THE INTRODUCTION OF NON-NATIVE SPECIES TO MARINE ENVIRONS: AN UNINTENDED AND HIDDEN CONSEQUENCE OF INTERNATIONAL SHIPPING

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INTRODUCTION

One unintended byproduct of the increase in global trade and the phenomenon generally known as "globalization" has been the introduction of non-native species (NNS) to new environs (Ruiz and Carlton, 2003). Since a great proportion of cargo destined for foreign markets is transported by ship, the international shipping trade has become a powerful vector for spreading NNS. As biologists continue to monitor this expanding threat to marine, coastal, and freshwater ecosystems, companies are also beginning to acknowledge responsibilities related to the "greening" of the supply chain, including concern for the introduction of NNS. This article provides an overview of the role international shipping plays in the spread of NNS, describes damage inflicted by ship-borne NNS, describes regulatory responses to the problem, then offers strategies for addressing the issue at the supply chain level.

HISTORICAL OCEAN TRADE ROUTES AND THE GROWTH IN GLOBAL SHIPPING

This is not a new problem. Man's travels have not been with a light foot. Domesticated animals—herds, flocks and pets—have been a part of our travels for thousands of years. The Spaniards brought horses to the North American continent in the 16th century. Escaping horses set upon the prairies producing herds of offspring.

Our experience in North America is not unique. Australians brought camels to help move products in the Outback, and began releasing them in the 1920's. The population, now over 700,000, is set to double about every eight years. Their selective grazing on some trees and shrubs has led to local extinction of these species. Watering holes, along with agricultural infrastructure are also being damaged (Carbonell, 2005).

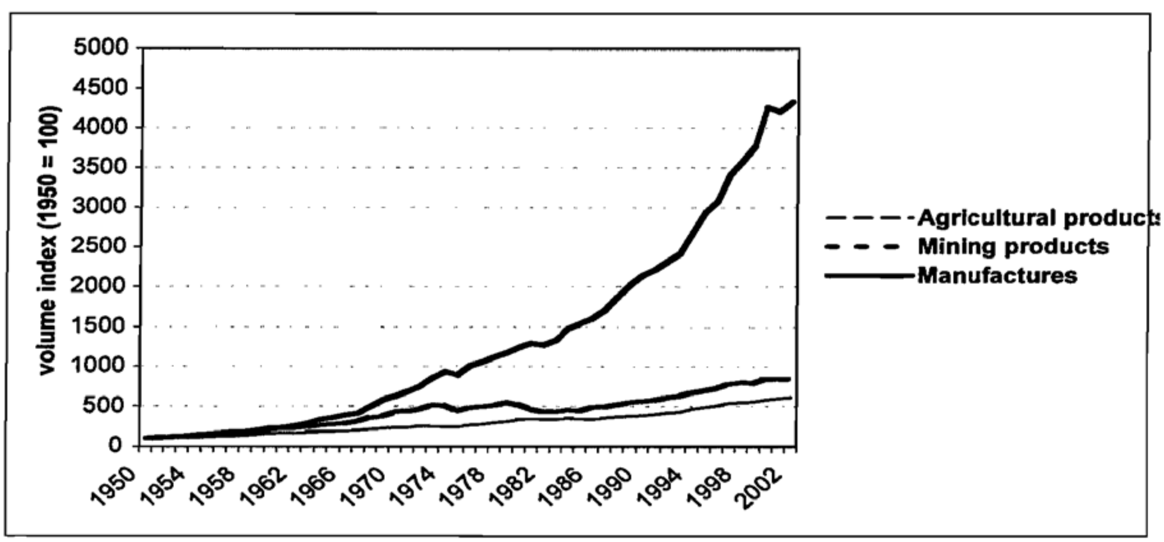
In turn, we have also carried non-native species of plants with us as well. It is estimated that thousands of plant species have been brought to the North American continent over the past three centuries. They were brought intentionally based on their food, ornamental or medicinal value. While appreciated by gardeners, many present a threat to the environment. (Thompson, 1999)

Given the projected amount of global trade, one can only anticipate that the problem will continue to grow. While intentional importation of various species is regulated, what travels below the waterline – and out of sight – should be of concern. For instance, most have heard of the introduction of zebra mussels into the Great Lakes around 1985 or Asian carp in the 1960's. Yet, few are aware of the damages caused by the Chinese mitten crab to the Chesapeake Bay ecosystem (Maryland Invasive Species Council, 2007). Invasive species are such a threat that the State of Maryland has established the Maryland Invasive Species Council (MISC). Many of these species are thought to have been carried in the ballast water of vessels.

Traveling to the West Coast, the situation is similar. Approximately 90 percent of the species and 99 percent of the biomass in San Francisco Bay are NNS. The pace of infestation is accelerating with trade. From 1851 to 1960, a span of 109 years, 117 NNS were introduced. From 1960 to 1995, a span of 35 years, 117 more arrived (Pimentel, 2003).

