A preliminary assessment of the risks of introducing non-indigenous phytoplankton, zooplankton species or pathogens/parasites from South Amboy, New Jersey (Raritan Bay) into Whites Point, Digby Neck, Nova Scotia

Submitted to: Global Quarry Products
Bridgewater, Nova Scotia

Submitted by: C.E. Carver and A.L. Mallet
Mallet Research Services Ltd.
4 Columbo Drive
Dartmouth, Nova Scotia
B2X 3H3

Phone: (902) 462-5884
Fax: (902) 484-6189
Email: ccarver@ns.sympatico.ca
amallet@ns.sympatico.ca

October 6, 2003

000123

Table of Contents

List of Figures

List of Tables

1 Introduction

The unregulated movement and discharge of ballast water by commercial shipping traffic has been repeatedly implicated in the global dispersion of invasive marine and freshwater species (Medcof 1975, Carlton 1985, Williams et al. 1988, Smith and Kerr 1992, Carlton and Geller 1993, Hallegraeff 1995). Although there are various means of inadvertently translocating organisms to new environments, such as fouling on ship hulls or the intentional transfer of commercial species, ballast water is considered a major vector of unwanted introductions (Fofonoff et al. 2002). With the projected increase in ship traffic and reduction in transit time between ports, the probability of exotic organisms surviving the passage to new environments is steadily increasing.

Given the ecological ramifications of introducing non-indigenous species into Canadian waters, it is appropriate that any company planning to discharge ballast water take steps to assess the potential risks associated with this activity. As part of their normal operations, ships under contract to Global Quarry Products will be taking on ballast water at South Amboy in Raritan Bay, New Jersey. Unless a ballast water exchange is conducted en route, this South Amboy water will subsequently be discharged at Whites Point, Digby Neck, Nova Scotia. The company has therefore requested Mallet Research Services to conduct an assessment of the possible ecological risks associated with this discharge activity.

A risk assessment analysis is a process by which information is collected to derive an understanding of the factors involved, and to provide a basis for making decisions with regards to the impact of that activity. It should be noted that the Bay of Fundy is currently the site of extensive commercial shipping activity; for example, over 400 ships carrying ballast water visited the ports of Saint John, Hantsport, and Bayside in 2000 of which 83% originated from US east coast ports (Balaban 2001). Many of these ships now comply with Transport Canada voluntary guidelines which request a ballast water exchange en route to Canadian ports in order to reduce the threat of introduction of non-indigenous species. This risk assessment study must take these factors into consideration, as well as the proposed traffic specific to Whites Point in order to evaluate any additional risks which may be derived from the proposed commercial activities of the quarry.

In principle, there are a number of steps that should be followed to complete this risk assessment:

1. Identify the potential species of concern that could pose an ecological and/or economic threat to the Whites Point community/ecosystem. Technically, this would require a

comprehensive comparison of the biota present at the two ports and the surrounding region;

2. Document the life history and environmental tolerances of the species of concern; this information is very important to identify the periods of greatest risk as well as determining appropriate risk mitigation strategies. A comparison of habitat characteristics may help in predicting the likelihood of invasion, but the best predictor may be whether a species has shown invasive potential elsewhere;
3. Identify the risk of entry by means of normal and alternative pathways. In the case of Whites Point, the ballast water and the hull of the ship are the potential vectors, but other commercial ship traffic in the Bay of Fundy could also be responsible for introducing non-indigenous species;
4. Identify the potential risks and consequences of transferring these species of concern. This will depend on the characteristics of the various organisms and the sensitivity of the local ecosystem, particularly the commercial fisheries;
5. Propose appropriate risk mitigation strategies to reduce the probability of introducing non-indigenous species;
6. Recommend a monitoring regime to ensure that species information at both the source and discharge points are updated regularly in order to verify the safety of current commercial practices.

The objective of the following risk assessment is to evaluate the potential for transferring non-indigenous, possibly invasive species from South Amboy, NJ to Whites Point, NS. The scope of the study is, however, constrained in that it is based only on information available from the scientific literature, or from a series of web sites focusing on invasive species issues. Attempts to contact US researchers in the New York - New Jersey region yielded limited information, possibly because the relevant data sources do not exist or were not discovered within the available time frame. The report is divided into two major sections, the first part focusing on the species of concern in the South Amboy region and the second evaluating the factors which may affect the risk of introduction into Whites Point.

2 Background information

2.1 Ballast water management

Growing concern over the potential impacts of non-indigenous species invasions have prompted many countries to develop guidelines and regulations governing the management of ballast water. In 1997, the IMO Environmental Protection Committee adopted Resolution A.868(20), "Guidelines for the Control and Management of Ship's Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens". In response to the IMO's recommendation that all maritime nations adopt these voluntary guidelines, the Shipping Federation of Canada developed a "Code of Best Practices for Ballast Water Management"[1]. In an attempt to avoid another zebra mussel crisis in the Great Lakes, the Canadian government developed "Guidelines for the Control of Ballast Water Discharge from Ships in Waters under Canadian Jurisdiction"[2]. According to these Guidelines, it is highly recommended that ships originating from foreign ports undertake a ballast water exchange in waters >2000 m deep, before entering the St. Lawrence seaway. As of September 2001, all ships arriving at ports in Eastern Canada must report ballast water information to Transport Canada, Marine Safety (Annex V: Ballast Water Procedures for Vessels Proceeding to Ports on the East Coast of Canada)[3]. At present, Canada has no official regulations for ballast water management, but countries such as the United States and Australia are in the process of implementing such regulations and it is anticipated that many countries will follow suit in the upcoming years.

2.2 Species of concern

When invasive species establish populations in new environments, they have the potential to disrupt the ecological integrity of the native community, and pose a significant threat to local fisheries and human health. Numerous cases have been documented where the introduction of exotic species has had serious ecological and economic ramifications; some of the worst examples include the introduction of the European zebra mussel *(Dreissena polymorpha*) into the Great Lakes (Nalepa and Schlosser 1993), the Asian clam (*Potamocorbula amurensis*) into San Francisco Bay (Carlton et al. 1990, Nichols et al. 1990), and the Atlantic comb jelly (*Mnemiopsis leidyi*) into the Black Sea (Vinogradov et al. 1989). Recent cases in Atlantic Canada, which have been tentatively linked with ballast water and/or hull fouling, are the introduction of the green crab *(Carcinus maenas*) which is currently disrupting the clam fishery, and the club tunicate *(Styela clava*) which is threatening the mussel aquaculture industry in PEI.

Given that there is insufficient information to conduct an exhaustive comparison of all the phytoplankton and zooplankton present in Raritan Bay versus those present in the Bay of Fundy, this review will focus on those species which are of greatest immediate concern. These fall into three general categories: (1) phytoplankton associated with harmful algal blooms; (2) non-indigenous invertebrate species with a pelagic larval phase; and (3) pathogens or parasites responsible for disease.

---

[1] www.shipfed.ca/library/ballastwater/ballastwaterbestpractices.html
[2] www.tc.gc.ca/Marine Safety/tp/Tp13617/menu.htm
[3] www.tc.gc.ca/Marine Safety/tp/Tp13617/annex-v.htm

2.2.1 Phytoplankton: harmful algae

Phytoplankton are microscopic floating plants (<0.2 mm) or microalgae; certain species are classified as "harmful" because they produce toxins which, when they accumulate in shellfish, pose a threat to human health, and/or they form dense "red", "green" or "brown tides" which may cause discomfort to humans and lead to mortality in shellfish and/or finfish populations.

Considerable attention has been directed at documenting the potential for the dispersal of toxic phytoplankton species in ballast water (e.g. Subba Rao et al. 1994). In particular, certain species have the capacity to form highly-resistant cysts which can survive for years in the sediments which accumulate at the bottom of ballast water tanks (MacDonald 1995). Awareness of the risks associated with ballast water transport was heightened by the discovery of toxic phytoplankton species in Australian waters (Hallegraeff et al. 1988). Paralytic Shellfish Poisoning (PSP) was unknown in Australia until the 1980's when the first outbreaks of toxic species appeared in the ports of Hobart (*Gymnodinium catenatum*), Melbourne (*Alexandrium catenella*) and Adelaide (*Alexandrium minutum*). Viable cysts of *G. catenatum* and *A. catenella* were subsequently found in the ballast tank sediments of ships originating from Japan and Korea (Hallegraeff and Bolch 1992a,b), and the source of *A. minutum* was eventually traced to shipping traffic from the Mediterranean (Scholin and Anderson 1991). The proliferation of these toxic species has had major economic consequences for the Australian aquaculture industry; widespread blooms now necessitate the prolonged closures of shellfish farms in several areas (Hallegraeff and Sumner 1986, Hallegraeff et al. 1995).

There is also growing concern over the risk of transporting "nuisance" phytoplankton species, blooms of which may cause mortality in shellfish or finfish or disrupt human activities. For example, the introduction of the tropical species *Coscinodiscus wailesii* to northern European waters had serious consequences for the fishing industry; this species produces a copious slime which can clog or break fishing trawl nets (Boalch 1977b, Mahoney and Steimle 1980, Rince and Paulmier 1986, Rick and Durselen 1995). Blooms of other phytoplankton species can cause mortality in molluscan shellfish, such as *Heterocapsa circularisquama* which is responsible for massive mortalities of cultured shellfish in Japanese waters (Matsuyama et al. 2001). Other species can cause mortalities in wild and cultured finfish; for example *Chrysochromulina leadbeateri*, *Chrysochromulina polyepsis*, and *Prymnesium parvum* in Europe and *Heterosigma akashiwo* on the west coast of Canada. None of these species has ever been reported in Eastern Canada, but the alarming increase in the global incidence of harmful algal blooms suggests that the probability of introduction is increasing (Hallegraeff 1993). One notable phytoplankton species, *Pfiesteria piscicida*, has been linked to massive fish kills and human illness in Maryland, Virginia, and North Carolina (Burkholder et al. 1995). Concern over the possible spread of this species has prompted many ports on the US East coast to deny entry to any ships carrying ballast water from the Baltimore area which has been severely affected by this organism; yet, ballast water from Baltimore is frequently discharged without treatment in several Atlantic Canadian ports.

