

Ballast Water Exchange

Alternate Areas or Alternative Methods?

Lessons from the Gulf of St. Lawrence

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Note: The alternative treatment discussion is not an endorsement for this process (ed.).

INTRODUCTION

The problem of aquatic species introductions is certainly as old as the transport of goods and merchandise by ship. The replacement of “solid ballast” used in the old days by “liquid ballast” in modern ships has exacerbated the problem, such that ballast water discharge is now recognized as the main pathway of species introduction and transfer in aquatic ecosystems (Carlton 1985, 1996; Carlton and Geller 1993; Wiley and Claudi 2000). Although the importance of this vector is now widely accepted, there are still numerous questions and unverified statements relative to the mechanisms determining the success of species transport and transfer via ballast water. Notwithstanding these unknowns, ballast water management was rapidly foreseen by scientists, governments, international maritime agencies and the shipping industry as a necessary tool to resolve the environmental problem of

aquatic species introductions (IMO 2004). Theoretically, ballast water can be managed either via ballast water exchange (BWE) at sea or via ballast water treatment methods. In practice, due to its ease of application and relatively inexpensive operational cost, BWE was adopted quickly by the shipping industry and it currently represents the main method of preventing the introduction and transfer of aquatic species.

BWE in mid-ocean may pose a risk to ship safety, so the use of alternate zones in coastal environments has been recommended in cases where BWE cannot be performed at offshore locations. Ideally, these alternate zones should be defined and delineated after rigorous assessment of their appropriateness to minimize the risk of introductions. Since the use of alternate zones should be minimal and restricted to particular cases, the option of using alternative methods to treat ballast water is worth considering. The present paper reviews information on the appropriateness, effectiveness and benefits of alternate zones versus alternative treatment technologies to manage ballast water, using the Gulf of St. Lawrence alternate exchange zone as an example. First, we present an historical overview of the “back-up” zone for BWE in the Gulf of St. Lawrence; secondly, we provide a preliminary assessment of the impact and effectiveness of BWE in the Great Lakes - St. Lawrence basin; and, finally, we discuss the use of alternative treatment methods in the foreseeable future.

THE “BACK-UP” EXCHANGE ZONE IN THE GULF OF ST. LAWRENCE

In response to the environmental crisis resulting from the introduction and invasion of the Laurentian Great Lakes by zebra mussels (*Dreissena polymorpha*) in the mid-1980s and at the urging of the Great Lakes Fishery Commission, the Canadian Coast Guard, with the scientific guidance of several departments and agencies, established in May 1989 “voluntary” interim guidelines for BWE for ships entering the Great Lakes. These guidelines were first set for ships going upbound of Montreal harbour only. These voluntary guidelines designated a secondary (or “alternate”) BWE zone within the

