INVASIVE SPECIES

State of the Scotian Shelf Report

AUTHOR(S):
Greg Klassen
Tau Biodiversity
49 Parkindale Rd
Pollett River, NB
E4Z 3A7

STEERING COMMITTEE:
Melanie MacLean, Project Coordinator, Fisheries and Oceans Canada, Ecosystem Management
Jay Walmsley, Fisheries and Oceans Canada, Ecosystem Management
Glen Herbert, Fisheries and Oceans Canada, Ecosystem Management
Maxine Westhead, Fisheries and Oceans Canada, Ecosystem Management
Tom Sephton, Fisheries and Oceans Canada, Science
Sean Weseloh McKeane, Nova Scotia Department of Fisheries and Aquaculture
Andrew Sherin, Atlantic Coastal Zone Information Steering Committee

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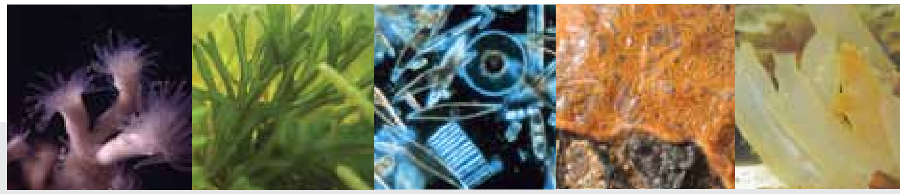


CONTENTS

1 ISSUE IN BRIEF

LINKAGES

This theme paper also links to the following theme papers:

- Climate change and its Effects on Ecosystems, Habitats and Biota
- Species at Risk

Introductions of non-native species, and the biological invasions that may result, are increasingly considered to threaten native biodiversity in the marine environment (Carlton and Geller 1993; IUCN 2000). Worldwide, the number of introduced marine species continues to grow in a linear or even exponential manner (Boudouresque et al. 2005). Species introductions are sometimes called a form of "biological pollution," but unlike some other forms of pollution the introduction of a species is generally irreversible, and the impact

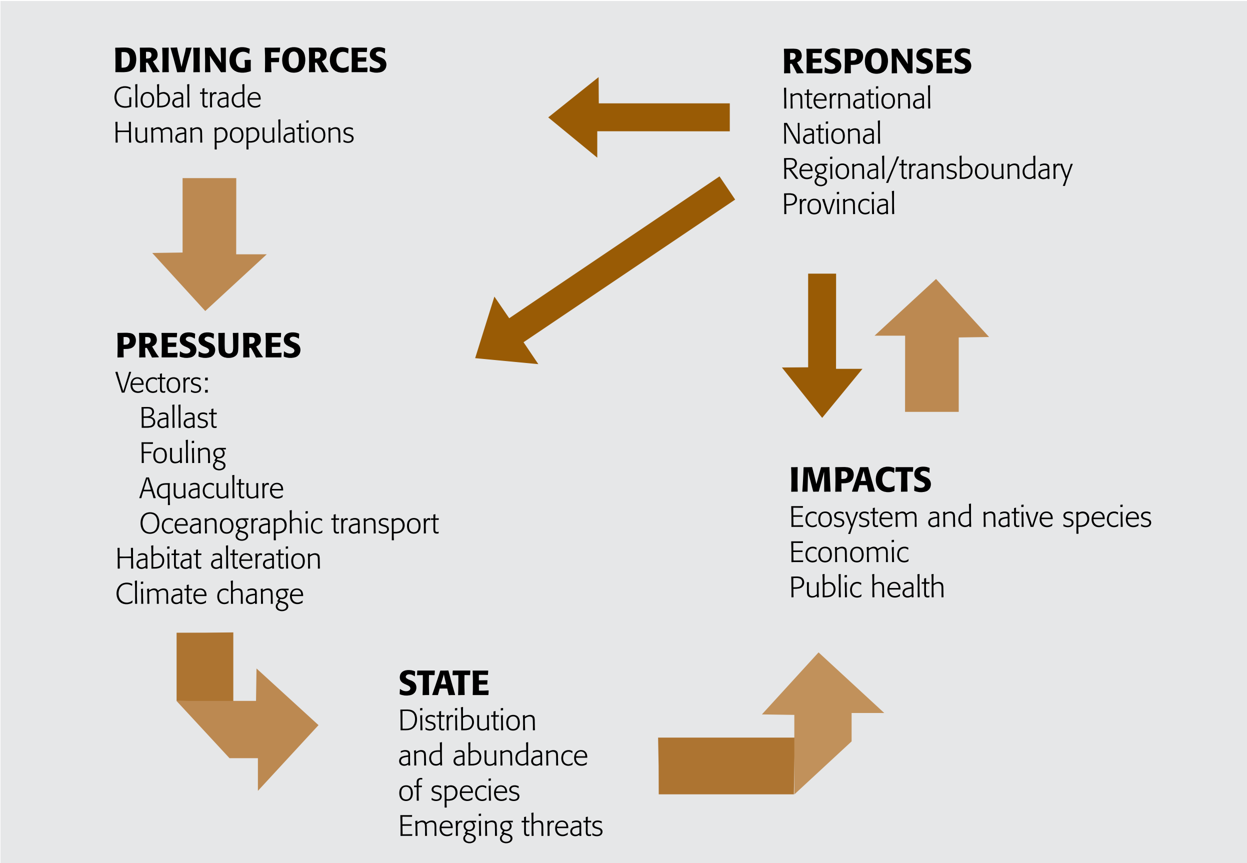


Figure 1: Driving forces, pressures, state, impacts and responses (DPSIR) to marine invasive species on the Scotian Shelf. The DPSIR framework provides an overview of the relationship between the environment and humans. According to this framework, social and economic developments and natural conditions, as driving forces, exert pressures on the environment which result in changes in the state of the environment. Resultant impacts on ecosystems, economy, and human health may elicit government or societal responses that modify the driving forces or pressures.

does not decrease over time nor with distance from the source, but instead can continue to increase in spatial scale and intensity over time.

The damage caused by invasive species to native species and ecosystems is known to cause biodiversity loss (IUCN 2000). Some invaders are "ecosystem engineers" with the potential to permanently change ecosystems and habitat (Crooks 2002). Competition with or predation upon native species, or the introduction of diseases (pathogens) or parasites, can alter food webs and the flow of nutrients within ecosystems. While marine species have most likely been transported by human activities for as long as humans have moved around the world, the volume and frequency of transport has intensified in the past several decades (Carlton and Geller 1993).

At least 22 introduced species are documented from the Scotian Shelf, and to date at least seven of these have demonstrated ecological and/or economic consequences in the region, and are most likely invasive. Pressures such as global and local shipping, recreational boating, aquaculture, climate change, habitat disturbance and facilitation by established introduced species will continue to inoculate, and enhance the establishment of, non-indigenous species to the Scotian Shelf (**Figure 1**). As these processes continue, and research leads to greater understanding of the non-indigenous species already present, it is likely that more introduced and invasive species will be added to this list in the future. Management of invasive species on the Scotian Shelf has only recently been initiated, and should benefit from ongoing regulatory reforms at the international, federal, and provincial level.