2.2.2 Zooplankton: invasive invertebrate species

Many invertebrate species such as bivalve shellfish, crabs and tunicates have a planktonic or pelagic phase in their life history during which they may be taken up and transported in ballast waters (Harvey et al. 1999). In many instances, these species probably fail to survive the transition to new environments, or the knowledge of the local marine biodiversity is so limited that their presence is never detected. Certain opportunistic species, however, possess characteristics which increase the probability of their survival; these include hardiness under a range of conditions, high reproductive rates and the ability to disperse rapidly into new areas. When released from the competitive or predatory restrictions present in their original environment, these "invasive" species have the potential to overwhelm and disrupt the local community ecology.

A classic example of an "invasive species" is the European green crab (*Carcinus maenas*) which has been introduced to various areas of the world such as Australia, South Africa, the US and Canadian Atlantic coast, and the US Pacific coast. It is not known exactly how the crabs are being introduced, but it has been suggested that the larvae were likely transported in the ballast water of ships. This species can tolerate a wide range of temperatures and salinities, grow quickly, and produce large numbers of offspring. Green crabs are aggresive predators feeding on mussels, oysters, other crabs, and small fish. They have dispersed from the Atlantic coast of Nova Scotia into Cape Breton and PEI and are currently blamed for disrupting the local softshell clam fishery.

Another invasive species, the club tunicate (*Styela clava*) was recently introduced into PEI where it is disrupting the mussel culture industry. It has the ability to rapidly colonize the surfaces of floating structures such as marker buoys, docks and suspended aquaculture gear. When it attaches to the outer surface of mussel sleeves, it may cause severe slippage or loss of mussels as well as a substantial reduction in growth due to food competition. The club tunicate may have arrived as a planktonic larvae in ship ballast water but was more likely transported as an adult attached to ships' hulls. Anecdotal and published accounts suggest that various species of tunicates are becoming a substantial problem for many aquaculture operators worldwide (e.g. Karayucel 1997, Hecht and Heasman 1999).

2.2.3 Pathogens/parasites

It has been suggested that ballast water could be an important vector in the spread of viruses, parasites and bacteria that could threaten the ecology, the economy and possibly the health of local residents in the discharge zone. French researchers (Masson et al. 2000) documented the presence of *Clostridium* bacteria, typically associated with gastrointestinal tract infections, in 50% of the ballast water samples tested. Also observed were several types of pathogenic *Vibrio* bacteria, as well as species known to be harmful for people with lowered immune defences. McCarthy and Khambaty (1994) argued that the bacteria responsible for cholera in humans (*Vibrio cholera*) could be introduced into coastal areas via ballast water. Although there are presently limited data available, these types of organisms are believed to be particularly robust and well capable of surviving the conditions present in ballast water tanks.

Another concern is the potential for transmitting parasites and disease agents via ballast water. For example, on the US East Coast, the northerly movement of oyster diseases has been partially attributed to the movement of ballast waters by the marine sector. It has been predicted that the parasite responsible for causing the MSX oyster disease in Chesapeake Bay, Virginia, and Bonamia in European oysters in Maine, will find their way via ballast waters to our ecosystem (P. Fofonoff, Smithsonian Research Centre, pers. comm.). One of the problems in mitigating this risk is the poor knowledge of the various life stages of these disease-causing organisms and at times, the lack of even a species identification for the organism responsible for the disease.

3 Risk assessment

3.1 South Amboy, New Jersey

3.1.1 Port of origin

The point source of the ballast water is the port of South Amboy, New Jersey (Lat: 40°21', Long: 74°10'), located to the south of Staten Island, New York at the confluence of the Raritan River and the Arthur Kill where they open onto Raritan Bay (Figure 1). No specific environmental or species information was available for the port of South Amboy, but data were obtained for the Raritan Bay system.

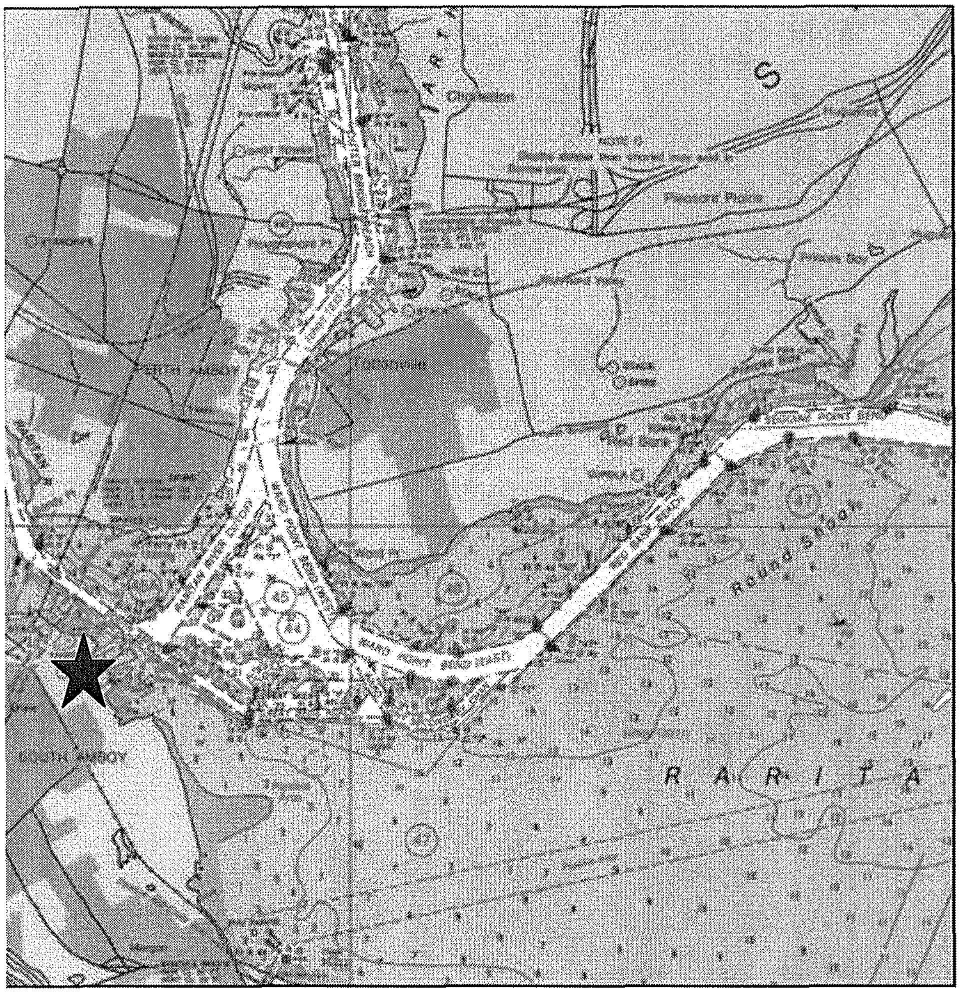

Figure 1. Chart indicating the general location of the port in South Amboy, NJ at the mouth of the Raritan River, with Raritan Bay opening out to the east.

3.1.2 Raritan Bay: Environmental conditions

Raritan Bay is classified as an estuarine river-dominated system with an average daily freshwater inflow of 65 million cubic meters, originating primarily from the Hudson and Raritan Rivers (Zimmer and Groppenbacher 1999). The residual circulation pattern is cyclonic (counter-clockwise) with the tide flooding primarily along the northern shore of Raritan Bay, mixing with the river discharge at the head of the bay, and then ebbing out along the southern shore (Jeffries 1962). One set of bottom temperature data (1992-1996) for the western part of Raritan Bay indicated an annual range of 1 to 24°C (Figure 2).

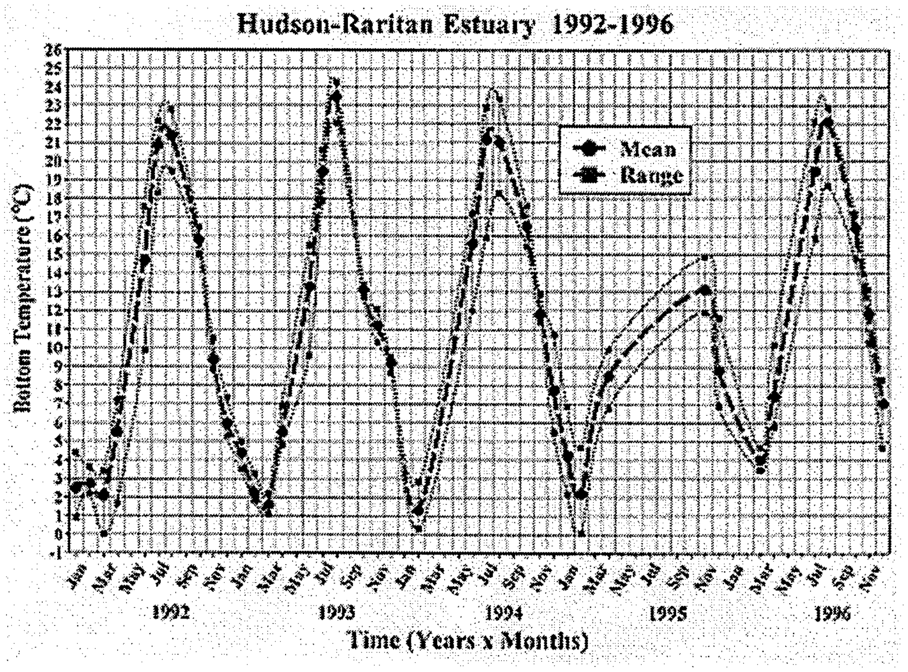

Figure 2. Bottom temperature data for the western end of Raritan Bay (1992-1996)[4].