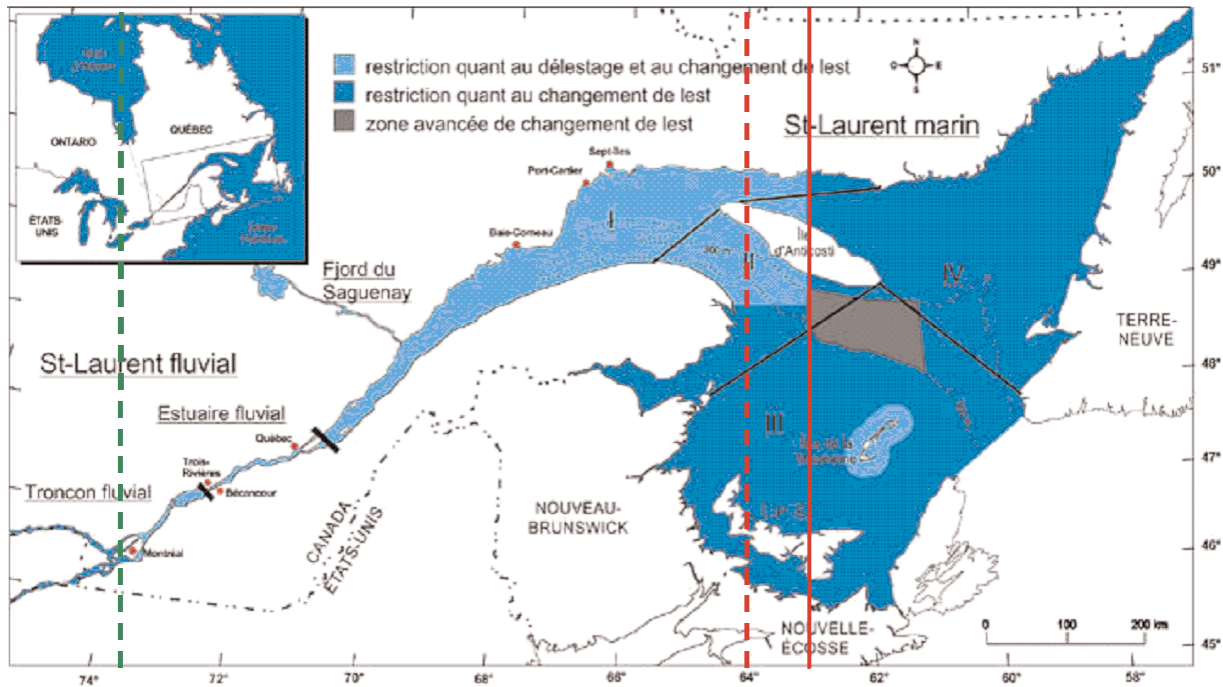


Figure 1. Map of the St. Lawrence River, the estuary and the Gulf of St. Lawrence. The shaded area corresponds to the alternative zone for ballast exchange and vertical lines indicate the various limits of application of the Canadian voluntary guidelines, (adapted from Bourgeois et al. 2001).

Gulf of St. Lawrence. The area was initially designated in the Laurentian Channel waters east of the Gaspé peninsula at 64°W longitude and over sounding depths >300 m (Figure 1). The eastern limit of the alternate exchange zone remained undefined but apparently extended into the Atlantic Ocean beyond Cabot Strait.

In 1990, a scientific expert group commissioned by the Department of Fisheries and Oceans recommended to redefine the boundaries of the alternate zone for exchange as the Laurentian Channel waters located between 63°W and 61°W longitude and over depths >300 m (Kerr 1990). Reasons for this proposed change were that the western boundary was considered too “risky”, due to the proximity of the Gaspé current which could potentially entrain surface water over the Magdalen Shallows and nearby coastal waters. The proposed eastern boundary was set at 61°W longitude was set to minimize the risk of entrainment of ballast water being discharged in Cabot Strait over the coastal waters of the Nova Scotian shelf (Kerr 1990). This proposition would have substantially reduced the size of the zone, so that ship transit time through it might be shorter than the amount

of time required to complete BWE. On the other hand, the smaller size of the area would presumably minimize or eliminate its use on a “routine” basis, rather than under exceptional conditions only, as originally intended. The recommendation for an eastern limit to the alternate exchange zone never really came into force.

Ships steaming to ports in the St. Lawrence River (Montreal and downstream) as well as ports in the estuary and the Gulf of St. Lawrence were exempt from these guidelines and remained a risk with regards to non-indigenous species introduction. In 1993, the Canadian “voluntary” guidelines were changed to accommodate the U.S. mandatory regulation for ships entering the Great Lakes, so that all ships passing 63°W longitude were authorized to use the alternate exchange zone. This would presumably help protect the freshwater section of the St. Lawrence River downstream of Montreal. The Canada Shipping Act is currently under review and enforcement of new legislation should make BWE mandatory for ships entering the Great Lakes—St. Lawrence River system. The western limit of the alternate zone has remained unchanged at 63°W longitude.