Definitions:

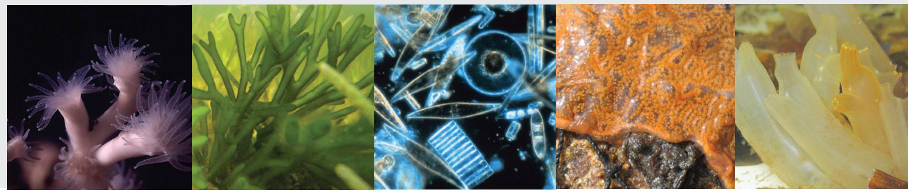
TERM	DEFINITION
Introduced, exotic, alien, non-native or non-indigenous species	*Any species intentionally or accidentally transported and released by humans into an environment or facility with effluent access to open-water or flow-through system outside its present range*
Invasive species	*A non-indigenous (non-native) species, the introduction of which into an ecosystem may cause harm to the economy, environment, human health, recreation, or public welfare*

Source: A Canadian Action Plan to Address the Threat of Aquatic Invasive Species (2004)

2 DRIVING FORCES AND PRESSURES

For millennia, natural barriers such as oceans provided isolation in which unique species and ecosystems evolved. However, in the past century, major global forces have combined to breach these barriers (IUCN 2000). The number of introduced species in an ecosystem is a function of both the supply of potential invaders, and the susceptibility of the ecosystem to invasion (Crooks et al. 2011). Drivers of biological invasions operate at several scales and levels, for example increase of trade operates at the regional or global scale, and factors resulting in fragmentation or disturbance of ecosystems at the local scale (Rodriguez-Labajos et al. 2009). Globalisation and growth in the volume of trade, an increasing emphasis on free trade, and improvements in the speed of transport combine to move species more effectively than ever before. Disturbances to the receiving ecosystem, whether due to global forces such as climate change, or regional pressures on habitats, may make it easier for the inoculated species to become established. The presence of non-indigenous species already established in the ecosystem may also increase the likelihood of survival and establishment of newly arrived non-indigenous species, a process known as facilitation (Simberloffe and Von Holle 1999). For example, the growth of the invasive coffin box bryozoan *Membranipora membranacea* on kelp *Laminaria* sp. on the Scotian Shelf made the kelp prone to breakage and facilitated the invasion of kelp beds by a second invasive species, the oyster thief alga *Codium fragile fragile* (Scheibling and Gagnon 2006).

The driving forces that influence the supply of potential invaders are mainly associated with human activities (because for a species to be considered introduced, it must have been transported by humans to a region which it could not have reached by natural dispersal), and cannot be separated from underlying socio-economic development processes (Rodriguez-Labajos et al. 2009). A species that is subsequently dispersed from an area into which it has been introduced, into another area that was not part of the native range, even if this dispersal occurs by natural means such as oceanographic currents, is still considered an introduced species in the second area. In contrast, the dispersal by natural means of a species from its native range, in the absence of human-assisted transport, is considered a range expansion.



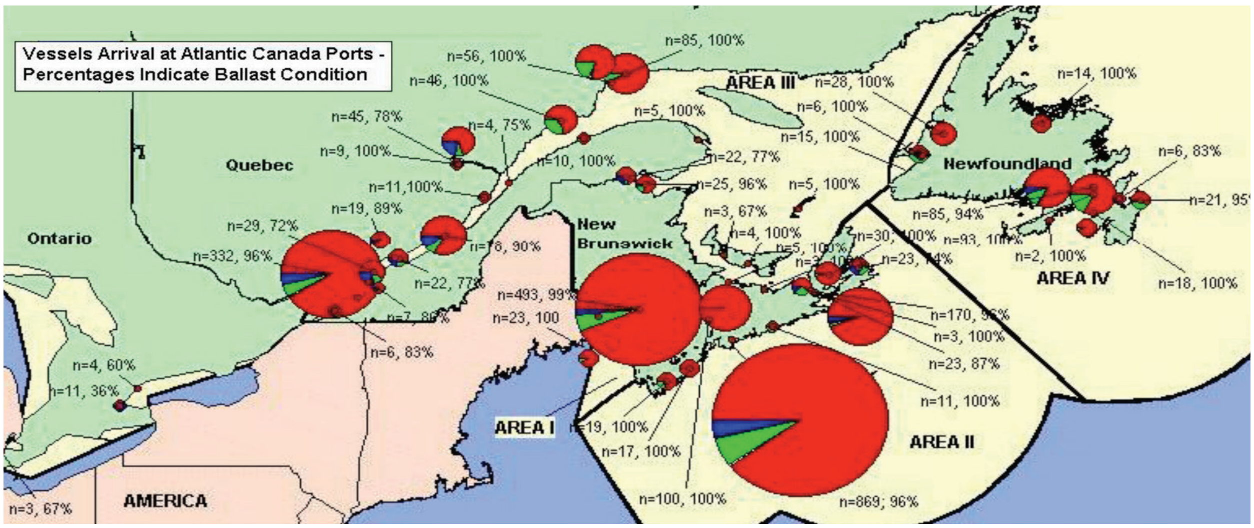


Figure 2: International vessel arrivals in ports of Atlantic Canada in 2002. Halifax, the largest port, had 869 vessel arrivals, of which 96% were in full or partial ballast. In the pie chart, red indicates partial ballast, green full ballast, and blue no ballast. Source: Kelly 2004.

2.1. GLOBAL TRADE AND SHIPPING

Commercial shipping is considered to be one of the most significant vectors of introduction for non-indigenous aquatic species. More than 80% of global trade moves by ship, and the merchant shipping fleet grew by 8.6% in 2010 (United Nations Conference on Trade and Development, 2011). An increase in the volume and frequency of ocean crossing vessels since the 1970s is correlated with increased worldwide introductions of non-indigenous species near the close of the 20th century (Carlton 1996). Ship-based vectors of invasive species include ballast water and sediments in the ballast tank, bilge water, and fouling of hull, sea chest/water intake, anchor, chain, and propeller shaft.

A large number of commercial vessels originating from outside Canada's Exclusive Economic Zone pass through waters of the Scotian Shelf, either bound for ports in Nova Scotia or to other locations in Atlantic Canada or the Great Lakes. Ports in Nova Scotia (Halifax, Little Narrows, Liverpool, Mulgrave, Point Tupper, Port Hawkesbury, Sheet Harbour, Shelburne, Sydney and Yarmouth) receive between 1000 and 2000 international ship arrivals annually (Kelly 2004). Halifax is the major port in Atlantic Canada (**Figure 2**). Most of the international arrivals originated from the east coast of the USA or western Europe.

2.1.1 Ballast water

Ballast water samples from 86 ships arriving from international ports and sampled in the St. Lawrence Seaway in 1991-1992 contained three diatom and ten dinoflagellate species not recorded from Atlantic Canada, out of a total of 102 taxa identified (Subba Rao et al. 1994). In all, 21 potentially bloom-forming, red tide and/or toxic genera were represented in the samples.

Ballast water sampling of 98 ships arriving in Atlantic Canada in 2001-2002 found 349 phytoplankton taxa, of which 44% were indigenous, 25% were non-indigenous, and 31% were of unknown geographic affiliation (Carver and Mallet 2004). Twenty taxa were classified as toxic or harmful, of which seventeen taxa were known to accumulate in shellfish and cause gastrointestinal or neurological illnesses in consumers and the remaining three taxa were known to cause fish kills. In total, five taxa were non-indigenous. Another 33 phytoplankton taxa were assigned to a 'possible concern' category, e.g., bloom-forming species, or members of a genus in which other species were known to be toxic or harmful. In the same study, 75 microzooplankton species were detected, but were not identified to species and could not be evaluated for risk (Carver and Mallet 2004).

Sampled ballast water in 63 ships arriving in Atlantic Canada in 2007-2009 contained 96 taxa of zooplankton, of which 10% were non-indigenous (DiBacco et al. 2011). The samples were dominated by copepods, which accounted for 89% of zooplankton density. Ballast sediments (i.e., the sediments on the bottom of the ballast tanks) in these vessels contained the cysts of 14 non-indigenous dinoflagellate species not yet recorded from Canadian waters, including four harmful and/or toxic species (Casas-Monroy et al. 2011).

2.1.2 Hull fouling

Hull fouling is another important vector of invasions. In Halifax, video analysis of the hulls of 20 commercial vessels (average length 220 m) found that on average each hull carried 3,618 individuals belonging to 15 species. On average, each hull carried 3.2 non-indigenous species not yet established in the region (Sylvester et al. 2011). Further, with the international ban on Tributyltin (TBT)-based antifouling hull paints in 2003, hull fouling has the potential to increase in the future. Decreased use of TBT-based paints has been correlated with increased hull fouling (Carlton 2001).