International trade is one of the drivers to the continued infestation of various species. As reported by the EEA, volume of trade has dramatically escalated since 1950 (Figure 1 below). Most of this trade is supported by ocean carriers, which in turn leads to potential contamination of local environments from the vessel's ballast waters. "Shipping moves over 80 percent of the world's commodities and transfers approximately 3 to 5 billion tonnes of ballast water internationally each year." (Global Ballast Water Management Programme Website). In Australia, about 60 million tonnes of ballast water are discharged annually into their ports. (http://www.austmus.gov.au/factsheets/ballast.htm).

FIGURE 1
GROWTH OF WORLD TRADE AS REPORTED BY EEA



Source: Sustainable use and management of natural resources, EEA Report No 9/2005, EEA, Copenhagen 2005, Figure 2 – 3, page 13. FYI, from WTO 2003.

The purpose of this article is to provide an overview of the role international shipping plays in the spread of NNS, describe some of the damage inflicted by ship-borne NNS, briefly describe regulatory responses to the problem and offer strategies for addressing the issue at the supply chain level.

THE SIGNIFICANCE OF THE INTRODUCTION OF NON-NATIVE SPECIES BY OCEAN SHIP BORNE CARRIERS

The introduction of non-native species (NNS) to coastal habitats is generally accepted as harmful to the health of the local ecosystem and the commerce derived from that resource. In the case of pathogens, they can be harmful to human health, as well. Even those who think these introductions to be natural and inevitable agree that, at least from a short-term perspective, they are disruptive and can have devastating financial consequences for commerce. The introduction of NNS is different from other problems, like pollution or overharvest of resources. Simberloff (2005A, p. 216) points out that the introduction of NNS should be viewed as an "irrevocable act" as living organisms, once established in a new environment, have the capacity to independently reproduce, expand, and even evolve (Cox, 2004 as cited in Simberloff 2005A). In addition, eradication of such an invasive species is generally unsuccessful and prohibitively expensive (Veitch 2002 as cited in Simberloff 2005A). In many cases, invading NNS occupy an environmental niche that is vacant, with few or no predators and untapped sources of nourishment.

The damage inflicted by NNS comes in many forms. Nunes and van den Bergh (2004), in their examination of the effects of harmful introduced algal bloom species, categorized the damages inflicted by NNS into Use Value and Non-Use Value. Use Value includes the effect on marine resources with commercial value, the effect on the health of the marine ecological system, the effect on human health, and the impact on tourism and recreational benefits. Non-Use Value includes the risk of the loss of "legacy benefits" (the risk that future generations would not have access to certain marine resources) and the risk of "existence benefits" (the risk that certain marine species would go locally extinct).

Ocean ships are the primary vector for the spread of marine non-native species (NNS) to new coastal environs. Ocean ships typically carry living organisms either attached in some manner to the exterior hull of the ship or as passengers in the water used as ballast in interior tanks. As the use of ships to transport cargo continues to increase, there is a corresponding increase in the number of introduced NNS (Levine and D'Antonio, 2003, reported that as international trade increased, so did the introduction of NNS). Organisms that have been introduced using these vectors include but are certainly not limited to fish, plants, mollusks, crustaceans, algae, plankton, bacteria, and viruses.

The absolute scope of the problem of marine NNS is very difficult to determine. Some of the introductions are old and some are recent. Quantitative assessment of the problem is complex, expensive, and often inadequate. The marine environment undermines the ability of scientists to determine population size and distribution. In many cases, introduction of NNS is but one of several potential causes of ecosystem harm, so the true impact of the NNS is difficult to quantify with validity.

Even so, estimates of the damages inflicted by marine invaders are extremely high. In the United States, damages associated with non-native fish introductions exceed 5.4 billion dollars per year, damages for zebra and quagga mussels 1 billion dollars per year, Asiatic clam 1 billion dollars per year, and green crab 100 million dollars per year (Pimental, 2003).

Drake and Keller (2004) believe that even though the problem of ballast-water introduced NNS affects all coastal nations, the problem will be most severe in developing nations. They posit that developing nations will suffer in a dis-proportionate manner because of two factors. First, because most developing nations are exporting large bulky cargos of raw materials, the types of ships used to carry this cargo are more likely to require ballast tanks. These ships arrive in port with ballast tanks full, then empty the tanks as the heavy cargo is loaded. Thus, more so than with container ships and other ships that frequent more developed ports, more ballast water is released into the poorer coastal areas. Second, less developed countries are less likely to have the financial and scientific resources that would allow them to identify and/or assess the environmental threat of introduced NNS and treat any infestation before it reached a critical sustainable mass.

Ballast-Borne Introduction of NNS

Prior to using water as a ballast, sailors would use stones. As you can imagine, using rocks or stones as a ballast was time consuming. In the 1950's ship builders started to use water as a ballast to help minimize the time needed at port. Water-filled tanks within the hull of a ship are used to maintain stability generally when a ship is not carrying a full load of cargo. As cargo is added to the vessel water from the ballast can be discharged; if the vessel is empty, more ballast water is added to help it sail safely to the next port.