The changes in the definition and application criteria of the voluntary guidelines and the limits of the alternate zone merely reflect the complexity of this issue. The problem arises principally from the desire to apply a single rule for protecting three different ecosystems: the Great Lakes, the freshwater St. Lawrence River and the marine sector comprising the estuary and the Gulf of St. Lawrence. In order to assess the potential risk of species introductions into each of these ecosystems, Bourgeois et al. (2001) compiled the information on foreign shipping traffic entering the Gulf of St. Lawrence between 1978 and 1996. Results on the number of ships, ballast capacity and effective volume of ballast being discharged into each ecosystem (Table 1) revealed that the risk of introduction would be obviously much higher within the marine sector. This sector accounted for over 50% of the estimated risk due to the presence of much larger ships (with much larger ballast capacity) potentially discharging at ports of destination. The freshwater sector of the St. Lawrence River ranked second with a risk estimate of 38%, while the risk for the Great Lakes sector was 8%. When considering the percentage of ships reported to carry ballast on board (BOB) during a survey made between 1994 and 1996 (Harvey et al. 1999), the total volume of ballast water discharged into the estuary and the Gulf was estimated to be approximately 10 million tons per year, or 78% of the total amount of ballast water discharged by foreign vessels in the Great Lakes and St. Lawrence basin. Paradoxically, the potential risk was lowest in the Great Lakes sector where the annual discharge of ballast water was 0.25 million tons (~2% of the total). The difference between sectors was essentially due to the percentage of ships without ballast on board. While the vast majority (87%) of ships stopping in the marine sector declared carrying ballast on board, the percentage dropped to 20% for ships at destinations along the St. Lawrence River and to 4% for ships entering the Great Lakes in years 1994-1996 (Table 1).

An analysis of the transoceanic shipping into the Great Lakes since the opening of the seaway in 1959 showed that the percentage of ships with no ballast on board or in partial ballast (NOBOB), has increased slightly since the estab-

Table 1. Information on foreign shipping traffic to the Great Lakes and the St. Lawrence basin between 1978 and 1996 (data from Bourgeois et al. 2001 and Harvey et al. 1999).

Destination	Ships		Ballast Capacity		Ballast discharged in 1994-1996	
	(Nb. yr ¹)	%	(10 ⁶ T yr ¹)	%	% BOB*	(10 ⁶ T yr ¹)
Great Lakes	249 ±39	13	2.3 ±0.5	8	4	0.25 (2%)
St. Lawrence River	1048 ±104	53	10.8 ±2.3	38	20	2.70 (20%)
<i>Montréal</i>	735	70	6	60		
<i>Québec</i>	179	17	3	27		
<i>Other ports</i>	135	13	1.8	13		
Estuary and Gulf	674 ±75	34	15.6 ±2.8	54	87	10.46 (78%)

* Ballast on board

lishment of the Canadian voluntary guidelines in 1989 and even more since that of the mandatory U.S. rules in 1993 (Grigorovich et al. 2003). Assuming that misreporting was not a problem, reasons for this increase could presumably be related either to economic pressure which forced the shipping industry to maximize cargo in recent years or to the fact that ships, in order to comply to guidelines and legislation, do discharge ballast water but not necessarily take new ballast on-board before entering the Great Lakes. Data from the U.S. Coast Guard on ship surveillance at the entrance of the Great Lakes indicated that full compliance with BWE rules and guidelines has been relatively high and exceeded 90% since 1993 (Figure 2). Depending on the year, up to 7% of ships were considered technically non-compliant. These ships did comply with salinity standards (>26 ppt), but not with the zone of exchange (>200 nautical miles offshore and over depth >2000 meters) and may therefore include ships using the alternate zone for salinity compliance. The above values are indeed very similar to the percentage of ships (7%) using the Gulf alternate zone for ballast exchange in 1989 immediately following the establishment of the voluntary guidelines (Kerr 1990). Given the number of foreign ships entering the Great Lakes, the number of ships that used the alternate exchange zone each year would probably be very small. The compliance rate varies seasonally and is usually lower in early spring and late fall, probably a result of harsh weather and poor sea conditions rendering