Exploration or oil production may increase shipping pressures on the Scotian Shelf. Shipping traffic would increase and many of the ships would be arriving in ballast (for example, 85% of vessels arrived at the oil refinery at Come-by-Chance, NL, in ballast; Blakeslee et al. 2010). Depending on the source of the ballast water, this could increase the risk of novel species introductions. In addition to increasing shipping pressure, oil and gas platforms are also a vector for transport of invasive species. Non-indigenous species are often present on oil drilling platforms (Page et al. 2006), which would be towed to the region. Rigs then often remain anchored in one location for extended periods of time, becoming colonized by hull foulers as a sort of artificial reef, before being moved to the next drilling site. Drilling rigs also use ballast water to control stability and buoyancy similar to ships.

2.2 AQUACULTURE

Long-distance transfers of species brought into new areas for aquaculture have often been responsible for species introductions, including intentionally introduced species, as well as 'hitch-hiking' epibionts and parasites (Ruiz et al. 2000). This is unlikely to be a factor in introductions to the Scotian Shelf at present; international transfers of shellfish for aquaculture took place in previous decades but have not occurred recently (Locke et al. 2007; A. Locke, pers. comm.).

2.3 CLIMATE CHANGE

Climate change may affect both the likelihood of uptake of species at their place of origin, and their likelihood of establishing a viable population if released on the Scotian Shelf. For example, ocean conditions may be linked to annual variations in the population size of European green crab (Yamada and Kosro 2010). Global warming may reduce or eliminate oceanic temperature "barriers" to dispersal (see Climate change and its effects on ecosystems, habitats and biota), or alter the relative competitive abilities of native versus non-native species. Recently invaded tunicate species in New England outcompete and overgrow native tunicates and tunicate species that invaded New England more than two decades ago in years with above-average temperatures, but rarely do so in below-average temperatures (Stachowicz et al. 2002). Climate change may also enhance the establishment of tropical and subtropical species carried to the Scotian Shelf in the warm Gulf Stream (Wroblewski and Cheney 1984). Typically these survive in Nova Scotian waters for short periods only, and do not overwinter (Markle et al. 1980). Finally, climate change may allow an introduced species to become invasive, perhaps even after decades of presence as an apparently harmless addition to the local biota, if the altered climate provides better growing conditions for the species (Witte et al. 2010).

2.4 REGIONAL OR LOCAL SCALE PRESSURES

Local movement of smaller vessels is often implicated in the spread of non-indigenous species from an initial point of introduction. Shipping vectors involved in local dispersal are likely to be fishing vessels, recreational boats, slow-moving barges, or dredging rigs moving between ports or fishing grounds. Commercial tuna fleets, for example, move between the Scotian Shelf and Prince Edward Island seasonally (Locke et al. 2007). Recreational vessels often move frequently between ports, both by water and over land on trailers (Darbyson et al. 2009). Some of the larger vessels carry ballast water, but the fouling of hulls or other gear is more likely to be involved in local transport (Darbyson et al. 2009).

Local aquaculture transfers frequently take place within Nova Scotia or between Nova Scotia and neighbouring provinces. Elsewhere, bivalve aquaculture transfers have been implicated in the transport of several tunicate species (Carver et al. 2006a, b). Cyst-forming toxic and nuisance phytoplankton may commonly be transported in the guts of transferred bivalves (McKindsey et al. 2007).

2.5 OCEANOGRAPHIC CONDITIONS AND HABITAT ALTERATIONS

Oceanographic transport of non-indigenous species is more likely to occur at the local than at the global scale. Species which could be carried on ocean currents include planktonic species, species with planktonic larval stages, as well as species carried on floating marine debris (e.g., discarded/lost fishing or aquaculture gear and plastics) or floating vegetation (e.g., macroalgae, grasses, etc.).

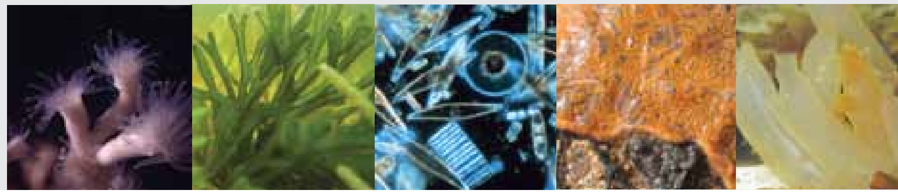
Pollution or habitat disturbance can aid the establishment of non-indigenous species (Bando 2006). Many non-indigenous species live in a wide variety of habitats (which allows them to readily adapt to new environments) or are tolerant to disturbed environments (for example, polluted harbours, from which they may be transported by ships). Sometimes native species are less well-adapted to adverse conditions and are outcompeted by the new arrivals.

3 STATUS AND TRENDS

Violet tunicate *(Botrylloides violaceus)*. Photo: DFO.

3.1 LIST OF SPECIES

Significant information gaps exist with respect to the introduced or invasive species of the Scotian Shelf. No formal species list has ever been compiled. The species listed in **Tables 1 and 2** present a conservative picture of 22 known introductions on the Scotian Shelf and almost certainly underestimate the introduced flora and fauna of the region. For most of these species, insufficient data exist to describe the abundance, trends and range



distribution. Targeted monitoring programs for marine invasive species in Nova Scotia focus primarily on tunicates (in particular, trends in *Botrylloides violaceus, Botryllus schlosseri* and *Ciona intestinalis* populations, and surveillance for new species inoculations) (Sephton et al. 2011) and on the European green crab (Tremblay et al. 2005, Vercaemer et al. in prep.). The public is encouraged to report sightings of any unusual species to Fisheries and Oceans Canada (http://www.qc.dfo-mpo.gc.ca/publications/envahissant-invasive/carnet_anglais.pdf).

3.2 EMERGING THREATS

3.2.1 Species present on Scotian Shelf

***Botrylloides violaceus*, Violet tunicate, and *Botryllus schlosseri*, Golden star tunicate**

Violet and golden star tunicates are similar in ecology although they originate from different parts of the world. Both are colonial tunicates that occur as fouling species on natural and artificial substrates. Natural dispersal is by very short-lived planktonic larvae (maximum duration of larval stage is approximately 36 hours), or by reattachment of budded fragments. Unattached fragments can drift and survive for up to 150 days, and those which are attached to a floating substrate have the potential to

Undoubtedly, man's activities are partially responsible for the remarkable spread of [green crabs]…I have seen live crabs in crates of live lobsters and have noticed them aboard sardine carriers and fishing boats.

– Scattergood, 1952

survive longer (Carver et al. 2006b). While the short-lived nature of the larvae makes them unlikely to be dispersed in ballast water, it is possible that drifting fragments or colonies could be taken up in ballast water. Both species are well-adapted to dispersal on fouled boat hulls, especially slower boats such as recreational vessels, barges and fishing boats (Carver et al. 2006b). Transfers and harvests of cultured bivalves have also been implicated in the transport of these tunicates (Carver et al. 2006b).

The violet tunicate is a recent arrival in North America, most likely originating

Golden star tunicate *(Botryllus schlosseri)*. Photo: DFO.

in Japan (Carver et al. 2006b). The first observation in Atlantic Canada was in Lunenburg and Mahone Bay in 2001. Golden star tunicate has been present on the Scotian Shelf (Atlantic coast and Bras d'Or Lakes) for several decades and in the Bay of Fundy since approximately 1983 (Carver et al. 2006b). Both species are currently distributed in nearshore waters of the Scotian Shelf from Wedgeport to Dingwall, including the Bras d'Or Lakes (Sephton et al. 2011).

Table 1. Freeliving species considered to be introduced on the Scotian Shelf (source: Locke and Hanson, unpub. ms.).