A second set of environmental data (surface water temperature and salinity for 1993-1997) was obtained for four sampling sites on the southern shore of Raritan Bay (Zimmer and Groppenbacher 1999). These values were generally higher than the bottom water estimates; spring values ranged from 10-15°C, summer values from 20-30°C and fall and winter values from 3-10°C (Figure 3a). Salinity data for the same four sites indicated a range of 20 to 30°/oo with the highest values occurring during the summer when freshwater inputs are at a minimum (Figure 3b). It is highly likely that salinity estimates for the South Amboy region would be consistently lower than those reported in this report, given the greater proximity to the Raritan River and the Arthur Kill.

Dissolved oxygen levels at the surface during the summer may fall below the level of 5.0 mg/l or the NOAA standard for waters that are biologically stressed. High nutrient levels support the development of significant algal biomass; mean chlorophyll levels for the May to September period (1975-1995) ranged from 17 to 59 ug/l (Gastrich 2000).

---

[4] http://sh.nefsc.noaa.gov/hudsrars.htm

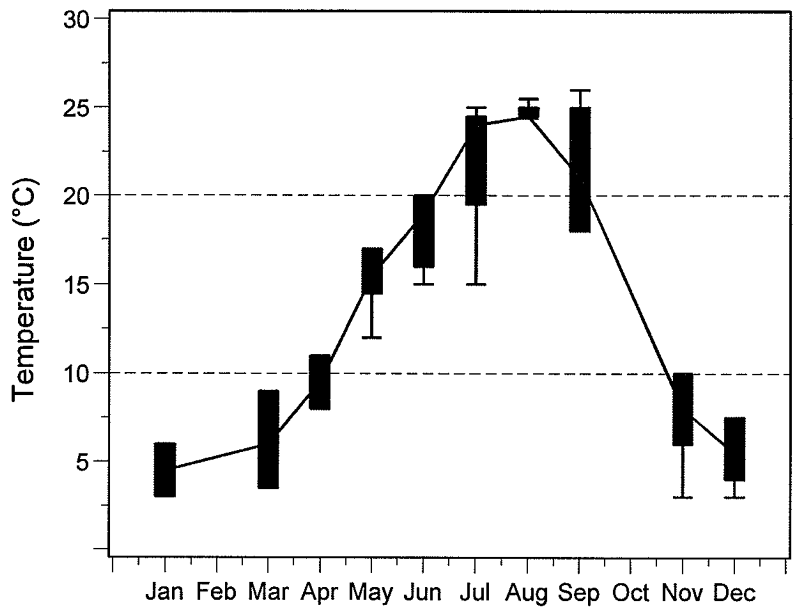

Figure 3a. Annual temperature profile averaged over four sites in Raritan Bay for 1993-1997 (prepared by MRS from data of Zimmer and Groppenbacher 1999).

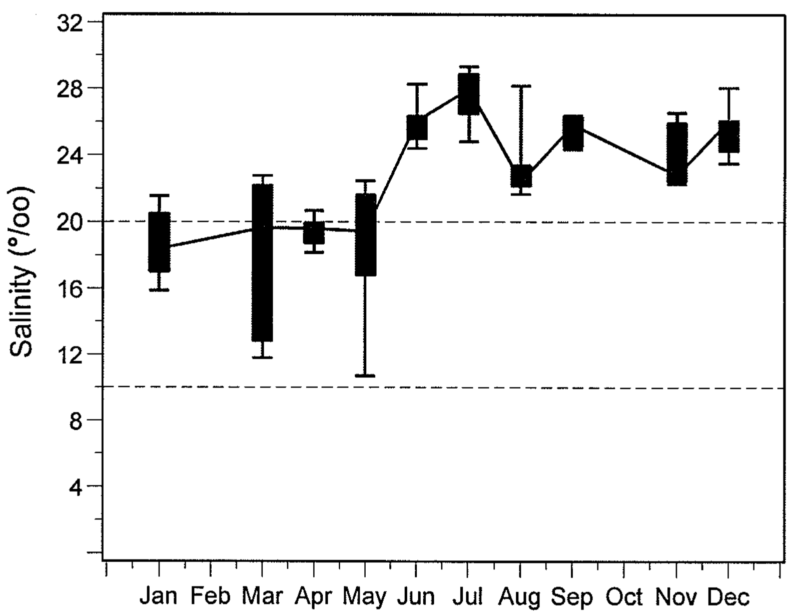

Figure 3b. Annual salinity profile averaged over four sites in Raritan Bay for 1993-1997 (prepared by MRS from data of Zimmer and Groppenbacher 1999).

3.1.3 Species of concern

3.1.3.1 Harmful algae

The Hudson-Raritan Estuary has been the site of chronic harmful algal blooms for over three decades due in part to the high nutrient levels associated with land runoff from natural and domestic sources (Gastrich 2000). Some of these blooms have been associated with human health effects while others have had negative ecological impacts. In particular, the decomposition of dying cells during and following an algal bloom lowers the ambient oxygen level creating "hypoxic" conditions which may result in the asphyxiation of shellfish and/or finfish populations (Reid et al. 2002).

The New Jersey Department of Environmental Protection has a comprehensive longterm monitoring program for harmful algal blooms in the Raritan Bay area (e.g. NJDEP Annual Phytoplankton Reports 1999). Based on these records, a list was compiled of those phytoplankton species believed to be non-indigenous to the Bay of Fundy. Note that this distinction was made by comparing the NJDEP list with the phytoplankton data available for the Passamaquoddy Bay/Grand Manan area (Martin et al. 1999, 2001) and the Annapolis Basin (Keizer et al. 1996). It should also be noted that there are several other phytoplankton species which are considered potentially "harmful" in New Jersey, but commonly occur at non-bloom levels in the Bay of Fundy, e.g. *Procentrum micans, Skeletonema costatum* and *Cerataulina pelagica.*

- *Aureococcus anophagefferens:* "brown tide" blooms of this golden-brown chrysophyte are associated with a reduction in juvenile hard clam growth, damage to scallops, clams and oysters including catastrophic effects on bay scallops (*Argopecten irradians*); certain isolates may produce a toxin which inhibits bivalve suspension-feeding (Bricelj et al. 2001); blooms may also damage eelgrass beds during prolonged periods of occurrence and have adverse effects on zooplankton, anchovies and kelp beds (Cosper et al. 1987, Smayda and Fofonoff 1989);
- *Gyrodinium cf. aureolum*: "green tides" of this dinoflagellate species have been associated with mild sickness in swimmers as well as mortalities of blue mussels (*Mytilus edulis*) and lady crab (*Ovalipes ocellatus*) (Mahoney et al. 1990)
- *Heterosigma akashiwo* (previously mis-identified as *Olisthodiscus luteus*)*:* "red tides" of this raphidophyte are reported in NJ waters (NJDEP Annual Phytoplankton Reports, 1999); blooms are associated with respiratory discomfort among swimmers as well as potential toxicity to fish (Mahoney and McLaughlin 1977); this species causes major problems for salmon growers in BC
- *Massartia rotundata (*previously *Katodinium rotundatum*): "red tides" of this dinoflagellate species may cause hypoxia leading to mortality in local fauna as well as adverse effects on

recreational resources, including discomfort among swimmers, and a diminished aesthetic value of beaches (Olsen and Mulcahy 1991)

- *Nannochloris atomus:* "green tide" blooms of this chlorophyte are associated with water discolouration in Raritan Bay

3.1.3.2 Invertebrate species

The invertebrate species of greatest concern are those with a documented history of successfully invading new ecosystems. These species may be transferred in ballast water during the planktonic larval phase of their life-cycle or settle directly on the hull of ships where they are dispersed to new ecosystems. Information on the specific distribution of these species in the Raritan Bay area is difficult to obtain, but they are reported to occur in the New York/New Jersey region and/or in New England. For more details on the life history of these species see the MIT Sea Grant Center for Coastal Resources: Marine Bioinvasions website[5]. Non-indigenous species such as the green crab (*Carcinus maenas*) which is now widely established in Atlantic Canada have been excluded from this list.

✦ **Ascidians (tunicates or sea squirts)**

- *Ascidiella aspersa*: solitary ascidian - broadcast spawner whose larvae become competent to settle within 12-24 h following fertilization (Niermann-Kerkenberg and Hoffman 1989)
- *Botrylloides violaceus:* compound or colonial species of Pacific origin, which may be responsible for severe fouling of mussels, bay scallops and other shellfish (recently recorded in the Lunenburg area of NS); brood short-lived larvae which settle almost immediately upon release
- *Didemnum sp.:* compound or colonial species recently introduced into New England-potential for severe overgrowth of shellfish in culture
- *Diplosoma listeranum:* compound or colonial species recently introduced into New England
- *Styela clava* (club tunicate): solitary species native to Asia, broadcast spawner whose larvae become competent to settle in 12-24 h following fertilization; presently causing severe fouling problems for mussel growers in Prince Edward Island but not yet observed in Nova Scotia

✦ **Crustaceans (crabs, lobsters, barnacles)**

- *Hemigrapsus sanguineus* (Asian or Japanese shore crab): small crab, native to Japan and the western North Pacific; first observed in Long Island Sound in 1992 possibly as a result of ballast water discharge (Figure 4); now recorded from Maine to North Carolina, it has caused significant ecological disruption in the rocky intertidal zone by outcompeting native crab species; poses a threat to the juvenile stages of various commercial shellfish species including clams, mussels, oysters
- *Balanus amphitrite* (Striped Barnacle, Purple Acorn Barnacle): non-indigenous species recorded in Long Island Sound in 2002; ecological impact unknown

---

[5] http://massbay.mit.edu/exoticspecies/index.html

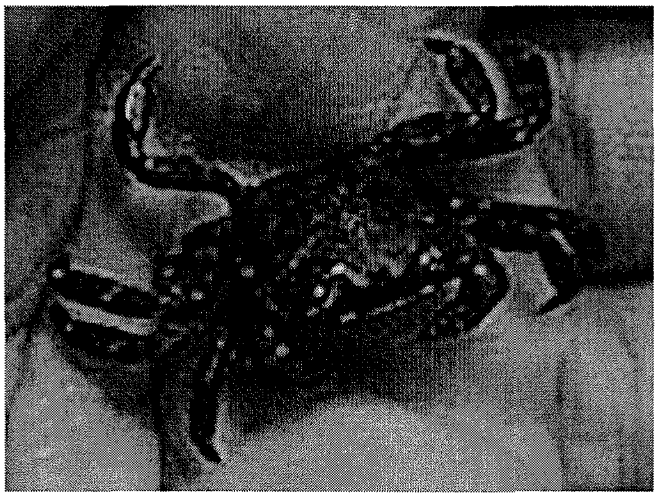

Figure 4. Asian or Japanese shore crab *Hemigrapsus sanguineus*

✦ **Molluscs (nudibranchs, whelks)**

- *Rapana venosa* (Veined Rapa whelk): (not an immediate risk) predatory gastropod native to Japan, but spread to the Mediterranean in the 1940's; presently outcompeting native species in Chesapeake Bay; dispersal north into the Cape Cod region is considered a high probability over a period of decades; range extension believed to be mediated by transport of larval stages in ballast water (O'Neill 2000)
- *Tritonia plebeia* (nudibranch): imported from Europe into New England, responsible for damaging coral populations (Allmon and Sebens 1988).