ballast water exchange more difficult and risky (data not shown). Unfortunately, comparable data on ship compliance are lacking for other Canadian sectors (the St. Lawrence River, the estuary and Gulf of St. Lawrence). In the absence of mandatory rules for Canadian waters, monitoring or surveillance programs for ship ballast are still nonexistent and there is no formal checkpoint for ships entering the St. Lawrence River and the maritime sector in eastern Canada. Preliminary survey results from Transport Canada during year 2002 indicated that only 3 out of 573 foreign ships (0.7%) at destination ports in the Quebec region only (not including ships entering Gulf of St. Lawrence ports in the remaining provinces) did report exchanging ballast water in the alternate zone (D. Duranceau, Transport Canada, Quebec Region, pers. comm.). This would confirm that the alternate back-up zone in the Gulf of St. Lawrence is not frequently used for BWE.

Knowing the potential risk of species introductions associated with shipping traffic, we compiled the available information relative to the number of exotic species introduced into each of the three sectors in the Great Lakes – St. Lawrence basin in order to assess and compare the relative risk of species establishment among sectors. A recent analysis by de Lafontaine and Costan (2002) showed that the number of non-indigenous species introduced since 1820 in the upstream Great Lakes (160 species) was almost twice that reported in the downstream St. Lawrence River (85 species). The relative proportion of the various taxonomic groups (algae,

vascular plants, invertebrates, fish) differed significantly between the two regions, suggesting different dynamics of introduction and establishment. Considering that the risk of introduction by shipping (simply based on traffic and ballast volume estimates) was presumably higher in the river than in the lakes, this result may be surprising and somewhat counterintuitive. From an ecological perspective, riverine systems are far more dynamic than lakes and would not necessarily favour the establishment of all forms of organisms. The rapid flow rate of the St. Lawrence River may indeed accelerate the drift of plankton and other larval forms toward the saline estuary, therefore reducing the risk of species establishment and invasion in the river. In fact, most introduced species reported in the river were either benthic organisms (vascular plants and molluscs) or mobile animals (fish, benthic crustaceans). Moreover, nearly all species (98%) introduced in the St. Lawrence River since 1960 were first reported in the Great Lakes, suggesting that these species were introduced and established in the Great Lakes first before being subsequently transferred and spread into the St. Lawrence River by either passive or active transfer. Although several ecological reasons could be called for explaining this regional difference in the introduction and establishment success of non-indigenous species, it does not seem to parallel the potential risk associated with shipping (estimated on proportion of BOB ships and ballast capacity). In fact, these results support the hypothesis put forward by Grigorovich et al. (2003) that NOBOB ships after re-ballasting with water in the Great Lakes may indeed be the major cause of species introductions. This implies that untreated residual waters and sediments remaining at the bottom of tanks in NOBOB ships would present a higher risk factor and should be managed with adequate treatment methods.

On the positive side however, the number of species introductions associated with the shipping vector in freshwater (Great Lakes and St. Lawrence River) seems to have declined slightly over the last decade (1990-2000) since the implementation of the exchange guidelines by Canada and the U.S. during the early 1990s (de Lafontaine and Costan 2002; Grigorovich et al.

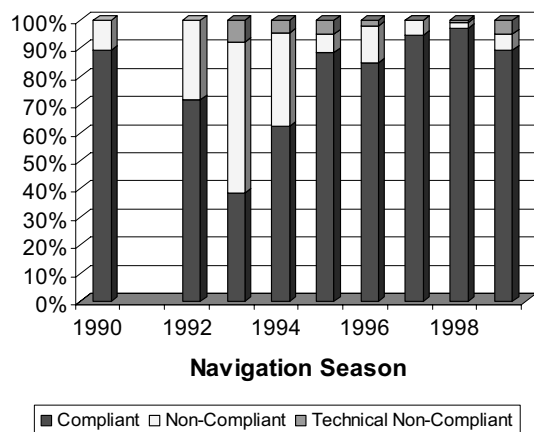


Figure 2. Ballast water compliance rates.