As a ship offloads cargo, water is drawn into the ballast tanks to offset the weight of the cargo leaving the ship. The water drawn into the ballast tanks often contains organisms that are capable of survival during transit. These include organisms in many forms of development including adults, eggs, and larvae. Almost all marine species have at least one stage of development that would allow them to be carried by the water used to fill a ballast tank. Biologists estimate that more than 7,000 marine species are being transported alive in ballast tanks. (Global Ballast Water Management Programme Website, 2008). After arrival in any port to take on cargo, the ballast water is pumped out into the local estuary as cargo is loaded, as it is no longer needed to provide stability.

The amount of water carried in the ballast tank of some large ships is vast, as much as "200,000 cubic meters of water—equivalent to 2,000 Olympic-sized swimming pools (Bright 1999, p 52)." Given that ballast tanks are almost never completely flushed (in many cases they are incapable of complete flushing), it is impossible to trace organisms to any one location. In other words, the organisms residing in a ballast tank represent a unique assortment of plants, animals, and pathogens dependent on the particular travel routes covered and history of the ship itself.

The amount of water taken in and released by the process of filling and flushing ballast tanks makes it a daunting task to keep track of the scope and potential of the problem of introduced marine species. As an example, the port of Baltimore in the United States, as reported by Valigra (1999), is the dump site of more than 12 million metric tons of ballast water each year from 48 different foreign ports. Making the problem more complex, NNS carried in ballast water can be introduced to a locale through either pumping water in or out of a tank. Infestation can occur in either direction.

Even when ships which enter coastal waters with empty ballast tanks, they often contain pockets of sediment in the bottom of the ballast tanks. Studies have shown that these sediments often carry biologically viable organisms (Bailey, Duggan, and Van Overdijk, 2003).

Some Notable Examples

While there have been literally thousands of NNS marine infestations around the world, Table 1 provides examples of a few notable introductions.

There are so many routes for the introduction of human pathogens that tracing a single introduc-tion to ocean shipping is problematic.

There are probably more ship-borne beginnings of epidemics than are currently recognized. To the extent that scientists can tell, the cholera

Table 1
(continued)

TABLE 1
EXAMPLES OF AQUATIC BIO-INVASIONS AND THEIR IMPACT

Name	Native to	Introduced to	Impact
Cholera*Vibrio cholerae* (various strains)	Various strains with broad ranges	South America, Gulf of Mexicoand other areas	Some cholera epidemics appear to be directly associated with ballast water
Cladoceran Water Flea*Cercopagis pengoi*	Black and Caspian Seas	Baltic Sea	Reproduces to form very large populations that dominate the zooplankton community and clog fishing nets and trawls, with associated economic impacts
Mitten Crab*Eiocheir sinensis*	Northern Asia	Western Europe, Baltic Sea and West Coast North America	Undergoes mass migrations for reproductive purposes. Burrows into river banks and dykes causing erosion and siltation. Preys on native fish and invertebrate species, causing local extinctions during population outbreaks. Interferes with fishing activities
Toxic Algae (Red/Brown/ Green Tides)Various species	Various species with broad ranges	Several species have been transferred to new areas in ships' ballast water	May form Harmful Algae Blooms. Depending on the species, can cause massive kills of marine life through oxygen depletion, release of toxins and/or mucus. Can foul beaches and impact on tourism and recreation. Some species may contaminate filter-feeding shellfish and cause fisheries to be closed. Consumption of contaminated shellfish by humans may cause severe illness and death
Round Goby*Neogobius melanostomus*	Black, Asov and Caspian Seas	Baltic Sea and North America	Highly adaptable and invasive. Increases in numbers and spreads quickly. Competes for food and habitat with native fishes including commercially important species, and preys on their eggs and young. Spawns multiple times per season and survives in poor water quality
North American Comb Jelly*Mnemiopsis leidyi*	Eastern Seaboard of the Americas	Black, Azov and Caspian Seas	Reproduces rapidly (self fertilising hermaphrodite) under favourable conditions. Feeds excessively on zooplankton. Depletes zooplankton stocks; altering food web and ecosystem function. Contributed significantly to collapse of Black and Asov Sea fisheries in 1990s, with massive economic and social impact. Now threatens similar impact in Caspian Sea.
North Pacific	Northern	Southern Australia	Reproduces in large numbers, reaching

Table 1
(continued)