3.1.3.1 Pathogens/parasites

The species of greatest concern are those which could impact on local fishery resources; for more details see the Synopsis of Infectious Diseases and Parasites of Commercially Exploited Shellfish (Bower et al. 1994)[6] .

✦ **Molluscan diseases**

- *Haplosporidium nelsoni*: parasite which causes "MSX" (Multinucleate Sphere X) disease in American oysters (*Crassostrea virginica*); characterised by disruption of digestive tubules; mortalities occur in spring and summer; method of transmission unknown but the existence of an intermediate host is strongly suspected (Bower et al. 1994); recently introduced into the Bras D'Or Lakes by unknown means, presently causing major disruption of the local oyster industry
- *Perkinsus marinus:* parasite which causes "Dermo" disease in American oysters (*Crassostrea virginica*); characterized by systemic tissue disruption; may cause 95% mortality during periods of warm summer water temperatures (>20°C) (Bower et al. 1994)

[6] http://www.pac.dfo-mpo.gc.ca/sci/shelldis

- w *Pinnotheres spp*: parasitic pea crabs which infest the mantle cavity of molluscs (*Crassostrea virginica, Mytilus edulis, Argopecten irradians*); no known pathological effects but competes for food and potentially reduces market value

✦ Crustacean diseases

- w *Loxothylacus panopaei*: a rhizocephalan or barnacle parasitic on xanthid crabs including rock crabs (*Cancer irroratus*) and green crabs (*Carcinus maenas*)
- w *Paramoeba sp.*: parasitic amoeba tentatively associated with mass mortalities of lobsters (*Homarus americanus*) in Long Island Sound - has not been proven to be the cause of the mortalities, possibly a secondary agent following weakening of the immune system associated with stressful environmental conditions; can be found in healthy individuals with no symptom s of infection (Frasca 2001, Robohm and Draxler 2001).
- w *Paramoeba perniciosa*: agent responsible for "Grey Crab" disease; may cause limited mortality in rock crabs (*Cancer irroratus*), green crabs (*Carcinus maenas*) and lobsters (*H. americanus*); typically of concern following handling or holding in tanks

✦ Fish diseases

- w *Anguillicola crassus*: commonly referred to as the Asian Eel Swimbladder Nematode; an exotic parasite of the American eel (*Anguilla rostrata*) which inhabits the lumen and wall of the swimbladder; may cause debilitation and possibly mortality

3.2 Whites Point, Digby Neck, Nova Scotia

3.2.1 Location of discharge

Ballast water taken up in Raritan Bay, unless exchanged en route in US waters, will be discharged at Whites Point (Lat: 44°30', Long: 66°10'), a cove located on the western side of Digby Neck in the Bay of Fundy (Figure 5). This is a small fishing community in a non-industrialized region, with no regular commercial shipping activity. Given that there are few specific environmental data for the area, information on the Bay of Fundy system is presented.

3.2.2 Bay of Fundy: environmental conditions

The Bay of Fundy tides are among the highest in the world, with a mean tidal range of 3.5 to 10 m and a maximum tidal range of 6 to 14.5 m. The flood tide is stronger along the southern coast (NS) whereas the ebb tide is stronger along the northern coast (NB) resulting in a residual counterclockwise circulation pattern or cyclonic current gyre in the center of the Bay (Swift et al. 1973). The average tidal current velocities increase from around 0.7 m/s at the mouth of the Bay to 1.3 m/s at the head. Currents off the Whites Point region on the shore of Digby Neck would reach maximum values of 1.25 m/s at mid-tide (flow) during which the current direction is typically parallel to the shore (Figure 6). Seasonal wind patterns may influence the movement of surface water; for example, southwest winds during the summer will tend to retain the surface waters in the

Bay. The large intertidal volume combined with high current flow results in excellent mixing; an average flushing time of 75 d was estimated by Ketchum and Keen (1951).

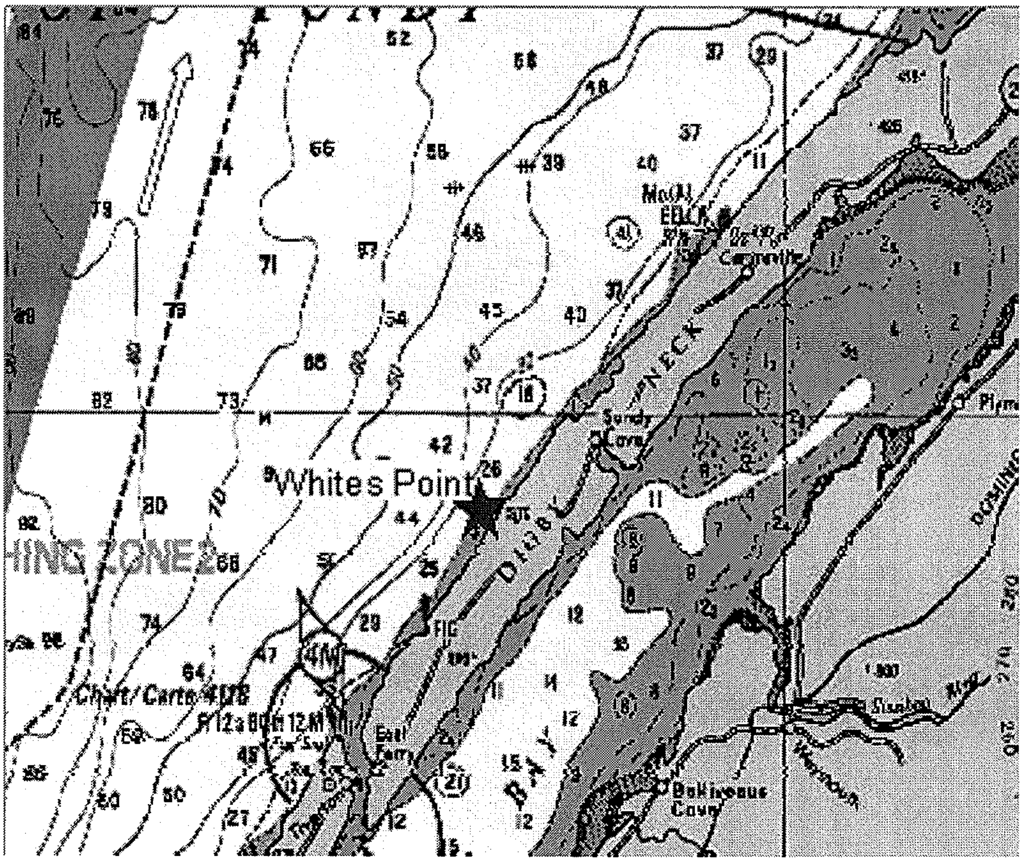

Figure 5. Location of Whites Point on Digby Neck, NS (DFO Fishing Zone 4Xr).

During the autumn and winter the water mass of the Bay of Fundy is vertically homogenous due to turbulent mixing (Hunter and Associates 1982). Salinity and thermal stratification develop during the summer months. Temperatures are relatively cold ranging from -1.7°C in winter to summer highs rarely exceeding 16°C. Summer surface temperatures are coolest at the mouth of the Bay (9-11°C) increasing to a mean of 14°C at the head of the Bay. In winter this trend is reversed with the warmest waters being found at the mouth of the Bay (4°C). Upwelling along the

Nova Scotia coast tends to maintain lower temperatures than along the north shore of the Bay (Hachey 1952).

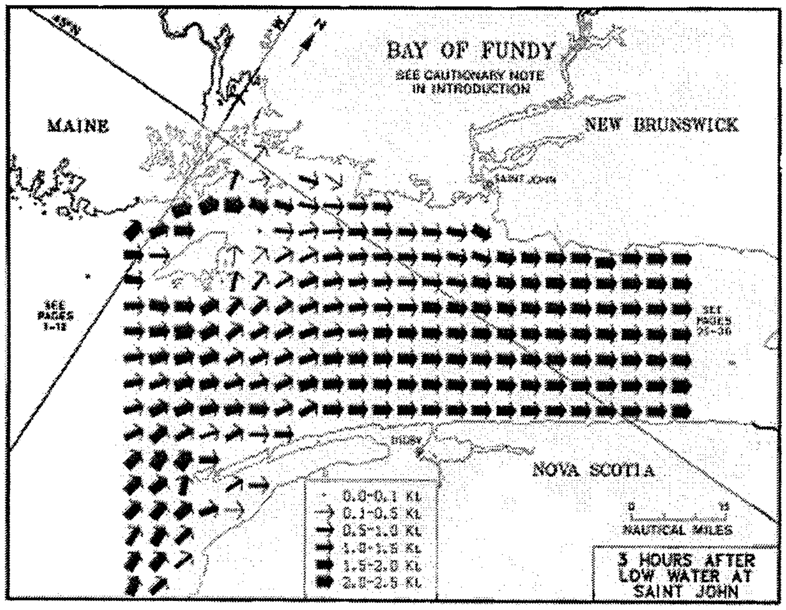

Figure 6: Current speed and direction on an incoming tide 3 h after low water. Other stages of the tidal regime can be obtained from the Atlas of Tidal Currents (1982).