TAXON	SPECIES	COMMON NAME	DATE AND PLACE FIRST REPORTED	REFERENCE
Bacillariophyta	*Coscinodiscus wailesii*		2000, central and western Scotian Shelf	Head and Harris 2001
Chlorophyta	*Codium fragile fragile*	Oyster thief, Sputnik weed, Green fleece	1989, Mahone Bay	Bird et al. 1993
Phaeophyta	*Fucus serratus*	Serrated rockweed	1903, Mulgrave	Bell and MacFarlane 1933
	Colpomenia peregrina		1960, Atkins Point (Halifax Co.)	Bird and Edelstein 1978
Rhodophyta	*Bonnemaisonia hamifera*	Hookweed, Pink cotton wool	Late 1960s, Bras d'Or Lakes and Atlantic coast	Chen et al. 1969; McLachlan and Edelstein 1971
	Furcellaria lumbricalis		1989, Chedabucto Bay area	Novaczek and McLachlan 1989
	Neosiphonia harveyi		1992, Mahone Bay	McIvor et al. 2001
	Seirospora interrupta		1983, St. Margarets Bay	Bird and Johnson 1984
Trematoda	*Convoluta convoluta*		1995, near Halifax	Rivest et al. 1999
Mollusca	*Ostrea edulis*	European oyster	1978-1980, Ketch Harbour and East Dover (intentional introduction)	Muise et al. 1986
Crustacea	*Caprella mutica*	Japanese skeleton shrimp	2005, Mahone Bay	A. Locke, pers. obs.
	Praunus flexuosus	Bent mysid	Before 1980, Nova Scotia zooplankton	Mauchline 1980
	Carcinus maenas	Green crab	1954, Wedgeport	MacPhail and Lord 1954
Bryozoa	*Membranipora membranacea*	Coffin box bryozoan	1992, Mahone or St. Margarets Bay	Scheibling et al. 1999
Ascidia	*Ciona intestinalis*	Vase tunicate	Population outbreak 1997, Lunenburg; may have been present earlier	Cayer et al. 1999
	Botryllus schlosseri	Golden star tunicate	Present "for several decades", Atlantic coast and Bras d'Or Lakes	Carver et al. 2006a
	Botrylloides violaceus	Violet tunicate	2001, Lunenburg and Mahone Bay	Carver et al. 2006b

Ciona intestinalis, Vase tunicate

The vase tunicate is a solitary tunicate that is most likely native to northern Europe, but is sometimes considered cryptogenic (of unknown origin) in eastern North America (Carver et al. 2006a). The earliest record in Atlantic Canada dates from 1852, but the species was rarely observed and was not recorded in the scientific literature on the Scotian Shelf until population outbreaks occurred along the southeastern coast of Nova Scotia in the late 1990s (Cayer et al. 1999; Carver et al. 2003). By 2003, it was also reported at aquaculture operations in the Isle Madame area of Cape Breton Island (Carver et al. 2006). Currently, the species occurs in nearshore, sheltered locations along the Nova Scotian coast from Wedgeport to Dingwall, but has not been observed in the Bras d'Or Lakes (Sephton et al. 2011).

Vase tunicate *(Ciona intestinalis)*. Photo: DFO.

The most important means of dispersal of *C. intestinalis* is shipping, especially hull fouling on slow-moving vessels such as barges, fishing or recreational vessels (Carver et al. 2006a). The species can also be transported as a hitchhiker on aquaculture transfers (A. Locke, pers. comm.). There is limited potential for natural dispersal, which occurs by means of non-feeding planktonic larvae that typically remain in the water column for only a few days (Carver et al. 2006a). Juvenile and adult *C. intestinalis* have also been observed to raft on drifting eelgrass *Zostera marina* and oyster thief *Codium fragile fragile* (Carver et al. 2006a; Kanary et al. 2011).

Carcinus maenas, European green crab

The green crab was first observed on the east coast of North America in Massachusetts in 1817 and was most likely transported from its native range (coasts of Europe and North Africa) in the ballast of ships (Grosholz and Ruiz 1996). This first wave of introductions spread up the coast of New England, reached Passamaquoddy Bay, NB, in 1951, and was first reported on the Scotian Shelf, in Wedgeport, NS, in 1954 (Leim 1951; MacPhail and Lord 1954). Further dispersal up the Atlantic coast of Nova Scotia, however, appeared to "stall" south of Halifax from the mid-1960s to the mid-1970s (Audet et al. 2003). It was speculated that green crab had reached its northern temperature limit in North America. However, by the late 1970s, green crabs were reported at Whitehead, south of Chedabucto Bay, 600 km north of the nearest known population (Audet et al. 2003). It is likely that these crabs represented a second, genetically distinct, introduction of green crabs to North America, which appears to have taken place either in Halifax or Chedabucto Bay, probably by means of ballast water (Roman 2006). By 1997, green crabs were found all along the Scotian Shelf at least as far north as Ingonish and had spread into the Gulf of St. Lawrence (Audet

European green crab *(Carcinus maenas)*. Photo: Wikipedia commons.

et al. 2003). In 2001, northern Nova Scotia and Gulf of St. Lawrence populations were found to be composed of genotypes found nowhere else in North America; however, populations south of Halifax and into the Bay of Fundy included genotypes from both northern Nova Scotia and the original US form (Roman 2006). The northern Nova Scotia genotypes match those found in the northern part of the green crab's native range, in Scandinavia and the North Sea (Roman 2006) and appear more tolerant of cold temperatures (A. Locke, pers. comm.). The northern genotypes are also significantly more aggressive, are more effective foragers, and may be outcompeting the US genotype, at least in the northern portion of the North American range (Rossong et al. 2011). Assuming that the northern genotype continues to increase in numbers in southern NS, it is likely that the impacts of green crabs in this area will also increase.

The European green crab is ranked among the 100 "worst alien invasive species" in the world (Lowe et al. 2000). It is a voracious omnivore and aggressive competitor with a wide tolerance of salinity, temperature, oxygen and habitat type (Klassen and Locke 2007). In all areas where the green crab has invaded, its potential for significant impacts on fisheries, aquaculture and the ecosystem has caused concern. Because the green crab has the ability to alter entire ecosystems through habitat modification, predation, and competition, it is considered an "ecosystem engineer" (Crooks 2002). Specific threats to fisheries, observed in Atlantic Canada, include (but are not limited to) predation on bivalves, competition with other decapods, and damage to eel fisheries (Klassen and Locke 2007). Anecdotal accounts suggest that levels of impacts on the Scotian Shelf appear to have increased in recent years, and are likely to continue to increase due to a recent genetic shift in green crab population structure.

Codium fragile fragile, Oyster thief

The oyster thief is a green alga that most likely originated in Asia but has been found in shallow, coastal waters of the Scotian Shelf since 1989, when it was first seen in Mahone Bay, NS (Bird et al. 1993). The first observations were on scallop aquaculture floats and on mussels, but it is unlikely these were the source of the infestation as the cultured stocks were of domestic origin. Bird et al. (1993) suggest recreational boat traffic or transport in water masses from the Gulf Stream are likely vectors. Initial dispersal followed prevailing currents to the south, suggesting predominantly natural dispersal. By 1991, the species was found from Mahone Bay to Prospect Bay, and began to be observed in the drift and on natural substrates. Within the next decade large populations had become established in Mahone Bay, St. Margarets Bay and at Cape Sable Island (Hubbard and Garbary 2002). In 2000, oyster thief was found along 95 km of the Atlantic coast of

Oyster thief (*Codium fragile fragile*). Photo: C. McKindsey, DFO.

Nova Scotia, by 2007 it was found along 445 km of coast (Watanabe et al. 2010). By this time, the alga had spread to the north, suggesting a mix of natural and anthropogenic vectors of dispersal. Currents, shipping, aquaculture, and entanglement in fishing nets are all potential vectors (Carlton and Scanlon 1985).