Name	Native to	Introduced to	Impact
Seastar*Asterias amurensis*	Pacific		“plague” proportions rapidly in invaded environments. Feeds on shellfish, including commercially valuable scallop, oyster and clam species
Zebra Mussel*Dreissena polymorpha*	Eastern Europe (Black Sea)	Introduced to: Western and northern Europe, including Ireland and Baltic Sea;eastern half of North America	Fouls all available hard surfaces in mass numbers. Displaces native aquatic life. Alters habitat, ecosystem and food web. Causes severe fouling problems on infrastructure and vessels. Blocks water intake pipes, sluices and irrigation ditches. Economic costs to USA alone of around US$750 million to $1 billion between 1989 and 2000
Asian Kelp*Undaria pinnatifida*	Northern Asia	Southern Australia,New Zealand, West Coast of the United States, Europe and Argentina	Grows and spreads rapidly, both vegetatively and through dispersal of spores. Displaces native algae and marine life. Alters habitat, ecosystem and food web. May affect commercial shellfish stocks through space competition and alteration of habitat
European Green Crab*Carcinus maenus*	European Atlantic Coast	Southern Australia, South Africa,the United States and Japan	Highly adaptable and invasive. Resistant to predation due to hard shell. Competes with and displaces native crabs and becomes a dominant species in invaded areas. Consumes and depletes wide range of prey species. Alters inter-tidal rocky shore ecosystem

Source: http://globallast.imo.org/poster4_english.pdf

outbreak in the Americas in 1991-1992 was probably due to introduction from ballast water emptied into port waters (WHO, 1992).

Introduction of algal-bloom species, in addition to producing fish and other marine life kills, has been known to produce skin irritation and gastrointestinal problems in humans as well as foamy, discolored, odiferous water conditions (Nunes and van den Bergh, 2004). Most of these species are filtered by shellfish and infestation frequently shuts down important oyster and clam beds. Consumption by humans can even cause paralysis and death (Global Ballast Water Management Programme Website 2008).

One of the most famous incidents is the introduction of zebra mussels into the Great Lakes ecosystem of the United States by release of the larval form in ballast water (McMahon, 1996). Zebra mussels now infest approximately 40 percent of inland waterways in the United States and cost hundreds of millions each year on control measures (Global Ballast Water Management Programme

Website 2008). Zebra mussels foul hulls, adhere to almost all solid objects in infested waters, clog intake and outtake pipes of the Of course, this issue transcends country borders. Leppakoski et al. (2002) report that the Baltic Sea has been invaded by approximately 70 NNS that have sustaining populations and in many cases are detrimental to fishing, shipping, and general commerce. A jellyfish from North America, Mnemiopsis leidyi, so severely infested the Black Sea that it clogged fishing nets and eventually produced an almost complete shutdown of fishing industries (Global Ballast Water Management Programme Website 2008)

Researchers have uncovered the origins of approximately 60 of these NNS. Thirty-eight are transoceanic (19 from America) and 18 are from the surrounding Ponto-Caspian region. Ballast water, introduced from the Baltic Sea to the Great Lakes in North America, has even become a secondary source of NNS that were originally from some other ecosystem (Leppakoski et al. 2002).

Valigra (1999) reports that several NNS exist in sustaining colonies in the U.S. and have the potential to have a devastating impact on coastal marine resources. An Asian snail, Rapana venosa, which eats oysters and clams, has invaded the Chesapeake Bay in the Mid-Atlantic region of the U.S. and could devastate attempts to reestablish an oyster industry already weakened by pollution and over-fishing. In Alaska, an introduced zooplankton from East Asia via San Francisco, competes for the same food preferred by the Dungeness crab, an expensive and highly valued delicacy. Niiler (2000) states that among many other infestations taking place in the U.S., that the Japanese shore crab (first infested in 1994) has destroyed native competitors in Long Island Sound and that in San Francisco Bay, a new marine species is successfully introduced every 14 weeks.

A ballast-water risk assessment report for Dalian, People's Republic of China, reported a

cooling systems of power plants, and possess shells that easily slice human flesh.

probable link between invasive NNS and greater incidences of increases in fouling and red tide events (Clark, Hilliard, Liuy, Polglaze, Xu, Zhao, and Raaymakers, 2003).

Developing economies, like the People's Republic of China, have seen dramatic increases in the number of NNS intercepted at their borders and in the number of actual infestations, including marine, which coincide with their tremendous economic growth. Ding, Mack, Lu, Ren, and Huang (2008) indicate that China is still more interested in maintaining its economic growth than in curbing the introduction of NNS, although the problems posed by the NNS are beginning to warrant attention.

REGULATORY RESPONSES TO THE PROBLEM

The negative impact of invasive marine NNS is now widely recognized and a regulatory response is evolving at the international, national, and state levels. Most regulation involves a combination of several options: a complete prohibition of coastal ballast water release, mid-ocean exchange of ballast tank water, in-tank ballast water treatment using an assortment of treatment protocols, and detailed documentation of all ballast operations (inflows, outflows, and flushing). There is no real enforcement at the international level.