2003). If this decline is significant and persists over the next decade, it would strongly suggest that BWE does effectively help minimizing the input of new species. However, the objective of no new introductions is still far from being met.

Information on non-indigenous species introduction in Canadian marine environments is more scarce, in particular for the estuary and Gulf of St. Lawrence. Despite the presumably very high risk associated with the high proportion of BOB ships arriving at destinations in the Gulf of St. Lawrence harbours, the total reported number of exotic species in both marine and estuarine environments is 26 (Table 2), which is much less than that reported for the Great Lakes. Algae accounted for nearly half of that number. Shipping would account for 25% (6 species) of the total number of these introductions, which is close to the value of 33% estimated for the Great Lakes according to Wiley and Claudi (2002). Reports of introduced species are very localized, but the spatial coverage of sampling effort and inventory is much less thorough for the entire Gulf of St. Lawrence than that realized in the Great Lakes. Given the paucity of information available, no conclusions may be reached regarding the risk and the impact of BWE within the Gulf of St. Lawrence. Evidence indicates, however, that species introductions and establishment in the marine sector is not as important nor as frequent as in the upstream freshwater environments. Alternatively the theory that cumulative invaders facilitate new introductions might suggest that the Great Lakes is in the midst of “invasion meltdown,” whereas the Gulf of St. Lawrence system may not have attained this phase of accelerating rates of invasion (Simberloff and Von Halle, 1999).

ALTERNATIVE TREATMENT METHODS

The above results highlight that BWE cannot be fully satisfactory to eliminate the risk of species introduction and protect the various aquatic environments. BWE at sea was originally recommended for protecting freshwater systems, by replacing freshwater in ballast tanks with oligotrophic marine waters to be discharged eventually in freshwater ports. The effectiveness

Table 2. Introduced non-indigenous species reported in the Gulf of St Lawrence. Data compiled from various sources by N. Simard (DFO-Mont-Joli), and A. Locke and M. Hanson (DFO-Moncton).

Taxonomic group	Total	Presumed vector of introduction			
		Shipping	Natural or cryptic	Deliberate	Unknown
Algae	11	4	2	-	5
Invertebrates	9	2	2	2	3
Freshwater Fish	2	-	-	2	-
Parasites/Pathogens	4	-	4	-	-

of the method for protecting marine coastal waters is questionable, however. Shipping activities along the North American coastal waters represent a good example of ships transiting and transferring ballast water between different marine systems. In this regard, the possibility of using the Gulf alternate zone more frequently in the future would increase the risk of species introductions in the area. In scenarios where BWE would not be possible, the use of alternative treatment methods is recommended.

Excluding the use of on-shore treatment that would require the installation of treatment facilities in every port, various on-board ballast water treatment technologies have been developed but only a few have been tested adequately. These technologies can be grouped into either physical/mechanical or chemical processes, and the pros and cons of each method have been reviewed in different reports (Pollutech 1992; Hay et al. 1997; Mountfort et al. 1999; Calvé 2001; Tamburri et al. 2002). Most physical treatment methods require major re-fitting of ships and some may be unsafe to use. The proposed chemical methods are often based on the use of biocides and toxic chemicals which make them environmentally unacceptable because these treated waters have to be discharged in natural environments. A notable exception is the deoxygenation process by which the concentration of dissolved oxygen in ballast water is rapidly reduced to very low levels inducing a massive kill of most aquatic living organisms (Stalder and Marcus 1997; Mountfort et al. 1999; Tamburri et al. 2002). The anoxic environment

in ballast tanks could also help prevent corrosion of a ship's structure, which could confer some advantage in using deoxygenation methods. Oxygen removal can be achieved either by saturating ballast waters with the addition of nitrogen gas as shown by Tamburri et al. (2002) or by bio-reactive processes as suggested by Mountfort et al. (1999).