Membranipora membranacea, Coffin box bryozoan

The coffin box bryozoan, a native of Europe, was first seen in Mahone Bay or St. Margarets Bay in 1992 and became abundant in the fall of 1993 (Scheibling et al. 1999). The Nova Scotian inoculation probably originated from an introduction in the Gulf of Maine, which was detected at the Isles of Shoals in 1987, reaching the northern Gulf of Maine by 1993 (Harris and Mathieson 1999). Infestations of the bryozoan spread rapidly in the kelp beds of southwestern Nova Scotia.

In 2000, the bryozoan was found in shallow habitats over 100 km of coastline, by 2007 it could be found along the entire Atlantic coast of Nova Scotia, about 650 km. The species was observed continuously throughout these ranges wherever kelps were present, suggesting natural dispersal via planktonic larvae was predominant (Watanabe et al. 2010).

Phytoplankton

The presence of numerous non-indigenous phytoplankton species in the ballast tanks of ships (e.g., Subba Rao et al. 1994; Carver and Mallet 2004; Casas-Monroy et al. 2011) suggests that there must be many non-indigenous phytoplankton found on the Scotian Shelf, although no list has been published. In the Bay of Fundy, 22 previously unrecorded planktonic diatoms and dinoflagellates have been detected since 1995 and are presumed to be non-indigenous species (Martin and LeGresley 2008; Klein et al. 2010).

An example of a non-indigenous phytoplankton species suspected to have been introduced in ballast water is the bloom-forming diatom *Coscinodiscus wailesii*. This Pacific species, previously unknown from the Scotian Shelf, was abundant and widespread throughout the central and western Scotian Shelf in the spring of 2000 (Head and Harris 2001). A known invader of northern European waters, the species is considered a nuisance even in its native range. The cells of *C. wailesii* are too large for many zooplankton (e.g., calanoid copepods) to eat, which may disrupt the flow of energy through the food chain. Mucilage produced by the diatom clogs fishing nets, and it is noxious to edible seaweeds harvested in Japan (Head and Harris 2001).

Table 2. Parasitic species considered to be introduced on the Scotian Shelf (source: Locke and Hanson, unpub. ms.).

TAXON	SPECIES	COMMON NAME	HOST	DATE AND PLACE FIRST REPORTED	REFERENCE
Protozoa (Mycetozoa)	*Haplosporidium nelsoni*	MSX	American oyster, *Crassostrea virginica*	2002, Bras d'Or Lakes	Stephenson et al. 2003
Protozoa (Sarcodina)	*Paramoeba invadens*		Sea urchin, *Strongylocentrotus droebachiensis*	1980-1983, southeastern NS	Scheibling and Stephenson 1984; Jellett et al. 1989
Platyhelminthes (Trematoda)	*Prosorhynchus squamatus*		Blue mussel, *Mytilus edulis*	1996, southeastern NS	McGladdery and Stephenson 1996

3.2.2. Species present in waters near the Scotian Shelf

***Didemnum vexillum*, Pancake batter tunicate**

The pancake batter tunicate, occasionally called "the blob" in the media, is a colonial organism which is most likely native to Japan (Lambert 2009). The pancake batter tunicate has not yet been recorded in waters of Atlantic Canada (Martin et al. 2011; Sephton et al. 2011; A. Locke pers. comm.). It has been present on the bottom in the American waters of Georges Bank since 1998 (Valentine et al. 2007; Lambert 2009; Lengyel et al. 2009), and on wharves at Eastport, Maine since 2003 or 2004 (Bullard et al. 2007; Lambert 2009). Over 230 km^2 of Georges Bank is covered 50-90% by this species (Valentine et al. 2007).

Introductions throughout much of the world (the eastern USA, several European countries, the west coast of the USA and Canada, and New Zealand) have been attributed to shipping, either hull or sea chest fouling (Lambert 2009). Adult colonies grow as fouling organisms attached to surfaces, where their potentially rapid rate of growth often causes them to become nuisance organisms. Colonies grow on both artificial and natural surfaces including boats, wharves, buoys and marine algae, where they may form hanging tendrils (hence the name, the "blob"). Colonies also grow on the sea bed, where they develop a lumpy appearance like uncooked pancake batter (Daniel and Therriault 2007). Natural dispersal occurs by planktonic larvae produced through sexual reproduction, as well as budding (asexual reproduction) of fragments of colonies that break off and drift to new locations. Local dispersal may also occur on fouled vessels and aquaculture gear (Lambert 2009).

***Diplosoma listerianum*, Compound sea squirt**

The compound sea squirt has been detected in the Magdalen Islands, Quebec, since 2008 (Willis et al. 2011). It had recently been classified as a likely potential invader of Atlantic Canada, likely to be able to survive throughout the region (Locke 2009), but so far has not been observed to spread from its original area of introduction in Quebec. The species is widely distributed in nearshore waters of New England (e.g., Massachusetts and New Hampshire) (Willis et al. 2011).

Like all other invasive tunicates presently found in Atlantic Canada, this colonial species has the potential to become a nuisance on suspended mussel aquaculture equipment (Gittenberger 2009; Rocha et al. 2009).

***Styela clava*, Clubbed tunicate**

In Atlantic Canada, clubbed tunicate occurs only in the estuaries of Prince Edward Island, where it was first detected in 1997 (Locke et al. 2007). To the south of the Scotian Shelf, the species is widely distributed in New England as far north as Maine (Clarke and Therriault 2007).

Clubbed tunicate *(Styela clava)*. Photo: Wikipedia commons.

Chinese mitten crab *(Eriocheir sinensis)*. Photo: Wikipedia commons.

Clubbed tunicate is most common in sheltered habitats with low wave action, such as bays and estuaries. It attaches to a range of artificial substrates including boat hulls (Clarke and Therriault 2007). In Prince Edward Island, this species has caused serious fouling problems, weighing down suspended mussel aquaculture gear, moorings, floating docks and ropes (A. Locke, pers. comm.).

Eriocheir sinensis, Chinese mitten crab

In Atlantic Canada, Chinese mitten crab has been detected only in the St. Lawrence River in fresh and estuarine waters from about 150 km above to 110 km below Quebec City (Veilleux and de Lafontaine 2007). In the northeastern USA, the crabs have been reported from the Hudson River, Delaware Bay and Chesapeake Bay. A mathematical model of the environmental requirements of the crab has identified all of Atlantic Canada as suitable for its establishment (Herborg et al. 2007).

The Chinese mitten crab is catadromous, meaning that the adults live in freshwater rivers but migrate downstream to salt water to spawn. It is listed among the "100 worst alien invasive species," mainly because of its ability to spread rapidly and develop very large populations once introduced to an area, as well as the impacts of these populations (Veilleux and de Lafontaine 2007). In particular, the adult crabs burrow into the clay banks of rivers, often causing collapse of the river bank. Another concern is that the crabs are the intermediate hosts of a parasite, the oriental lung fluke *Paragonimus westermani*, which can be transferred to mammals. In humans, the parasite causes tuberculosis-like symptoms. So far, no North American populations of the crabs have been found to carry the parasite, probably because a snail that the parasite requires to complete its life cycle has not been introduced to North America (Veilleux and de Lafontaine 2007).

4 IMPACTS

4.1 ECOSYSTEM IMPACTS

The impacts of invasive species on ecosystems are not fully understood, but are known to include alterations in predator-prey and competitive interactions, parasitism, and effects on habitat (**Table 3**). These impacts show that introduced species, currently widely distributed on the Scotian Shelf have interfered with the

community structure, biodiversity and functioning of a variety of ecosystems in Nova Scotia; these species should be considered to be invasive. Perhaps the most complex example of how this has occurred is the ongoing change to the kelp bed—urchin barrens ecosystem off the Atlantic coast of Nova Scotia.