Temperature recorders located in shallow water (0-12 m) in the western part of fishing zone 4Xr (including Digby Neck) indicated values ranging from a winter minimum of 0°C to a summer maximum of 14°C (Petrie and Jordan 1993). Overall mean values for this zone (estimated for the period 1970-1990) ranged from 1.5°C in February to 11.9°C in September (Figure 7).

In general, the Bay of Fundy is considered a full salinity environment. Salinities at the mouth of the Bay may be as high 32.9°/oo decreasing to 31°/oo at the head of the Bay (Hachey 1952). Salinity data for Whites Point was consistent with this pattern; a sample from June 17 2003 was 32°/oo (Kern, pers. comm). A depth profile of temperature and salinity running across the Bay of Fundy from West Point in August indicated salinities consistently exceeding 30°/oo (Hachey 1952). The upward slope of the isotherms indicates a tendency for upwelling of colder water in the zone adjacent to the coast.

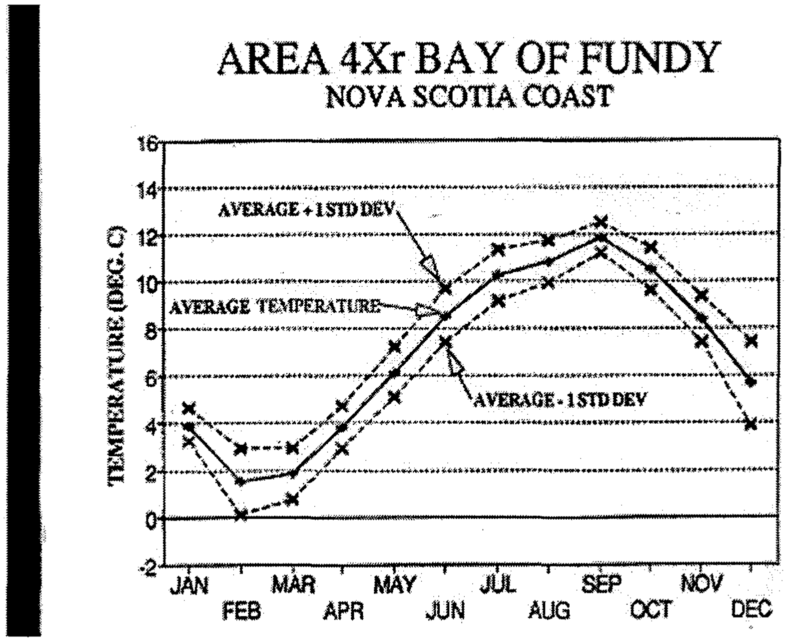

Figure 7: Average monthly temperatures (solid lines with pluses) and average plus or minus one standard deviation (dashed lines with "X"s) for the 4Xr zone off Digby Neck (from Petrie and Jordan 1993).

3.2.3 Risk of introduction

To successfully establish a new population, a non-indigenous species must survive several major transition phases - uploading through the ballast water pump system, the voyage in the ballast water tank and discharge into the new environment. Potential sources of mortality include biological factors such as starvation and predation, physical factors such as light limitation, temperature changes and injury from turbulence, and chemical factors such as oxygen limitation or exposure to toxic compounds (Carlton 1985, Lavoie et al. 1999, Wonham et al. 2001). Moreover, short term survival does not guarantee that the species will tolerate the seasonal range of temperature and salinity conditions in the new environment. This section will attempt to evaluate the risk of introducing the various species of concern.

3.2.3.1 Environmental considerations

The voyage from South Amboy will be relatively short (2 d) at an estimated distance of 500 nm which will tend to favour the survival of many species (Lavoie et al. 1999). Depending on the period of the year, i.e. particularly in winter and summer when the temperature differential between the ports is maximized, temperature will likely decline over the duration of the voyage. Salinity will remain unchanged unless a ballast water exchange is undertaken in which case the salinity will likely increase relative to the original water.

In general the Bay of Fundy is substantially colder than the Raritan Bay system. Summer temperatures rarely exceed 14°C, and winter temperatures may fall to 0°C (Figure 7). Salinities typically exceed 30°/oo; these levels are likely higher than the salinities in the more estuarine Raritan Bay system. The likelihood of brackish-water species surviving the discharge into the Bay of Fundy and becoming established in the area of Whites Point is low given the minimal freshwater input in this zone. The planktonic stages of certain species may, however, be transported into the Annapolis Basin or the upper reaches of the Bay; the odds on such an event occurring would be difficult to calculate.

3.2.3.2 Harmful algae

Blooms of harmful algae species are not necessarily associated with anthropogenic nutrient loading, but to a combination of regional circulation patterns (water flow, water column stratification, mixing rates) coupled to species' life histories (Gastrich 2000). However, based on the relatively high chlorophyll levels observed during the summer months (17-59 ug/l), it is reasonable to suppose that nutrient levels are significantly higher in Raritan Bay than those typically observed in the Bay of Fundy. For example, maximum annual chlorophyll values for the nearby Annapolis Basin were 10 ug/l in September (Keizer et al. 1996).

The phytoplankton species of greatest concern is *Aureococcus anophagefferens*, the organism responsible for "brown tides" which may cause significant losses of various shellfish species and eelgrass beds. Although it has been found in the Hudson-Raritan estuary, this species does not bloom regularly, possibly because it is highly sensitive to organic and metal toxicants (Mahoney et al. 2003). It has been suggested that higher salinities during summers with reduced rainfall may have been conducive to the development of "brown tides" in Long Island bays in the mid-1980's (Cosper et al. 1989). The preference of this species for high salinities >28°/oo (Cosper et al. 1990) would be consistent with the conditions at Whites Point; however it is unlikely to be taken up in bloom densities in the South Amboy region where salinities are presumably <25°/oo. Growth rates are maximum at 20-25°C (Cosper et al. 1990) which is substantially higher than the summer temperatures for the Whites Point area. It should be noted that in addition to high water temperatures, the conditions required for bloom initiation are typically high organic levels in shallow bays with restricted flushing. These conditions would not occur in the cold highly turbulent environment of the Whites Point region. However, it is conceivable that cells might be transported into the warmer nutrient-rich upper reaches of the Bay of Fundy or the Annapolis

Basin. It is not known whether this species would be capable of blooming in the high turbidity conditions typical of the upper Bay of Fundy.

The "green tide" species *Gyrodinium cf. aureolum* is listed by Martin et al. (2001) as occurring in the Bay of Fundy although it is relatively rare, possibly because the conditions are unsuitable for bloom development.

One approach to assessing the risk of introduction is to compare the range of environmental conditions typically associated with the various harmful algal species versus those which would be encountered in the Bay of Fundy. It can be argued that the greater the mis-match between these tolerance limits and the conditions at Whites Point (temperatures <15°C, salinities >30°/oo), the lower the risk of introduction. Unfortunately specific information on tolerance limits is often lacking.

Table 1. Summary of the environmental tolerance data for the harmful algal species from Raritan Bay.

Species	Temperature range	Salinity range	Seasonal occurrence	Concern	Possible threat	Survival potential
Aureococcus anophagefferens	Blooms at >20°C	Blooms at >25°/oo	Jun-Sep?	Brown tides	Bivalve shellfish, eelgrass and kelp beds	Low?
Gyrodinium cf. aureolum	>20°C?	?	Aug-Sep	Green tides	Bivalve/crustacean mortality, discomfort in swimmers	Low?
Heterosigma akashiwo	>20°C?	?	Jun-Aug	Red tides	Mortality in finfish	Low?
Massartia rotundata	>20°C?	?	Jun-Aug	Red tides	Mortality of fauna, discomfort in swimmers	Low?
Nannochloris atomus	>20°C?	?	Jun-Aug	Green tides	Risk of hypoxia	Low?

3.2.3.3 Invertebrates

Most of the marine "invasive" species that have been documented in North America belong to the category of crustaceans or molluscs (Ruiz 2000). The lack of quantitative data on the environmental tolerances and dispersal rates of these species, particularly during their early life history phases, hinders the estimation of their potential to successfully colonize new environments (Table 2).

The invertebrate species of greatest concern for the Whites Point area is the Asian shore crab which has successfully colonized the northeast region of the US coast, as well as the Mediterranean. Apparently the spawning season for this species continues for at least four months (June to September) in the New Jersey region, considerably longer than that of the native crab species (Epifanio et al. 1998). The first part of the larval cycle or zoeal phase ranges from 16 d at 25°C to 55 d at 15°C. Salinity tolerance is temperature dependent; larvae can survive 15°/oo at 25°C but require >20°/oo at 15°C. During the second part of the larval cycle, the megalopa phase, the larvae are less tolerant of temperature/salinity variations. Megalopae will not develop to the juvenile stage at temperatures <20°C or salinities <25°/oo. These data suggest that although the larvae of these species might survive the passage to Whites Point, the temperature conditions would be too cold to complete the megalopa phase of development. It should be noted, however, that these data were obtained in laboratory trials and may not be fully representative of the species ability to adapt to new environmental conditions (Epifanio et al. 1998).

The various ascidian species typically have a very short larval cycle (<3 d) and are very rarely observed in ballast water samples in ships arriving in Atlantic Canada (Carver and Mallet 2001). A much more likely vector for ascidian species is hull fouling; for example, the successful introduction of *Styela clava* to PEI is believed to have occurred via this route. In general, the increasing number of invasive ascidian species in New England waters does not bode well for the Bay of Fundy ecosystem with its similar environmental conditions.