While nitrogen addition has proven to be feasible and effective, its use is relatively costly, however, and might present some safety risk. Preliminary trials by Mountfort et al. (1999) suggested the potential of deoxygenating biological processes, but the development and use of such techniques can encounter many challenges. The treatment has to be effective in both fresh- and saltwater environments and at temperatures ranging from nearly 0 to ~30°C. The bio-reactive process has to be fully activated and completed over a short time period (<5 days) in order to be used during short voyages. The process should not release any toxic degradation product and treated ballast waters should be safe for release into the receiving environment. From a cost/benefit point of view, the technology should require no or minimal ship modification and it should be simple to handle and safe to use by the ship's crew.

Recent developments in biotechnological processes offer a new methodology that appears to be meeting the challenges of the criteria (see Table 1) and may become an effective and viable treatment alternative to ballast water exchange. Laboratory testing in 200 L vessels to assess the effectiveness and environmental impact of biological oxygenation, has shown promise in meeting Canadian discharge thresholds. Pilot-scale trials of this technique onboard ship are planned for the next year. We offer an example of one treatment to illustrate the type of data we expect from an alternative treatment prospective (Figure 3).

The development and testing of new techniques will eventually offer a variety of effective treatment methods to manage ballast water appropriately. The proposed existing techniques (including ballast water exchange) can be compared and evaluated with a list of different performance criteria. Based on literature information (Pollutech 1992; Hay et al. 1997; Calvé 2001; Moore and Ryan 2003; A. Valois, PolyGo,

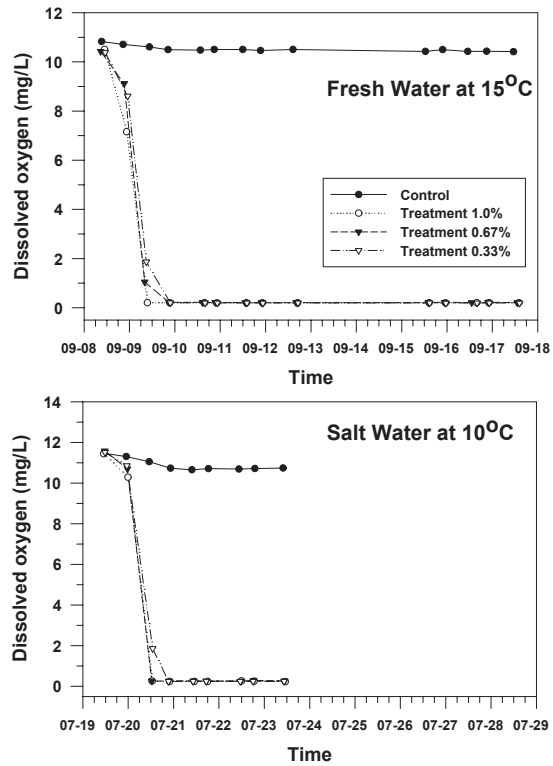


Figure 3. Concentration of dissolved oxygen as a function of time in both fresh- and saltwater experiments using a bio-technological process from 200 L vessel testing.

Montreal, pers. comm.), the characteristics of each method relative to each criterion were compiled in an information matrix (Tables 3 and 4). The estimated cost (in Canadian dollars) per trip was calculated for a 34,000 DWT vessel making 40 trips per year and carrying ballast 33% of the voyages. A 7-year depreciation time was assumed for capital investment. As expected, ballast water exchange was the least expensive method (\$ 250 per trip) but its control effectiveness to treat and control species introductions is considered generally poor (Locke et al. 1991). On the other hand, the three deoxygenating techniques can meet a large number of criteria, and ranked very high in terms of control effectiveness. The deoxygenation techniques are presumably also capable of treating residual waters, which normally remained untreated after ballast water discharge (as in the NoBOB condition). The total cost per trip was quite variable between the different treatment methods, but the biological deoxygenating treatment method was the second least expensive (\$ 1800 per trip)

Table 3. Comparative assessment of performance characteristics of different alternative technologies for treating ballast water.