Case study: impacts of two non-indigenous species in kelp beds of Nova Scotia

The rocky subtidal zone along the Atlantic coast of Nova Scotia has historically alternated between two states, kelp beds and "urchin barrens," where the kelp has been destructively grazed by the sea urchin *Strongylocentrotus droehbachiensis* (Watanabe et al. 2010). The urchin barrens return to the kelp-bed state when periodic outbreaks of disease decimate the local sea urchin populations. The interaction between oyster thief and coffin box bryozoan has disrupted this cycle. The bryozoan initially facilitated the replacement of kelp beds by the oyster thief. Initially, the bryozoan was found almost exclusively growing over fronds of kelp, but these fronds became brittle and were fragmented by wave action during the fall (Schiebling et al. 1999). By mid-November, formerly lush kelp beds were reduced to stands of stipes which eventually died and decomposed. Oyster thief cannot compete for space with healthy beds of kelp, but is able to establish rapidly in areas where kelp is absent. In many of these areas, dense, mono-specific stands of oyster thief developed and inhibited the re-colonization of kelp (Scheibling and Gagnon 2009). Oyster thief is of lower nutritional quality than kelp, and its presence resulted in changes in the benthic community structure. By facilitating the removal and replacement of kelps, the bryozoan altered the habitat of species such as sea urchins and American lobsters (Chapman et al. 2002). The bryozoan grows poorly on oyster thief. Following the reduction in its preferred substrate (kelp), the bryozoan switched to other seaweeds, but these are not subject to defoliation by the bryozoan (Watanabe et al. 2010). Simultaneously, the area around the epicenter of the invasion seems to be returning gradually to kelp beds, generally where oyster thief has been dislodged by wave action and winter storms. A 'boom and bust' cycle is commonly observed during the first few years after an invasion, after which a new equilibrium or cycle may be established (Boudouresque et al. 2005). Over time, the percent cover of oyster thief has declined; it was the dominant canopy alga at 54% of sites where it occurred in 2000, but at only 15% in 2007 (Watanabe et al. 2010). Since large populations of the bryozoan persist on alternative seaweed substrates, future increases in the kelp canopy may result in another episode of infestation and defoliation by the bryozoan, which in turn may be followed by a recurrence of the proliferation and spread of oyster thief (Watanabe et al. 2010).

4.2 SOCIO-ECONOMIC IMPACTS

There are numerous examples of impacts of invasive species on aquaculture, fishing, shipping, and recreation in Nova Scotia (**Table 4**). Currently, the effects of tunicates on aquaculture are most extensively studied and are presented here as a case study.

Case study: impacts of *Ciona intestinalis* on aquaculture

The first case of vase tunicate infestation in Atlantic Canada occurred in the summer of 1997, when a significant fouling problem developed on a mussel farm in Lunenburg and ultimately resulted in loss of the crop (Cayer et al. 1999; Carver et al. 2006a). In 1998 and 1999, vase tunicate fouling continued to be a problem for oyster and scallop aquaculture in Lunenburg (Carver et al.

Table 3. Examples of impacts of marine introduced species on native species and habitats in the Scotian Shelf ecosystem. These species should be regarded as invasive species in Nova Scotia. With the exception of MSX, which is found only in the Bras d'Or Lakes, each of these species is widely distributed in coastal waters of the Scotian Shelf.

IMPACT	SPECIES	IMPACT	SOURCE
Predation	Green crab	Predation on a wide variety of taxa, including juvenile American lobster, *Homarus americanus*.	Elner 1981; Klassen and Locke 2007
Competition (Food)	Green crab	Diet overlap with native rock crab, Cancer irroratus and American lobster, *Homarus americanus*	Elner 1981; Klassen and Locke 2007
Competition (Space)	Vase tunicate, Violet tunicate, Golden star tunicate	Overgrow and compete for space with native fouling species	Daniel and Therriault 2007; Carver et al. 2006a,b
Parasitism Habitat	Oyster thief	Overgrows areas denuded of kelp, *Laminaria* sp., preventing re-establishment of kelp beds and disrupting the kelp-sea urchin barrens cycle.	Scheibling and Gagnon 2006
	MSX	Increased mortalities of infected American oyster, *Crassostrea virginica*	Ford and Haskin 1982
	Green crab	Digs up and damages eelgrass beds.	Klassen and Locke 2007
	Oyster thief	Attachment to eelgrass, *Zostera* marina, and infaunal bivalves such as American oyster, *Crassostrea virginica*, in soft-bottom habitats; sometimes leading to the buoyant oyster thief floating away with the attached species.	Garbary et al. 2004
	Oyster thief and coffin box bryozoan	Replacement of kelp, *Laminaria* sp., resulting in reduced habitat quality for species for which kelp is a critical habitat, e.g., green sea urchin, *Strongylocentrotus droebachiensis* and American lobster, *Homarus americanus*	Scheibling and Gagnon 2006; Wharton and Mann 1981

2003). In 2000, a mussel farm in Mahone Bay and mussel and scallop operations near Chester experienced tunicate fouling problems and anecdotal reports suggest similar problems were experienced by fish growers in the Shelburne area (Carver et al. 2006a).

Economic losses to the shellfish industry in Nova Scotia have been partly due to inhibited growth and yield of shellfish through food and space competition (Daigle and Herbinger 2009). Mussel meat yields decreased and water content increased rapidly for the first 500 g of tunicates/m of sock, indicating a rapid loss of condition. Mussel size and density decreased with increasing tunicate densities, and the relationship predicts a loss of 1.4 kg of mussels/m of sock for every 1 kg/m increase in tunicate density. Up to 50% mussel mortality was observed with heavy tunicate fouling (2 kg tunicates/m of sock) (Daigle and Herbinger 2009; DFO 2010). Also, the vase tunicate infestations resulted in loose attachment of mussels leading to mussel loss at the time of harvest. Increased sock weight caused injuries to aquaculture workers, damage to equipment, and increased costs of harvesting, transporting, and processing. In Prince Edward Island, the cost of harvesting, transporting and processing mussel socks infested with the clubbed tunicate, a species with similar body form to the vase tunicate, was 15% of the gross landed value of the mussels (A. Locke, pers. comm.).

Table 4. Examples of socio-economic impacts of marine introduced species in the Scotian Shelf ecosystem.

ACTIVITY	SPECIES	IMPACT	SOURCE
Aquaculture	Vase tunicate	Competition with blue mussel, *Mytilus edulis*, in suspended culture. Added weight on aquaculture gear. Removal and disposal problem during processing of harvest.	Carver et al. 2003
	MSX	Increased mortality of cultured American oyster	Stephenson et al. 2003
Fishing	MSX	Increased mortality of wild populations of American oyster	Stephenson et al. 2003
	Green crab	Interference with eel fishery, damage to captured eels (but note possible benefit as lobster bait)	Klassen and Locke 2007
	Hookweed	Nuisance entanglement in fishing nets	M. Hanson, pers. comm.
Shipping	Vase tunicate, Violet tunicate, Golden star tunicate	Fouling of hulls, motors, and other surfaces.	Carver et al. 2006a, b
Impacts on recreation	Vase tunicate, Violet tunicate, Golden star tunicate	Fouling of floating docks, added weight makes docks difficult to remove at end of season	Carver et al. 2006a, b

Changes in cultural practices have been recommended as possible mitigation measures. Frequent gear rotation, cleaning gear with power washers or air drying, fallowing the aquaculture leases, adjusting the height of the mussel lines to allow crab predation on the tunicates, and adjusting work schedules to deploy gear after periods of tunicate recruitment wil help reduce, but not eliminate fouling (Carver et al. 2003; Vercaemer et al. 2011). At present, mechanical methods (specially designed equipment with high pressure (~700 psi) nozzles to wash off or kill (by physical damage) the fouling tunicates) or chemical (e.g., hydrated lime) treatments are used. The costs of treating fouling by *C. intestinalis* are in the order of $1 per metre of mussel socks (Carver et al. 2006a). Loss of products and additional efforts and operating costs are leading to mussel farm closures. For the year 2011 alone, 26 full- or part-time jobs have been lost from 4 rural Nova Scotia mussel operations (D. Sephton, pers. comm.)

