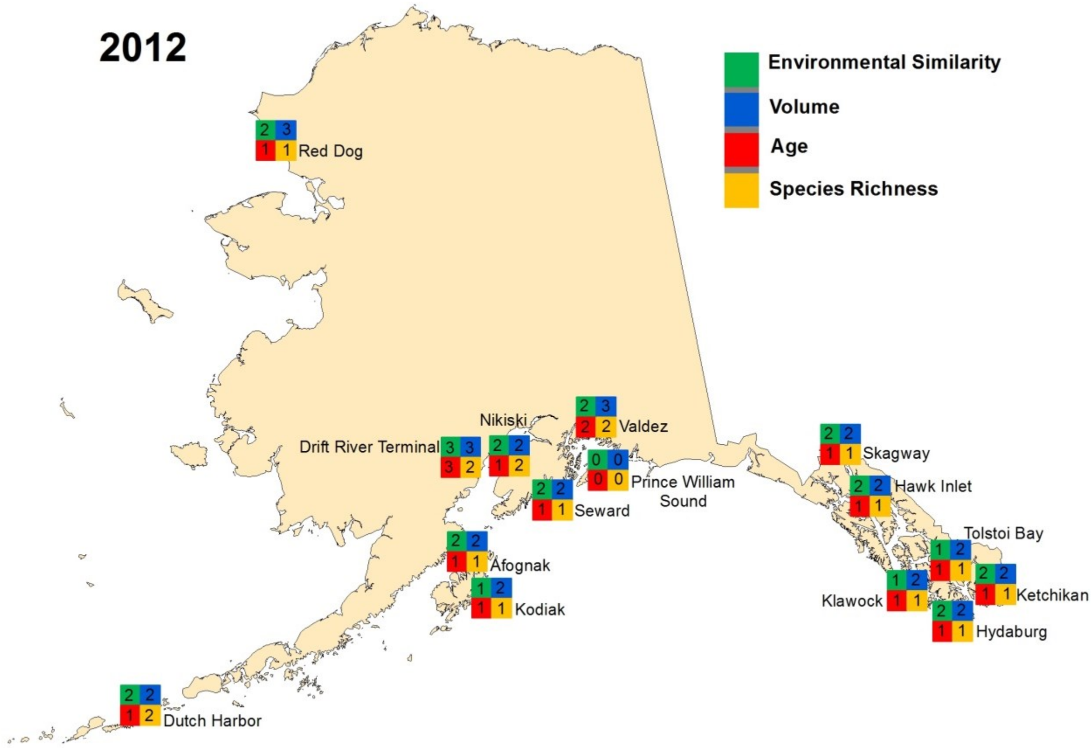

Figure 2.5. Relative risk of ballast-borne species invasions in 15 ports of Alaska during 2012.

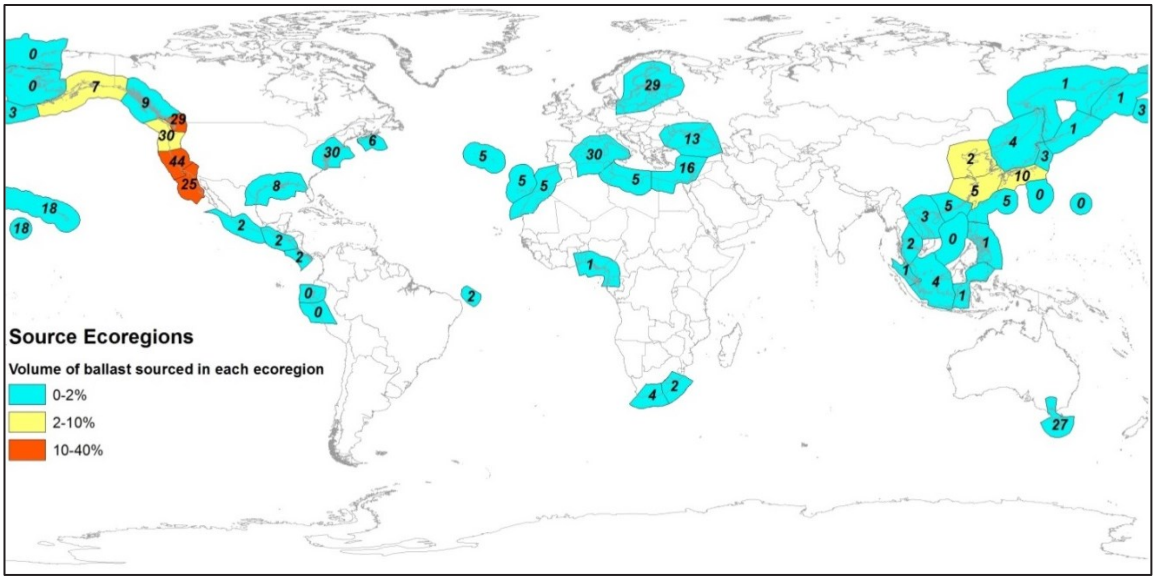

Figure 2.6. The number of ballast-borne marine invasive species per ballast water source ecoregion of Alaska, 2009 through 2012. Species data are from Molnar *et al*. 2008.