Criteria	BWE	Filtration	UV	Ozone	Chlorine	Vacuum Deoxygenation	Nitrogen Deoxygenation	Biological Deoxygenation*
Energy cost	Small	High	High	High	Medium	High	Medium	Null
Risk to safety	Medium	Medium	High	High	High	High	High	Null
Training personnel	Low	Medium	High	High	High	High	High	Low
Effect on ship lifespan	Almost null	Null	Null	Corrosion	Corrosion	Positive	Positive ?	Positive
Possibility for change	Yes	No	No	No	No	No	No	Yes
Environmental impact	?	?	Null	Null	Unacceptable	Acceptable	Acceptable	Acceptable
Equipment space (m ²)	Null	10	4	15	2	8	4	Null
Perishable space (m ²)	Null	Some ?	0	0	?	0	0	0.4

*Based on 200 L vessel trials.

Table 4. Comparative assessment of performance characteristics of different alternative technologies for treating ballast water (suite from Table 3).

Criteria	BWE	Filtration	UV	Ozone	Chlorine	Vacuum Deoxygenation	Nitrogen Deoxygenation	Biological Deoxygenation*
Capital investment (K\$CAD)	-	1000	1000	2000	500	1400	1000	?
Depreciation expenses (K\$CAD)	-	3.6	3.6	7.1	1.7	5.0	3.6	?
Maintenance (K\$CAD)	?	1.0	1.0	2.0	0.5	1.4	1.0	?
Perishables (K\$CAD)	-	-	-	-	1.0	-	-	1.8 (est.)
Time loss	?	?	-	-	-	-	-	?
Total cost per trip (K\$CAD)	0.30	4.6	4.6	9.1	3.2	6.4	4.6	1.8 (est.)
Control effectiveness	Poor	Partial	Medium	High	High	High	High	High
Residual waters treated	No	Partial	No	No	Partial	Yes ?	Yes ?	Yes ?

*Based on 200 L vessel trials.

after ballast water exchange. Of course, these calculations did not account for any socio-economic and environmental cost for controlling and mitigating the impact of species once they are introduced into an ecosystem.

TOWARD BETTER MANAGEMENT PRACTICES

In summary, 15 years after the establishment of the Canadian voluntary guidelines for BWE, it is quite obvious that accurate information to

adequately assess the control effectiveness of ballast water exchange is still largely limited. Circumstantial evidence suggests that BWE implementation has not resulted in an absolute decline in species introduction in freshwater systems and it cannot be truly effective for coastal shipping. Moreover, the problems of untreated residual waters after BWE and the lack of compliance monitoring and surveillance make difficult the management of ballast water to eventually stop the introduction and transfer of aquatic species via shipping. To meet this objective, BWE (even in alternate zones) may not represent the best method since the risk of introduction will always remain higher than with any alternative treatment method. Up to now, the switch to using other technologies for treating ballast water has been slow, primarily for two reasons. First, the lack of environmental standards for discharging the content of ballast tanks in aquatic systems does not provide a definition of reference criteria for comparing and testing the various treatment technologies, including BWE. It is hoped that the new convention proposed by the International Maritime Organization (IMO 2004) will be rapidly accepted in order to establish such standards at an international level. This will definitely serve as a first and essential step toward better management practices.

Second, in the absence of environmental standards, the shipping industry had no strong incentive to solve the problem of species introductions. Thus, BWE is still the best current practice due to its cheap operational cost. In order to meet our environmental objective of reducing the number of future introductions and to protect the integrity of our ecosystems, we must work toward finding and implementing effective treatment technologies that could also benefit the industry. With dedicated effort in this direction, the dream may come true more quickly than many think.

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longitude and at water depths exceeding 300 m. The Guidelines also recommend ballast water exchange for ships proceeding to Estuary and Gulf ports that are located west of 63° W longitude, which represents more than 80% of the entire maritime traffic from a foreign origin in the area on an annual basis.