4.3 PUBLIC HEALTH IMPACTS

The public health impacts most likely to occur are associated with phytoplankton introductions from ballast water or sediments. As explained in Section 2.1.1 (Ballast water), ships in Atlantic Canada may contain many potentially dangerous phytoplankton species. Of the 102 taxa collected by Subba Rao et al. (1994), 21% had the potential to form blooms, red tides, and/or toxins. Of the 349 taxa found by Carver and Mallet (2004), 5% were taxa known to accumulate in shellfish and cause gastrointestinal or neurological illnesses in consumers, 1% were known to cause fish kills, and 9% were classified as being of "possible concern" (bloom-forming, or related to toxic or harmful species. Of 51 taxa found in ballast sediments, 8% were identified as harmful and/or toxic species (Casas-Monroy et al. 2011).

In the spring of 2000, the phytoplankton of the central and western Scotian Shelf contained large numbers of a non-indigenous diatom, *Coscinodiscus wailesii* (Head and Harris 2001). No public health impacts are documented from this known nuisance species, but it provides an example of how a large bloom of a previously unobserved non-indigenous species could rapidly spread throughout much of the Scotian Shelf.

5 ACTIONS AND RESPONSES

5.1 INTERNATIONAL

Canada formally committed to control, eradicate or prevent the introduction of invasive species that threaten ecosystems, habitat or species under the 1992 *United Nations Convention on Biological Diversity*.

The United Nations Environmental Program addresses aquatic invasives in the context of ballast water and aquaculture. The *Code of Conduct for Responsible Fisheries* (1995) is concerned with fishing practices and aquaculture. The *International Convention for the Control and Management of Ships' Ballast Water and Sediments* was adopted in 2004. The ICES (International Council for Exploration of the Seas) *Code and Practice on the Introduction and Transfer of Marine Organisms* (2004) is another aquaculture-focused initiative.

5.2 NATIONAL

Early regulations about species introductions in Canada were primarily directed to address the risks of intentional introductions. The *Fisheries Act* (1985) addresses risk in the context of fish stocking, live bait, and aquaculture. Regulatory reforms to the Act, currently under development, have been suggested to expand the scope of the Act to cover other, unintentional, vectors. The *National Wildlife Policy* (1990) states that non-indigenous species should not be introduced into natural systems. The *Canadian Biodiversity Strategy* (1995) provides for identifying and monitoring alien organisms, screening standards and risk assessment. In 1999, the *Canadian Environmental Protection Act* requires risk assessments be undertaken before permitting a species introduction.

Canada's *Ballast Water Control and Management Regulations* (the Regulations), pursuant to the *Canada Shipping Act* (2001), came into force in June of 2006, and served to harmonize ballast water management in Canadian waters with provisions set out in international and United States law (Transport Canada 2007). The Regulations identify vessels that must manage their ballast water, define acceptable ballast water exchange and treatment standards, stipulate requirements for ballast water management and reporting, and provide rules for acceptable ballast water exchange activity in Canadian waters. Acceptable zones for ballast water exchange are defined in the Regulations and associated guidance materials (**Figure 3**; Transport Canada 2007). These zones are designed to help reduce the risk of invasive species introductions while permitting safe and economically feasible areas to conduct ballast water exchange

On September 19, 2001, at the Joint Council Meeting of Federal, Provincial and Territorial Ministers of Wildlife, Forests, and Fisheries and Aquaculture, the Ministers concluded that the threat of invasive alien species to biodiversity was one of four priority issues that must be addressed to further the implementation of the 1996 Canadian Biodiversity Strategy. This resulted in the documents *Addressing the Threat of Alien Invasive Species* (2002) and *An Invasive Alien Species Strategy for Canada* (2004). The Invasive Alien Species Partnership Program (2004) supports the goals of the Strategy.

Canada's guiding document on aquatic invaders is *A Canadian Action Plan to Address the Threat of Aquatic Invasive Species* (2004), developed by the Aquatic Invasive Species Task Group created in 2002 by the Canadian Council of Fisheries and Aquaculture Ministers (CCFAM). The former Task Group is now known as the National Aquatic Invasive Species Committee.

The *National Code on Introductions and Transfers of Aquatic Organisms* (2003) was also developed at the request of the CCFAM, and sets standards for assessing intentional introductions and transfers of aquatic organisms. Nova Scotia applies this code through a provincial introductions and transfers committee.

Initiatives of Fisheries and Oceans Canada include the Aquatic Invasive Species Program, which includes research (e.g., Brickman 2006; Brickman and Smith 2007; Vercaemer et al. 2011; Wong and Vercaemer, submitted) and monitoring, (e.g. Sephton et al. 2011). It includes various outreach products and collaborative initiatives and a toll-free reporting line for non-indigenous species sightings in Nova Scotia. DFO's Centre of Expertise for Aquatic Risk Assessment has led risk assessments on species already present on Scotian Shelf (green crab, vase tunicate, golden star tunicate, violet tunicate) and potential threats to the Scotian Shelf (mitten crab, clubbed tunicate, pancake batter tunicate). DFO also contributes to the funding of the Canadian Aquatic Invasive Species Network (CAISN), which focuses on research on pathways of introduction, factors affecting species establishment, and management of invasive species.

5.3 REGIONAL

The Northeastern Aquatic Nuisance Species Panel is the coordinating body for protection of ecosystems in northeastern North America from invasive aquatic nuisance species, but has no regulatory power. It is a regional panel under the U.S. Aquatic Nuisance Species Task Force. Both the province of Nova Scotia and Fisheries and Oceans Canada are represented on the panel. Since the problems caused

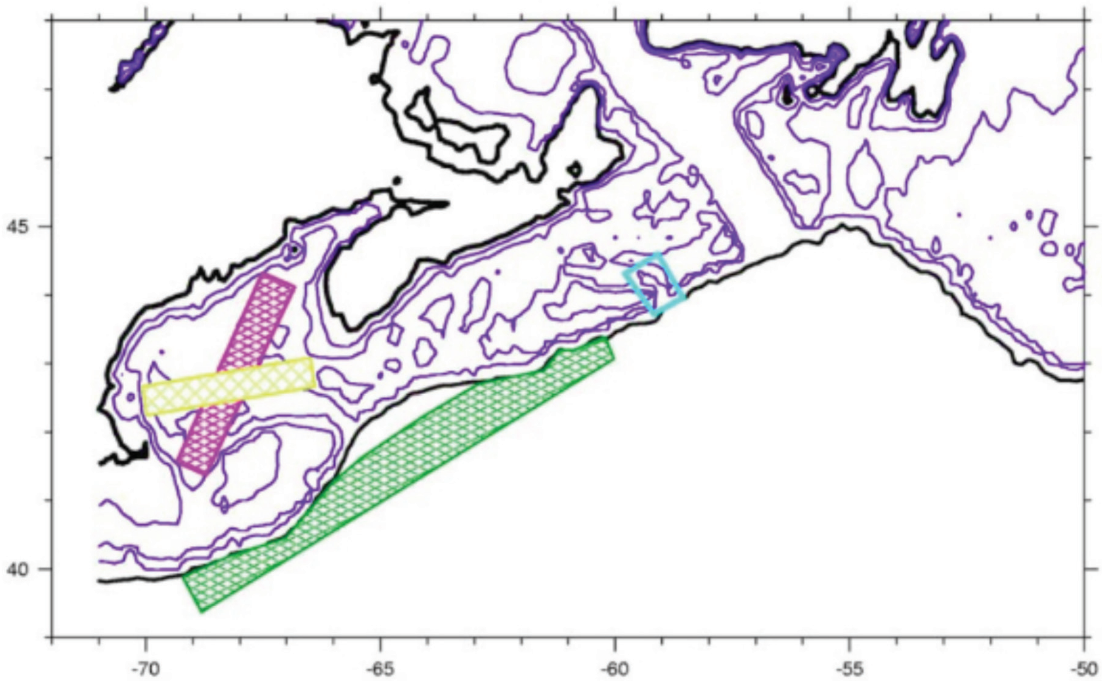


Figure 3. Recommended ballast water exchange zones on the Scotian Shelf and Gulf of Maine. The magenta zone indicates that traffic transiting to/from the Bay of Fundy should exchange in the Gulf of Maine, in waters deeper than 100 m. The yellow zone indicates that traffic crossing the Gulf of Maine and using a coastal route on the Scotian Shelf should similarly exchange in the Gulf of Maine, in waters deeper than 100 m. The green zone is the preferred exchange zone for on-shelf traffic heading to/from Nova Scotia, plus vessels following a shelf-break path. Exchange should occur in waters deeper than 1000 m, west of Sable Island and the Gully, and away from the entrance to the Northeast Channel. Source: Transport Canada, 2007.

by invasive species cross international and other jurisdictional boundaries, an important role of the panel is to promote cooperation and collaboration in the control, eradication, monitoring and prevention of invasive species, consistency in policies and enforcement between jurisdictions. Outreach products and best management practices are also shared.