Table 2. Summary of the environmental tolerance data for the planktonic larval phases of various invertebrate species in the New York/New Jersey area.

General category	Species	Larval temp range	Larval salinity range	Timing of larval production	Larval period	Concern	Possible threat	Potential for transfer
Ascidians	*Ascidiella aspersa*	?	?	?	<3 d	Ecological disruption	Native species	?
	Botrylloides violaceus	?	?	?	<1 d	Severe fouling, ecological disruption	Native species, cultured bivalves	?
	Didemnum sp.	?	?	?	?	Severe fouling, ecological disruption	Native species, cultured bivalves	?
	Diplosoma listeranum	?	?	?	<1 d	Ecological disruption	Native species	?
	Styela clava	15-25°C	15-30°/oo	?	<3 d	Severe fouling, ecological disruption	Native species, cultured bivalves	?
Crustaceans	*Balanus amphitrite*	?	?	?	?	Invasive species	?	?
	Hemigrapsus sanguineus (megalopa stage)	>20°C	>25°/oo	Jun to Oct	?	Ecological disruption	Outcompetes native crab species, preys on juvenile bivalves	?
Molluscs	*Tritonia plebeia*	?	?	?	?	Ecological disruption	Predator on coral	?

3.2.3.4 Pathogens/parasites

Very little effort has been directed towards assessing the potential for ballast water-mediated introduction of disease organisms. Successful transmission will depend on whether the disease is water-borne, how long and under what environmental conditions an infectious agent can survive outside its target organism, and whether there are intermediate hosts which can act as carriers for the agent (Table 3). With the advent of DNA probes it should eventually be possible to test samples of ballast water for the presence of specific disease organisms (e.g. Gast 2001, Gillevet et al. 2001). The disease agent of greatest immediate concern is the *Paramoeba sp.* which has been implicated in the mass mortalities of lobsters in Long Island Sound in 1998-1999. This *Paramoeba sp* may prove to be similar to *Paramoeba invadens*, the organism responsible for mass sea urchin die-offs in Nova Scotia (Jones et al. 1985, Jellett et al. 1988). Typically these sea urchin die-offs occur only when the population is overcrowded, food-limited and exposed to above average water temperatures. At other times *P. invadens* can be found in apparently healthy sea urchins. Similarly, researchers in Long Island report that *Paramoeba* sp. can be found in healthy lobsters with no apparent negative health implications. The die-offs in Long Island Sound occurred in the summer months during a period when the population was believed to be stressed by above average water temperatures and possible exposure to pollutants. It should be noted, however, that if this *Paramoeba* agent behaves similarly to the sea urchin variety, it is likely to be water borne or directly transmissible from one individual to another (Bower et al. 1994). The survival potential of this agent in ballast water has not been evaluated.

It should also be noted that even after several years of dedicated research (Long Island Sound Lobster Initiative - March 2003)[7], there is still no concensus as to the primary cause of the lobster mortalities. One possibility which has not been eliminated is that the mortalities were related to pesticide runoff, in particular those compounds (malathion, resmethrin and methoprene) used to control mosquito populations following the discovery of the West Nile virus in New York state. If pesticides were the primary cause or perhaps a significant contributing factor, then the potential of the disease occuring in the Bay of Fundy is substantially reduced.

The possible introduction of the disease organisms responsible for MSX and Dermo in American oysters is a very serious concern for shellfish growers and harvesters in Atlantic Canada. However, the Bay of Fundy environment is generally too cold for this oyster species; the closest

---

[7] http://www.seagrant.sunysb.edu/LILobsters/

population of American oysters to Whites Point is probably in Eel Lake near Argyle on the Atlantic coast of Nova Scotia. Unless the parasites could survive in an alternate host (e.g. a gastropod or other mollusc), it would seem unlikely that they would pose a serious threat to any mollusc population in the immediate vicinity of Whites Point.

The risk of introducing *Pinnotheres sp* or the parasitic pea crab is difficult to assess; DFO simply states that precautions should be taken to avoid such an occurrence but there is little life history information.

Table 3. Summary of environmental tolerance data for the infective stages of the various pathogens/parasites in the New York/New Jersey area.

Category	Species	Temp range for infection	Salinity range for infection	Seasonal occurrence	Concern	Possible threat	Potential for transmission
Molluscan diseases	*Haplosporidium nelsoni*	<20°C	>15°/oo	?	MSX disease	American oyster mortality	Low
	Perkinsus marinus	>20°C	?	?	Dermo disease	American oyster mortality	Low
	Pinnotheres sp.	?	?	?	Parasitic	Bivalve shellfish	?
Crustacean diseases	*Loxothylacus panopaei*	?	?	?	Parasitic castrator	Rock crabs, green crabs	?
	Paramoeba perniciosa	?	?	?	Grey crab disease	Crabs, lobsters	?
	Paramoeba sp.	?	?	?	Mass mortality	Lobsters	?
Fish diseases	*Anguillicola crassus*	?	Up to 30°/oo	?	Parasitic nematode	Eels	Lower in full salinity

3.2.4 Other risks

The commercial traffic in Eastern Canada is expected to continue to expand over the next ten years. In 2000, 5,504 vessels originating from foreign ports of origin entered Eastern Canadian waters and of these, 3386 visited ports in the Atlantic region. In terms of the Bay of Fundy, the ports of Saint John and Bayside, on the southern New Brunswick coast accounted for 293 of the ships arriving in ballast; the volume of water discharged by these ships would have varied depending on the type of cargo. On the Nova Scotia coast the port of Hantsport in the Minas Basin accounted for 119 gypsum ships, all of which would have discharged their ballast water in the Bay of Fundy en route to the Minas Basin or at the dock in Hantsport. A large proportion of this ballast water originated from intracoastal traffic arriving from ports in the US (Balaban 2001); depending on the suite of organisms present at the various ports of origin, some of the species identified above may be regularly discharged into the Bay of Fundy.

4 Risk mitigation measures

4.1 Ballast water management practices

The risk of invasive species being introduced into Eastern Canada is influenced by several factors such as origin and age of the ballast water as well as the season. It is believed that these risks can be significantly reduced by adopting environmentally-sensitive ballast water management practices. In accordance with the IMO's ballast water guidelines, most commercial shipping vessels now have a ballast water management plan on board. These plans are specifically designed for each class of vessel taking into account their structural and stability constraints. The IMO guidelines clearly state that under no circumstances should ballast water management activities in any way compromise the safety of the ship or crew.

4.1.1 Ballast water uptake

Precautions for reducing the probability of uploading undesirable species during ballasting include avoiding: (a) areas with a history of harmful phytoplankton blooms, outbreaks of known harmful species including pathogens, and/or sewage outfalls; (b) periods of darkness when bottom-dwelling organisms may rise to the surface; (c) shallow water where the ship's propellors may churn up sediment; and (d) areas with heavy sediment loading due to dredging activity, or soil erosion from inland drainage. With regard to these various specifications, the point source location of the ballast water in Raritan Bay would likely be considered high risk.

4.1.2 Ballast water exchange

Ballast water exchange involves replacing the water originally taken up in the port of origin with oceanic water; the ostensible purpose is to replace any undesirable organisms by oceanic species which would be less likely to survive when discharged into the coastal waters of a new environment (Locke et al. 1993). Depending on the conditions at the port of origin, the change in the temperature and salinity within the tank should also have a negative impact on organisms with a poor tolerance for oceanic conditions.

The most effective exchange strategy is to completely empty a tank and then re-fill with oceanic water (termed "E/R" exchange), but safety considerations may prohibit this procedure. The more common approach is to undertake a flowthrough (F/T) exchange which is designed to flush the tanks without changing the volume; typically a 300% exchange is recommended or in other words a volume of water three times that of the tank is passed through the system. The time required to undertake this procedure will depend on the size of the tank and the capacity of the ballast water pump. To maximize the effectiveness of this procedure, the IMO guidelines recommend that this activity be undertaken 200 nm offshore and in waters >2000 m deep. Ships on intracoastal voyages from the US to Canadian waters are not obligated to divert from their preferred course to meet these conditions, but are requested to undertake an exchange at the some appropriate offshore point along their route.

It is widely acknowledged that ballast water exchange is not always 100% effective at replacing the original community with a new suite of oceanic species. Estimates range from 88 to 99% (Locke et al. 1993, Zhang and Dickman 1999) and vary depending on the type of organism involved (Wonham et al. 2001). In particular, many ballast tanks have a residual volume or "unpumpable" component; organisms in this zone may be retained even during flushing activity. Similarly, organisms which adhere to the surface of the tank, swim away from the outflow point, or settle out as resting spores in the sediments may not be eliminated by the exchange procedure.

Although the practice of exchanging ballast at sea may not be 100% effective, it represents the minimum level of precaution that should be taken. We therefore recommend that ships carrying ballast water from New Jersey should be strongly encouraged to adhere to the guidelines published by Transport Canada, i.e. to exchange ballast water en route for the purpose of eliminating all or some of the original suite of Raritan Bay species, thereby reducing the possibility of introducing undesirable organisms. The option of ballast water exchange should be feasible on this route throughout the year. The distance between Whites Point and South Amboy is approximately 500 nm with an approximate transit time of 48 h. With the ballast pumps sized appropriately, the Empty/Refill method could be carried out in approximately 15 h whereas approximately 30 h would be required to complete a Flow-Through exchange. One option would be to exchange a number of tanks immediately upon leaving Raritan Bay, at water depths greater than 35 m up to a point south of Martha's Vineyard. Ballast water exchange could then be resumed at a point north of Nantucket and completed by the time the ship reached Canadian waters.

4.1.3 Discharge and maintenance procedures

There are a several possible strategies for reducing the probability of organisms surviving the ballast water discharge procedure. Assuming that safety regulations are not compromised, one strategy is to start discharging ballast water before arriving at the dock; this will tend to expose any surviving organisms to deeper offshore waters where they will be less likely to find a sheltered zone for settlement or encounter a potential host species.