Simberloff (2005B) points out that many regulatory bodies are given dual charges that may conflict with one another, for example the Animal and Plant Inspection Service of the United States Department of Agriculture, is asked to both facilitate imports and exports while at the same time reduce the risks associated with NNS. This is a common duality for regulatory agencies. Most countries are interested in expanding trade more than limiting trade (Bright, 1999).

International Response

The World Trade Organization, the preeminent organization devoted to the facilitation and protection of free trade, desires to both protect the environment but also prohibit the use of environmental restrictions to unfairly protect domestic industries. Article 20 of the General Agreement on Tariffs and Trade (GATT) gave member nations the right to manage trade in such a way to protect human and ecological health as long as it does not constitute an attempt to restrict trade in order to protect domestic industry. As GATT evolved into the World Trade Organization in January of 1995, this provision was explained in greater detail in the WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) which was part of the new WTO charter. Essentially, the SPS Agreement states that member countries must justify with scientific assessments the real danger posed by trade-related practices used to justify any restriction on trade. These assessments must be made with generally acceptable scientific methods and the results and methodologies must be fully transparent and available for review (WTO website, 2008).

Simberloff (2005B) describes the problems that arise from the required use of quantitative risk assessments (such as that required by the WTO above) for gauging the potential impact of introduced species, either intentional or unintentional. It is difficult, if not impossible, to quantify all the risks associated with such an introduction. Yet, the use of qualitative estimates opens a country to the charge that the country is simply interested in protecting its domestic markets from foreign competition with no real proof of the potential harm from possible introduction of NNS.

The International Maritime Organization is a special agency of the United Nations dedicated to "Safe, secure and efficient shipping on clean oceans" (IMO website www.imo.org). The IMO has been attempting to address the problem of NNS for more than 20 years. However, it has no real ability to enforce its recommended guidelines and conventions. The guidelines have remained essentially the same over the years. Avoid taking on ballast water in shallow coastal waters. Exchange ballast water far from shore in the deep ocean. Maintain a log of all ballast water activities. In 2004, the IMO adopted a set of rules called the "International Convention for the Control and Management of Ships' Ballast Water and Sediments." These rules are designed to assist countries in their efforts to reduce the spread of NNS and pathogens in ballast water. Among many provisions, this convention called for the development of ballast water manage-ment systems that have either the capacity to exchange three times the ballast tank volume or an efficiency of exchanging at least 95 percent of the ballast water volume (Annex-Section D, Regulation D-1). Performance standards related to the prevalence of organisms or pathogens in ballast water releases are also included. Microbes to be used as indicators include toxigogenic vibrio cholerae, Escherichia coli, and intestinal enterocci (Annex-Section D, Regulation D-2). Ballast water exchanges should be conducted whenever possible "at least 200 nautical miles from the nearest land and in water at least 200 meters in depth" (Annex-Section B) Member states are also allowed to set and enforce ballast water standards higher than those imposed by the Convention. Firestone and Corbett (2005) interpret the IMO Ballast Water Convention as a realization that flag-state control of ballast water management was not effective and that the new Convention, allowing member states to set and enforce their own rules, recognizes the necessity of coastal and port-state regulation. Coastal and port-states have the economic and ecological incentive to protect their coastal resources while international agencies generally do not.

The Global Invasive Species Programme (GISP) is a global nonprofit organization dedicated to the study and management of the invasive species problem. GISP is committed to the scientific study of the problem, the development of better identification and assessment techniques, more strict international regulation, and public education about the problem. Original members include CAB International, IUCN-The World Conservation Union, the Nature Conservancy, While the United States has known of the problem of NNS for some time, only recently has the government taken steps to actively control the problem. The National Invasive Species Act of 1996 was passed which reauthorized the provisions of the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990. In the United States, in 1998, the Coast Guard was authorized to enact a voluntary ballast water management program for all vessels operating in U.S. waters. If self-regulation was found to be inadequate to prevent the spread of NNS, the Coast Guard was charged with creating a mandatory system. After a trial period, the Coast Guard found that voluntary participation was not working. In 2004, the U.S. Coast Guard published an official set of regulations governing ballast water management and reporting protocols. These regulations also established penalties for non-compliance. (U.S. Coast Guard Office of Operating and Environmental Standards website 2008, www.uscg.mil/hq/g-m/mso/bwm.htm).

and South African Biodiversity Institute (GISP Website: www.gisp.org).

U.S. Response To The Problem

Today, the mandatory practices for all vessels with ballast tanks in U.S. waters include the following regulations. First, vessels must complete and maintain Ballast Water Reporting Forms in accordance with 33 CFR 151.2041, and these records must be kept on board the vessel for a minimum of two years. Vessels are NOT required to follow these rules if they endanger the safety of the vessel, crew, or passengers, although such an event must become part of the documented ballast management records. Other specific rules are presented below as Table 2 (taken directly from the U.S. Coast Guard website).