A MSX emergency response plan exists for Atlantic Canada (McGladdery and Stephenson 2005). Following the discovery of MSX in the Bras d'Or Lakes in 2002, the plan was developed to prevent spread of the parasitic disease to the rest of Atlantic Canada. MSX is a reportable disease under the international regulations of the World Organization for Animal Health, because it is considered a serious threat to the commercially significant Eastern oyster, *Crassostrea virginica*. MSX concerns a wide diversity of stakeholder interests, because oyster production spans federal and provincial authorities, First Nations' traditional food fisheries, commercial fisheries, licensed aquaculture lease-holders, processing plants and brokerage operations, and roadside/retail marketer activities. Positive, negative, and buffer zones for MSX in Canada have been established. Surveillance of oyster-producing areas occurs throughout Atlantic Canada, with emphasis on the buffer zone where the first indications of any spread might be expected (McGladdery and Stephenson 2005).

5.4 PROVINCIAL

At the provincial level, the Nova Scotia Introductions and Transfers Committee is chaired by Fisheries and Oceans Canada and includes members from the province of Nova Scotia and industry. Fishery (General) Regulations prohibit the release of live fish into any fish habitat without a license. This committee reviews proposals to move aquatic organisms from one water body to another according to guidelines established by the *National Code on Introductions and Transfers of Aquatic Organisms.* The code applies to all activities in which live aquatic (freshwater and marine) organisms are introduced or transferred into fish-bearing waters, or fish rearing facilities such as aquaculture. The committee evaluates the risk of harmful alterations of receiving ecosystems, deleterious genetic changes in indigenous fish populations, and risks to aquatic animal health if pathogens or parasites were to accompany the organisms to be moved. The committee then advises the decision-making authority (DFO)

The Nova Scotia government is reforming regulations specific to the possession of live fish under the *Fisheries and Coastal Resources Act*. The amendments to prohibit the possession of live fish are intended to reduce the number of illegal fish introductions in Nova Scotia, and the consequent adverse effects on native ecosystems and species (http://www.gov.ns.ca/fish/sportfishing/angling/fcra-q-and-a.pdf).

The Nova Scotia Department of Aquaculture and Fisheries actively monitors for coastal invasive species, especially tunicates (e.g. Cayer et al. 1999). Recent examples include partnering with DFO for biofouling monitoring and rapid assessment activities on the Eastern Shore and in the Bras d'Or Lakes.

5.5 COMMUNITY

The Invasive Species Alliance of Nova Scotia was established in 2008. Its activities include informing, engaging and coordinating stakeholders to address the issues of all invasive alien species in Nova Scotia. Another project of the Alliance is a legislative review and gap analysis. Among many other funding sources, the Alliance is partially supported by the Invasive Alien Species Partnership Program, a federal initiative managed by Environment Canada. The IASPP provides funding to provinces, municipalities, educational institutions, and non-government organizations, as well as to other groups who are working in support of the goals of the National Strategy. The goal is to engage Canadians in actions to prevent, detect, and respond rapidly to invasive alien species in order to minimize the risk the species pose to the environment, economy and society.

5.6 MANAGEMENT PRACTICES

Throughout this document, a number of management practices that reduce the risk of introducing or spreading non-indigenous species have been mentioned. The following management practices have been recommended by DFO:

General:

- Learn about invasive species and how to identify them. A resource for identification of the marine invasive species found in Nova Scotia is: http://www.qc.dfo-mpo.gc.ca/publications/envahissant-invasive/carnet_anglais.pdf
- Do not move organisms from one area to another.

- Never release live bait, aquarium fish or plants into an open water body or sewer.

When taking your boat out of the water:

- Inspect and remove fouling plants and animals from boat, motor, anchor, trailer, and equipment with freshwater or spray with vinegar (protect your eyes).
- Clean hull and dispose of removed material far from the water.
- Drain water from motor, bilge and wells. If possible, let equipment dry completely.
- Use environment-friendly anti-fouling paint or products on your boat hull.

Shellfish harvesting:

- Clean shellfish where they were collected.
- Move as little water as possible with the shellfish.
- Spread any leftover water on the lawn.
- "De-sand" shellfish in the original water or in a bucket with water that will be thrown onto the lawn.

Diving and other water sports:

- Rinse equipment with fresh water after every trip.
- Let equipment dry completely.

What to do if you find invasive species:

- Try to identify them. A photograph will be helpful for the report.
- Note the location (GPS coordinates if possible) and observation date.
- Contact the DFO invasive species reporting line for Nova Scotia at 1-888-435-4040.

INDICATOR SUMMARY

INDICATOR	POLICY ISSUE	DPSIR	ASSESSMENT[1]	TREND[2]
Number of established marine invasive species	Growth in global trade and other human activities	Driving force, Pressure	Poor	-
Distribution and spread of marine invasives	Increase in regional vectors and habitat pressures (i.e., hull fouling, aquaculture, habitat modification, climate change)	Pressure	Fair	-
Losses incurred by fishery and aquaculture industry	Losses of fishery resources from invasive species impacts	State	Poor	-
Costs incurred or spent on invasive species management	Investment in marine invasive management programs and education	State	Fair	-

[1]Assessment: assessment of the current situation in terms of implications for the state of the environment. Categories are poor, fair, good, unknown.
[2]Trend: is it positive or negative in terms of implications for the state of the environment? It is not the direction of the indicator, although it could coincide with the direction of the indicator.

Data Confidence:

- Information on the number of species on the Scotian Shelf was derived from a literature review and represents a very conservative number of marine introductions and invasives.
- Species of unknown origin were not included in the review, and it is likely that some of these may have been introduced.

Key:
Negative trend: -
Unclear or neutral trend: /
Positive trend: +
No assessment due to lack of data: ?

Data Gaps:

- Large data gaps exist.
- For most species addressed in this report, insufficient data exist to describe the abundance, trends and range distribution.
- Existing monitoring programs do not address most habitats and taxa. Targeted monitoring programs for marine invasive species in Nova Scotia focus primarily on fouling species and on the European green crab. There is little information on offshore species.
- Information on ecosystem and economic impacts is lacking. DFO is currently undertaking a national socio-economic assessment case study of invasive tunicates

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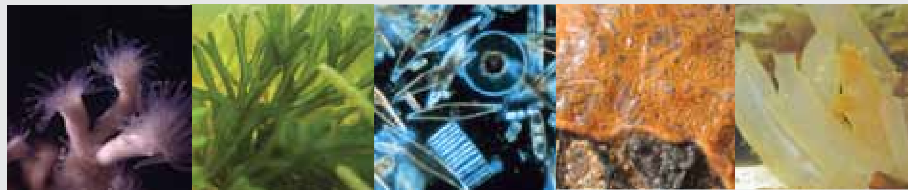

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