Another important consideration is the frequency of hull cleaning, ballast tank sediment removal and inspection of anchor chain lockers for the presence of non-indigenous species. Hull cleaning should only be undertaken in a facility with appropriate containment measures, preferably in the New Jersey region or other US ports as opposed to Canadian waters. Ballast water tanks are often inspected semi-annually, and any significant accumulation of sediment must be discarded in an appropriate fashion due to possible presence of cysts (MacDonald 1995). Similarly, mud associated with the anchors and chains should be washed down as part of the regular cleaning activities on the ship.

4.2 Developing a species database for US and Canadian ports

Compiling information on high-risk species and their environmental tolerances is an important step towards developing an targeted risk mitigation program. At present, many countries have toxic/harmful phytoplankton monitoring programs, but there is no easily accessible database indicating the potential risk species for a given port in a given season. The compilation of such a database would require considerable effort and co-operation on the part of participating countries, but would greatly facilitate the assessment of the risks associated with the movement of ballast water.

5 Conclusions

This report provides a preliminary evaluation of the risks involved in moving ballast water from South Amboy, New Jersey to Whites Point in Nova Scotia. Assessing the risks of introducing potentially harmful organisms is a developing field which is highly dependent on the availability and quality of the information. Given that no specific data were available for the port of origin, background information was obtained for the surrounding region and compared with general information on the Bay of Fundy to develop an assessment of the risk. More comprehensive information on the organisms present at the port of origin, their seasonal occurrence and environmental tolerances would be required to improve the quality of this assessment.

The greatest immediate concern for the Whites Point ecosystem and fishing community would be the potential introduction of the “pathogen” responsible for the mass lobster mortalities observed in the Long Island Sound area in 1999. Evaluating this risk is, however, very difficult given the current status of the research on this issue. First, it is not clear from the literature whether the possible disease-causing agent, a *Paramoeba sp.*, is indeed the primary cause or a secondary agent characteristic of a environmentally-stressed population. Second, very little is known about the life-history characteristics of this potential pathogen, particularly its ability to survive in a ballast tank, or in the relatively cold environment of the Bay of Fundy.

The two other organisms of major concern are *Aureococcus anophagefferens*, the algal species responsible for harmful "brown tides", and *Hemigrapsus sanguineus*, the highly successful invader, the Asian Shore Crab. A review of the environmental tolerance data for these species suggested that the potential for introduction and longterm establishment is likely restricted by the cold water temperatures during the summer period. However, there always remains the risk that these species could be transported by the strong tidal currents into more suitable regions such as the Annapolis Basin or St. Mary's Bay.

In the event that a species of potential concern were to become established in the Whites Point area, it would be difficult to establish whether the ballast water being discharged as part of the quarrying operation was necessarily the source of the introduction. It should be emphasized that ballast water from various US ports is frequently being discharged by commercial ships traveling to Hantsport and Saint John and that organisms in this water may be carried into the Whites Point area. Assessing this overall risk would require information on the extent of the ship traffic, their ballast water discharge patterns and the physical oceanography of the Bay of Fundy system.

In conclusion, a more extensive survey of the organisms which occur in South Amboy waters as well as data on their life-history characteristics would be required to provide a more complete evaluation of the risk of introduction. It is our impression, based on a review of the literature and limited contact with US scientists, that these data are apparently not available at this time. Additional efforts to contact local state authorities might, however, elicit more useful data in unpublished formats. The most important step towards mitigating the risk of introduction is to insure that the ship undertakes a ballast water exchange en route from Raritan Bay.

6 References

Allmon, R.A. and K.P. Sebens. 1988. Feeding biology and ecological impact of an introduced nudibranch plebeia. Mar. Biol. 99:375-385.

Atlas of Tidal Currents: Bay of Fundy and Gulf of Maine. 1981. Canadian Hydrography Service, Dept. Of Fisheries and Oceans. 36 pp.

Balaban, M. 2001. Vessel traffic / vessel shipping patterns on the east coast of Canada. 2000 Shipping Season. Transport Canada, Marine Safety, Atlantic Region.

Boalch, G.T. and D.S. Harbour. 1977. Unusual diatom off the coast of south-west England and its effect on fishing. Nature 269:687-688.

Bower, S.M., S.E. McGladdery, and I.M. Price. 1994. Synopsis of infectious diseases and parasites of commercially exploited shellfish. Ann. Rev. Fish Dis. 4: 1-199.

Bricelj, V.M., S.P. MacQuarrie and R.A. Schaffner. 2001. Differential effects of *Aureococcus anophagefferens* isolates ("brown tide") in unialgal and mixed suspensions on bivalve feeding. Mar. Biol. 139:605-615.

Burkholder, J.M., H.B. Glasgow, and C.W. Hobbs. 1995. Fish kills linked to a toxic ambush-predator dinoflagellate: distribution and environmental conditions. Mar. Ecol. 179: 301-310.

Carlton, J.T. 1985. Transoceanic dispersal of coastal marine organisms: the biology of ballast water. Oceanogr. Mar. Biol. Ann. Rev. 23: 313-374.

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

Carlton, J.T., J.K. Thompson, L.E. Schemel and F.H. Nichols. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. I. Introduction and dispersal. Mar. Ecol. Prog. Ser. 66: 81-94.

Carver, C.E. and A.L. Mallet. 2002. Assessment of the risks of ballast water introduction of non-indigenous phytoplankton and zooplankton species into Atlantic Canadian Waters. Transport Canada, Marine Safety

Cosper, E.M., E.J. Carpenter and M. Cottrell. 1987. Recurrent and persistent brown tide blooms perturb coastal marine ecosystem. Estuaries 10: 284-290.

Cosper, E.M., E.J. Carpenter and M. Cottrell. 1989. Primary productivity and growth dynamics of the "brown tide" in Long Island embayments. In: E.M. Cosper, V.M. Bricelj and E.J. Carpenter (eds.), Novel phytoplankton blooms: causes and impacts of recurrent brown tides and other unusual blooms. Springer-Verlag, Berlin. P. 139-158.

Cosper, E.M., C. Lee, and E.J. Carpenter. 1990. Nov el "brown tide" blooms in Long Island embayments: a search for the causes. In Graneli, E., B. Sundstrom, L. Edler and D.M. Anderson (eds.), Toxic Marine Phytoplankton, Elsevier Science Publishing, pp. 17-27.

Epifanio, C.E., A.I. Dittel, S. Park, S. Schwalm, and A. Fouts. 1998. Early life history of *Hemigrapsus sanguineus*, a non-indigenous crab in the Middle Atlantic Bight (USA). Mar. Ecol. Prog. Ser. 170: 231-238.

Fofonoff, P.W., G.M. Ruiz, A.H. Hines and J.T. Carlton. 2002. Patterns of biological invasions in estuaries of the northeast coast of North America. In: Chapman, R.O. (ed.) Marine Biological Invasions: A Perspective on Atlantic Canad and New England, Ecology Action Centre, Halifax, N.S. p. 9-10.

Frasca, S. 2000. Development of polymerase chain resaction and in situ hybridization-based tests for te specific detection of the paramoeba associated with epizootic lobster mortality by determination of the molecular systematics of the genus *Paramoeba*. In: Long Island Sound Lobster Health Symposium - Research Summaries, p 38-39.

Gast, R. 2001. Oligonucleotide-based detection of pathogenic *Paramoeba* species. In: Long Island Sound Lobster Health Symposium - Research Summaries, p 40-41.

Gastrich, M.D. 2000. Harmful algal blooms in coastal waters of New Jersey. New Jersey Department of Environmental Protection. Division of Science, Research and Technology.

Gillevet, P.M., C.J. O'Kelly, T. A. Nerad and T.K. Sawyer. 2001. Phenotypic and molecular identification of environmental specimens of the genus Paramoeba associated with lobster mortality events. In: Long Island Sound Lobster Health Symposium - Research Summaries, p 42.

Hachey, H.B. 1952. The general hydrography of the waters of the Bay of Fundy. Fisheries Research Board of Canada. Manuscript reports of the Biological stations. No. 455

Hallegraeff, G.M. 1993. Review of harmful algal blooms and their apparent global increase. Phycologia 32: 79-99.

Hallegraeff, G.M. 1995. Transport of toxic dinoflagellate cysts via ship's ballast water: an interim review. ICES CM 1995/O:15.

Hallegraeff, G.M. and C.J. Bolch. 1992a. Transport of toxic dinoflagellate cysts via ship's ballast water. Mar. Poll. Bull. 22:27-30.

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

Hallegraeff, G.M. and C. Sumner. 1986. Toxic plankton blooms affect shellfish farms. Australian Fisheries 45: 15-18.

Hallegraeff, G.M., M.A. McCausland and R.K. Brown. 1995. Early warning of toxic dinoflagellate blooms of *Gymnodinium catenatum* in southern Tasmanian waters. J. Plankton Res. 17: 1163-1176.

Hallegraeff, G.M., Steffensen, D.A. and R. Wetherbee. 1988. Three estuarine dinoflagellates that can produce paralytic shellfish toxins. J. Plankton Res. 10: 533-541.

Harvey, M., M. Gilbert, D. Gauthier and D.M. Reid. 1999. A preliminary assessment of risks for the ballast water-mediated introduction of non-indigenous organisms in the Estuary and Gulf of St. Lawrence. Can. Tech. Rep. Fish. Aquat. Sci. #2268, 56 p.

Hecht,T. and K. Heasman. 1999. The culture of *Mytilus galloprovincialis* in South Africa and the carrying capacity of mussel farming in Saldanha Bay. World Aquaculture 30(2):50-55.

Hunter and Associates 1982. Coastal Management Study Bay of Fundy New Brunswick. Prepared for the NB Department of Natural Resources, St. John's NB.

Jeffries, H.P. 1962. Environmental characteristics of Raritan Bay, a polluted estuary. Limnol. Oceanogr. 7:21-31.