TABLE 2
COAST GUARD BALLAST WATER MANAGEMENT

(EEZ) Entry (33 CFR 151.2035(a))

· Avoid ballast operations in or near marine sanctuaries, marine preserves, marine parks, or coral reefs.
· Avoid or minimize ballast water uptake:
  · Where infestation, harmful organisms and pathogens are located.
  · Near sewage outfalls.
  · Near dredging operations.
  · Where tidal flushing is poor or when a tidal stream is known to be more turbid.
  · In darkness when organisms may rise up in the water column.
  · In shallow water or where propellers may stir up the sediment.
  · Areas with pods of whales, convergence zones and boundaries of major currents
· Clean ballast tanks to remove sediment regularly.

· Only discharge minimal amounts of ballast water in coastal and internal waters.
· Rinse anchors and anchor chains during retrieval to remove organisms and sediments at their place of origin.
· Remove fouling organisms from hull, piping, and tanks on a regular basis and dispose of any removed substances in accordance with local, state and federal regulations.
· Maintain a vessel specific ballast water management plan.
· Train vessel personnel in ballast water and sediment management and treatment procedures.

(33 CFR151.2035(b))

· In addition, for vessels in U.S. waters containing ballast water that was loaded within 200 NM of any coast outside the U.S. the following regulations apply. Vessels must:

· Conduct one of the following:
· a. conduct mid-ocean ballast water exchange prior to entering U.S. waters;
· b. retain the ballast water on board while in U.S. water; or
· c. use a Coast Guard approved alternative environmentally sound method to treat the ballast water

The U.S. Department of Agriculture sponsors a Program of Research on the Economics of Invasive Species Management (PREISM) that funds and coordinates research related to NNS introductions in the U.S. From 2003-2007, 17 percent of the funding went to studies concerning trade and invasive species (USDA website http://www.ers.usda.gov/briefing/InvasiveSpecies/preism.htm).

Various states in the United States have passed ballast water-related restrictions that are more specific than the general U.S. regulations explained above. California, Hawaii, Washington State, Maryland, and Michigan are among those with such rules. Landis-Marinello (2007) points out that such states, impatient with federal and international guidelines that are difficult or impractical to enforce, have begun creating ballast-water treatment regulations on their own. Michigan, beginning in 2007, is requiring that all oceangoing vessels passing through state waters must obtain a permit from the Department of Environmental Quality. Such permits are only available to persons that agree not to discharge ballast water in the state or have their ballast water treated by acceptable means before discharge. Acceptable treatment methods approved by the state of Michigan include ultraviolet radiation, deoxygenation, and two named biocides (hypochlorite and chlorine dioxide). Beginning in 2009 (Dobroski et al., 2007), new ships 5000 metric tons and less operating in California are expected to meet the treatment performance standards (approaching a zero discharge standard for ballast water containing living organisms and bacterial standards similar to those established by the Environmental Protection Agency) established by the State Legislature. All ships have to meet the standards by 2016.

STRATEGIES FOR COMBATING THE BALLAST WATER PROBLEM

Given that humans have been generally unsuccessful eradicating or even controlling marine NNS infestations, Secord (2004) calls for a greater emphasis on the prevention of the introduction of NNS and for better tools for earlier identification of the problem while the infestation is small. Keller, Drake, and Lodge (2007) suggest that biologists attempt to identify species with high potential for becoming a NNS and focus on prevention. Once a colony is established and spreads beyond its initial infestation site, the track record indicates that it is generally too late. Strategies for combating infestation of NNS generally focus on prevention of the initial colonization. Other than mid-ocean exchange, all are costly with some in the range of $500,000 (HSDailywire.com, 2008) or higher. Dobroski, Takata, Scianni, and Falkner (2007) estimate that the cost of installing treatment systems on an ocean-going vessel will be in the neighborhood of 1-2 percent of the total cost of the ship. The lack of regulatory consistency regarding standards and protocols and implementation timetables is an impediment to commercial development of treatment systems and while many systems are in development, few are ready for commercialization (Dobroski et al., 2007). Several techniques and technologies are highlighted below.

Mid-Ocean Exchange

By far the most commonly practiced and least expensive method for reducing the chance of infestation is the mid-ocean exchange of ballast water. When a ship is far out to sea and over deep water (per IMO guidelines explained above), the ship pumps the ballast tanks empty and then refills them with fresh seawater. The difference in the salinity (coastal salinity is low; mid-ocean/deep water salinity is high) and/or temperature is believed to kill many of the organisms that are in the ballast water that was drawn from coastal sources. Organisms that are not killed by the exchange will at least be dispersed in such a way that makes colonization unlikely.

Yet, this technique is fraught with problems.

The process can take several days and never fully empties the tanks as some minimal amount of water must remain in the tanks to insure stability. In rough open seas, the process can be dangerous as ship stability may be compromised during the process (Bright, 1999).

There is also evidence that mid and/or deep ocean ballast water exchange protocols may not be as effective as had been hoped. The justification for using this technique arises from the belief that organisms from low-salinity coastal regions would not be able to survive in the high salinity environment of mid and/or deep ocean areas and vice-versa. However, evidence that supports this justification is inconsistent (summarized in Brickman, 2006).

Finally, enforcement of mid-ocean ballast exchange is problematic. The traditional method for determining whether or not a ship properly exchanged water in mid-ocean is to test the salinity of the water in the ballast tanks. High salinity water comes from mid/deep ocean. Low salinity comes from coastal areas. The U.S. Coast Guard is currently seeking better tests and is testing a system that measures the fluorescence of dissolved organic matter in the ballast water. This can discriminate between water taken from as little as 10 miles apart and if successful, will lead to easier testing and enforcement (Pelley, 2005).

Shore-Based Treatment

Shore-based strategies are essentially the same as wastewater treatment protocols. Ships, while in port and loading cargo, flush their ballast tanks into a treatment system based on shore. This, of course, requires substantial investment on the part of the port, and most municipal systems are not capable of treating saline water (Dobroski et al., 2007).

Flow-Through Systems: Ballast Free Ship Design

The University of Michigan is testing a hull design that provides stability without the use of ballast tanks. The design relies on the use of a series of large pipes that run from bow to stern below the waterline. The flow of water through the pipes provides stability, and according to initial tests of models, may result in significant fuel savings. Prototypes are in development (HSDailywire.com, 2008).

Filtration Systems

Filtration systems operate using some form of mesh or other porous material to catch particles in a flow of water. The size of the holes in the material determines the level of filtration, however, as the size of the holes decrease, the amount of time needed to filter an equivalent unit of water typically increases, reducing efficiency. Captured items, organic and inor-ganic, are them discarded in an appropriate manner (Dobroski et al., 2007).

Hydrocyclonic Separation

Hydrocyclonic separation uses a pumping system that creates a vortex that uses centrifugal force to push more dense particles and organisms to the outside of the flow where they can be captured and later discarded. This system does not effectively remove organisms or debris of the same general density of sea water (Dobroski et al., 2007).

Deoxygenation

Another strategy is deoxygenation. Removing the oxygen from ballast tanks by purging with nitrogen gas has the dual benefit of killing NNS and reducing the level of corrosion in the tank. As early as 1999, Matsuda et al. reported that injecting nitrogen gas into ballast tanks greatly reduced corrosion, thus producing cost savings for upkeep and refitting. In a pilot dockside study of Venturi Oxygen Stripping, a process created by NEI Treatment Systems,LLC, Tamburri and Ruiz (2005) found both mortality of ballast water organisms (within IMO specifications for invertebrates and bacteria) and a reduction in corrosion. Real-world testing of the system is underway (Kearney, 2006).

Ultraviolet Radiation

Ultraviolet radiation is well known for its ability to kill viruses (Wright, Dawson, Orano-Dawson, Morgan, and Coogan, 2006) and is often found in combination systems at municipal treatment facilities. It is generally not effective on higher order organisms so is best suited in concert with other techniques.

Heat

Attempts are being made to find a way to use heat produced by ship engines to raise the temperature of ballast water to a level that would kill harmful organisms. This typically does not work with bacteria (Rigby, 2004).

Biocide Treatment

One potential strategy is to treat the ballast tanks with a biocide, such as menadione under the trade name SeaKleen. In tests, SeaKleen proved highly effective killing live and resting eggs of aquatic invertebrates in ballast water. However, SeaKleen was not effective at killing invertebrate resting stage creatures which were imbedded in the sediment retained in the bottom of ballast tanks (Raikow, Reid, Maynard, and Landrum, 2006). There are two general categories of biocides (Dobroski et al., 2007). One consists of chemicals that are oxidizing agents that work by breaking down cell walls. The other employs chemicals that act like pesticides. In either case, there is lingering concern over dumping treated ballast water into the natural environment. Any use of biocides must be accompanied with an analysis of the persistence and impact of any released chemicals.

Public Awareness

Public awareness is an essential step in thwarting the spread of invasive NNS (McNeely, 2004). Making the public aware of the threats posed by marine NNS and the vectors responsible for their introduction would encourage firms to take a more active role in protecting the environment with more eco-friendly strategies. All stakeholders engaged in any activity related to the introduction of marine NNS should be made aware of the consequences of their actions (or inaction).

Drake and Keller (2004) call for the creation of an international fund, which less developed countries can draw from to identify and combat NNS infestations. Some states, such as Hawaii, are now charging a fee to establish a "pest inspection, quarantine, and eradication fund" which can be used to find and eliminate the unintended entry of NNS. In Hawaii, the fee is $1 per standard shipping container. California and Washington state already have similar fees. (Anonymous, 2007).