Jellett, J.F., A.C. Wardlaw and R.E. Scheibling. 1988. Experimental infection of the echinoid *Strongylocentrosis droebachiensis* with *Paramoeba invadens*: quantitative changes in the coelomic fluid. Dis. Aquat. Org. 4: 149-157.

Jones, G.M., A.J. Hebda, R.E. Scheibling and R.J. Miller. 1985. Histopathology of the disease causing mass mortalities of sea urchins (*Strongylocentrotus droebachiensis*) in Nova Scotia. J. Invert. Pathol. 45: 260-271.

Karayucel, C. 1997. Mussel culture in Scotland. World Aquaculture 28(1): 4-10.

Keizer, P.D., T.G. Milligan, D.V. Subba Rao, P.M. Strain, and G. Bugden. 1996. Phytoplankton monitoring program: Nova Scotia component - 1989 to 1994. Can Tech. Rep. Fish. Aquat. Sci. 2136, 74 pp.

Ketchum, B.H. and D.J. Keen. 1951. The exchanges of fresh and salt waters in the Bay of Fundy and in Passamadquoddy Bay. Woods Hole Oceanography Institution. No 593. 25 p.

Lavoie, D.M., L.D. Smith and G.M. Ruiz. 1999. The potential for intrcoastal transfer of non-indigenous species in the ballast water of ships. Est. Coast. Shelf Sci. 48: 551-564.

Locke, A., D.M. Reid, H.C. Van Leeuwen, W.G. Sprules and J.T. Carlton. 1993. Ballast water exchange as a means of controlling dispersal of freshwater organisms by ships. Can. J. Fish. Aquat. Sci. 50: 2086-2093.

MacDonald, E.M. 1995. Dinoflagellate resting cysts and ballast water discharges in Scottish ports. ICES Coop. Res. Rep. 224:24-35.

Mahoney, J.B. and J.J.A. McLaughlin. 1977. The association of phytoflagellate blooms in Lower New York Bay with hypertrophication. J. Exp. Mar. Biol. Ecol. 28:53-65.

Mahoney, J.B. and F.W. Steimle. 1980. Possible association of fishing gear clogging with a diatom bloom in the middle Atlantic Bight. Bull. New Jersey Acad. Sci. 25: 18-21.

Mahoney, J.B., P. Olsen, and M. Cohn. 1990. Blooms of a dinoflagellate *Gyrodinium cf. aureolum* in New Jersey coastal waters and their occurrence and effects worldwide. J. Of Coastal Research 6(1): 121-135.

Martin, J.L. and M.M. LeGresley, P.M. Strain and P. Clement. 1999. Phytoplankton monitoring in the southwest Bay of Fundy during 1993-1996. Can Tech. Rep. Fish. Aquat. Sci. 2265, 132 pp.

Martin, J.L. and M.M. LeGresley and P.M. Strain. 2001. Phytoplankton monitoring in the Western Isles region of the Bay of Fundy during 1997-1998. Can Tech. Rep. Fish. Aquat. Sci. 2349, 85 pp.

Mahoney, J.B., D. Jeffress, C. Zeitlin, P.S. Olsen, H. Grebe and J. Brooks. 2003. Distribution of the brown tide picoplankter *Aureococcus anophagefferens* in western New York Bight coastal waters. Northeast Fisheries Science Center Reference Document 03-13, 32 pp.

Masson, D., O. Courtois, N. Masson, S. Guesdon and G. Rocher. 2000. Ballast water research in France: current status. ICES/CM 2000/U12, 7 pp.

Matsuyama, Y., T. Uchida, T. Honjo, and S.E. Shumway. 2001. Impacts of the harmful dinoflagellate *Heterocapsa circularisquama*, on shellfish aquaculture in Japan. J. Shellfish Res. 20(3) 1269-1272.

Medcof, J.C. 1975. Living marine animals in a ship's ballast water. Proc. Natl. Shellfish. Assoc. 65: 11-12.

McCarthy, S.A. and F.M. Khambaty. 1994. International dissemination of epidemic *Vibrio cholerae* by cargo ship ballast and other nonpotable waters. Appl. Environ. Microbiol. 2597-2601.

Nalepa, T.F. and D.W. Schloesser. 1993. Zebra Mussels: Biology, Impacts and Control. Lewis Publishers, Boca Raton, Florida: 810 pp.

New Jersey Department of Environmental Protection. Annual Summary of phytoplankton blooms and related conditions in New Jersey Coastal Waters. 1978-1998; Water Monitoring Management Group, Bureau of Freshwater and Biological Monitoring, Trenton, NJ.

Nichols, F.H., J.K. Thompson and L.E. Schemel. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potomocorbula amurensis*. II. Displacement of a former community. Mar. Ecol. Prog. Ser. 66: 95-101.

Olsen, P.S. and R. Mulcahy. 1991. In the Hudson-Raritan estuary, recurrent red tide blooms dominated by *Katodinium rotundatum* are associated with hypoxia and consequent fauna kills. Poster Session, Abstract (pg.90). Fifth International Conference on Toxic Marine Phytoplankton, Newport, RI.

O'Neill, C.R. 2000. Salinity tolerance of larval *Rapana venosa*: implications for dispersal and establishment range on the U.S. East coast. http://massbay.mit.edu/exoticspecies/conferences/2000/abstracts08.html

Petrie, B. and F. Jordan. 1993. Nearshore, shallow-water temperature atlas for Nova Scotia. Can. Tech. Rep. 145: 84p.

Reid, R.N., P.S. Olsen and J.B. Mahoney. 2002. A compilation of reported fish kills in the Hudson-Raritan estuary during 1982 through 2001. Northeast Fisheries Science Center Reference Document 02-09. 16 p.

Rick, H.-J. and C.-D. Durselen. 1995. Importance and abundance of the recently established species *Coscinodiscus wailesii* Gran and Angst in the German Bight. Helgolander Meeresunters 49: 355-374.

Rince, Y. and G. Paulmier. 1986. Donnees nouvelles sur la distribution de la diatomee marine *Coscinodiscus wailesii* Gran and Angst (Bacillariophyceae). Phycologia 25: 73-79.

Robohm, R.A. And A.F.J. Draxler. 2001. Effects of environmental stressors on disease susceptibility in lobsters: a controlled laboratory study. In: Long Island Sound Lobster Health Symposium - Research Summaries, p 33-34.

Ruiz, G.M. 2000. Implications of coastal marine communities in North America: apparent patterns, processes, and biases. Ann. Rev. Ecol. Syst. 31:481-531.

Scholin, C.A. and D.M. Anderson. 1991. Population analysis of toxic and non-toxic Alexandrium species using ribosomal RNA signature sequences. Fifth Int. Conf. Tox. Mar. Phyto. Abstracts, p.113.

Smayda, T.J. And P. Fofonoff. 1989. An extraordinary, noxious brown-tide in Narragansett Bay. II. Inimical effects: In: Red Tides: Biology, Environmental Science, and Toxicology, pp. 133-136. T. Okaichi, D.M. Anderson and T. Nemoto (eds.). Elsevier

Smith, T.E. and S.R. Kerr. 1992. Introductions of species transported in ships' ballast waters: the risk to Canada's marine resources. Can. Tech. Rep. Fish. Aquat. Sci. 1867:v+16p.

Subba Rao, D.V., W.G. Sprules, A. Locke and J.T. Carlton. 1994. Exotic phytoplankton from ships' ballast waters: Risk of potential spread to mariculture sites on Canada's east coast. Can. Data Rep. Fish. Aquat. Sci. No. 937, 51 p.

Swift D.H et al. 1973. In: Coastal Management Study Bay of Fundy New Brunswick. Prepared by Hunter and Associates for the NB Department of Natural Resources, Mississaga, St. John's. 1982.

Vinogradov, M.Y., E.A. Shushkina, E.I. Musayeva, and P.Y. Sorokin. 1989. A newly acclimated species in the Black Sea: the ctenophore *Mnemiopsis leiydi* (Ctenophora: Lobata). Oceanology 29:220-224.

Wonham, M.J., W.C. Walton, G.M. Ruiz, A.M. Frese, B.S. Galil. 2001. Going to the source: role of the invasion pathway in determining potential invaders. Mar. Ecol. Prog. Ser. 215: 1-12.

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

Zhang, F. and M. Dickman 1999. Mid-ocean exchange of container vessel ballast water 1: Seasonal factors affecting the transport of harmful diatoms and dinoflagellates. Mar. Ecol. Prog. Ser. 176: 243-251.

Zimmer, B.J. And S. Groppenbacher. 1999. New Jersey Ambient Monitoring Program Report on Marine and Coastal Water Quality 1993-1997. New Jersey Department of Environmental Protection, 114 p.

7 List of websites

- United States Geological Survey (USGS) Nonindigenous Aquatic Species (NAS) database - http://www. nas.er.usgs.gov
- Smithsonian Environmental Research Center - Ballast Water Clearing House - http://www.serc.si.edu/ballast.htm
- Synopsis of Infectious Diseases and Parasites of Commercially Exploited Shellfish - http://www.pac.dfo-mpo.gc.ca/sci/shelldis
- Fundy Forum Marine Issues in the Bay of Fundy - http://www.fundyforum.com/issues.html
- New Jersey Bureau of Marine Water Monitoring - http://www.state.nj.us/dep/wmm/bmw
- NY/CT Sea Grant's Long Island Lobster Initiative - http://www.seagrant.sunysb.edu/LILobsters/
- New York - New Jersey Harbor-Estuary Program - http://www.harborestuary.org
- New York - New Jersey Baykeeper Webpage - http://nynjbaykeeper.org
- Smithsonian Environmental Research Center - Marine Invasions Research Lab - http://invasions.si.edu
- Northeast Aquatic Nuisance Species Panel - http://www.northeastans.org
- MIT Sea Grant Cente for Coastal Resources: Marine Bioinvasions

  - http://massbay.mit.edu/exoticspecies/index.html