WHY SHOULD FIRMS CARE? THE GREEN MARKETING IMPERATIVE IN THE SUPPLY CHAIN

The problem of introduction of marine NNS should be a primary concern for shipping companies and any company that employs ocean shipping in any manner. There are three basic reasons why companies should be concerned. First, it is the right thing to do from an ethical standpoint. Laczniak (1983) posed a series of 8 questions that should be answered to determine if a marketing action is ethical. If any can be answered "yes," then the action is probably unethical. Several of the questions are pertinent to a marketer's responsibility regarding ship-borne introduction of NNS. Among them, "Are any major evils likely to result from or because of Action A?" and "Is a satisfactory Action B, which produces equal or more good with less evil than A, being knowingly rejected?". The answer to both of these questions is undoubtedly "yes." In simple terms, failing to take steps to curb the introduction of unwanted marine NNS would be an ethical violation. Many industry codes of ethical conduct have statutes that call for responsible stewardship of ecological resources (such as the American Marketing Association—"We will strive to protect the natural environment in the execution of marketing campaigns" American Marketing Association Statement of Ethics).

Second, concern for the environment, and green marketing in general, is good for brand image and financial performance. Although consumers remain more interested in a brand's functional performance rather than its environmental contribution, when consumers believe that their use of a product contributes to ecological welfare, their attitude toward the brand improves (Rios, Martinez, Moreno, and Soriano, 2006). Ginsberg and Bloom (2004) Third, there is great likelihood that regulation and enforcement of ballast-water related rules will tighten. There is significant realization that the current international "guidelines" have not worked to produce voluntary control. suggest that businesses seek to answer two sets of questions.

> How substantial is the green consumer segment for the company? Can the company increase revenues by improving on perceived greenness? Would the business suffer a financial blow if consumers judged the company to be inadequately green? Or are there plenty of consumers who are indifferent to the issue that the company can serve profitably?

Then,

> Can the brand or company be differentiated on the green dimension? (Ginsberg and Bloom 2004, p. 81)

In addition, firms that express environmental responsibility in their business strategies enjoy reputational advantages that increase both marketing and financial performance (Miles and Covin, 2000). Both customers and investors appreciate environmental sensitivity. In the last two years in particular, there seems to be renewed interest by companies in the adoption of sincere attempts to operate in a manner that does not harm the environment. One way that a firm can do this is to adopt environmentally responsible value-adding processes, with the goal of reducing the environmental impact of the value-creation chain (Prakash, 2002). If a firm desires external validation of its concern for environmental responsibility, it can seek certi-fication from the International Organization for Standardization with its ISO14000 environ-mental management standards (International Organization for Standardization website, http://www.iso.org/iso/iso_catalogue/management_standards/iso_9000_iso_14000/iso_14000_essentials.htm.)

The U.S. has already shifted from voluntary to involuntary participation, and many states are adopting ever more restrictive operating protocols. Thus it makes sense for companies to anticipate and prepare for such exigencies. As companies anticipate that environmental demands in their industry will rise, the more they should include environmental considera-tions in the development of their business strategies (Karna, Hansen, Juslin, and Seppala, 2002). Outside pressures to be sensitive to environmental issues and to exhibit corporate social responsibility push companies to adopt environmental marketing planning (Karna, Hansen, and Juslin, 2003).

DIRECTIONS FOR FUTURE RESEARCH AND SUMMARY

Much work remains to be done. The various treatment methods and their strengths and weaknesses must be subjected to scientific review. While some of this important work has begun, it is by no means complete.

Second, carriers will have to consider whether there is a market opportunity to adopt "clean" ballast systems before the competition? Currently, much has been said and written about the impact of green technology on transportation providers and shippers. Federal intervention is in the wings in the form of a carbon tax or carbon trading. Will the same energy and focus be turned to invasive species as well?

These advances no doubt will come at a cost. Will shippers be willing to pay a higher price for a benefit that is difficult if not impossible to quantify and of no direct financial consequence? What will the consequences be for shipping companies that choose to do nothing? Are companies that employ marine shipping in their supply chain even aware of the problem? Do they have a moral imperative to care? What about consumers of products distributed via marine shipping?

Finally, the general public and regulatory agencies are becoming more and more aware of and interested in the environmental footprint of various business functions, including the supply chain. The increasing emphasis on "green marketing" is evidence that businesses anticipate that this trend will continue. "Sustainability" is emerging as part of the evaluative criteria for judging the viability of logistical processes. Will consumers be willing to pay a higher cost for "green" goods and services that cost more, while at the same time less expensive alternatives are on the shelf? And, if so, how much more? Will the incremental cost cover the cost of the "green" initiatives and processes?

While the impact of NNS on marine environs is well known among coastal biologists and within coastal communities, to date this awareness has not extended far outside of those groups. Few invasive species have captured the national attention as a threat; the silent invasion has yet to attract the resources needed to stem the flow. As the impact of these invasions becomes more acute, the notoriety will bring more attention to the problem in general and more specifically on the international shipping industry. The attention will not be positive unless shippers adopt a proactive stance regarding the problem.

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