An important oceanographic feature of the Gulf that has relevance for this study is the inward net transport of deep waters upstream to the head of the Laurentian Channel. The prescribed area is also located relatively close to the coastal waters of Anticosti Island, the Gaspé Peninsula and the Magdalen Islands which support important fisheries, including snow crab, lobster, and shrimp, in the Laurentian Channel. Thus, the location of the alternate exchange zone, particularly its upstream part, may represent an additional risk for the introduction of nonindigenous marine organisms in coastal areas of the Gulf of St. Lawrence.

OBJECTIVES

The objectives of this study were to assess risks for the introduction of nonindigenous marine organisms associated with ballast water exchange by foreign ships in the alternate zone of the Gulf of St. Lawrence and to minimize these risks in order to maintain an alternate ballast water exchange zone (ABWEZ) in the Gulf of St. Lawrence.

METHODS

A three-dimensional model of circulation and thermodynamics in the Gulf of St. Lawrence (Saucier et al. 2003) was used to: (1) simulate the seasonal dispersion and fate of plankton inoculated with ballast water discharges in the ABWEZ and (2) identify areas from where surface waters are quickly flushed out of the Gulf so as to identify areas that could be used for alternate ballast water exchange (ABWE). The determination of these areas was put into context with other factors such as ballast water salinity and time of the year to derive a set of conditions under which backup exchanges could be allowed

with an acceptable level of risk for the introduction of nonindigenous species in the Gulf of St. Lawrence.

DESCRIPTION OF THE MODEL

The model is a three-dimensional prognostic coastal model (Backhaus 1985) for currents, temperature, salinity, turbulence, and ice thickness and concentration in the Estuary and Gulf of St. Lawrence. The model has a horizontal resolution of 5 km and its vertical resolution is composed of 73 layers. Surface meteorological forcing is prescribed by six-hourly air temperature, winds, dew point, relative humidity, pressure, dry/liquid precipitation, and radiation. These data are provided by 20 virtual stations distributed throughout the Estuary and Gulf and derived from actual observations. Hydrological forcing is derived from monthly runoff at Quebec City and daily runoff for all major tributaries, and is adjusted to account for net basin drainage. An open boundary forcing at Belle-Isle Strait and Cabot Strait includes 15 water level tidal constituents and climatological water mass properties for entering Atlantic Ocean and Labrador Sea waters.

In terms of validation, the model was shown to reproduce well conditions that were observed in 1986 and 1987, including temperature and salinity profiles, current meter and tide gauge records, summer coastal temperature measurements, all of which with a relatively good precision. For example, the model was able to recreate freshwater pulses, storm events, and the formation, stability and dispersion of the Gaspé Current, which is one of the major features of circulation in the Gulf.

SIMULATIONS

All simulations of the dispersion of plankton were run by simultaneously releasing a predetermined number of particles over a given area that was limited to the upstream part of the alternate area for clarity purposes and to address greatest concerns. All particles were tracked by recording their position at the beginning of each day of simulation. Two-dimensional simulations were run to follow the discharge and surface dispersion

of phytoplankton. A total of 8 simulations over 90 days were run, each starting at the beginning of the months of April to November. No simulations were run for winter months because of ice conditions which affect surface transport, particularly at small scales. For the dispersion of zooplankton, three-dimensional simulations integrating vertical migrations were run. However, given the CPU requirements for multi-variable simulations, these were limited to four, (starting in April, June, August, and October) and lasted for 60 days. For these simulations, the integration of daily vertical migrations was achieved by driving vertical movements of particles at dusk and dawn at a speed of $2 \text{ cm}\cdot\text{s}^{-1}$. Vertical migrations were forced down to 150 meters in the Laurentian Channel to allow particles to reach deep waters as usually observed, and to the bottom when water depths decreased to less than 150 m. Finally, to determine suitable areas for exchanges, simulations of the flushing of surface waters out of the Gulf were run in conjunction with phytoplankton dispersion simulations to identify initial positions of surface water particles that would be evacuated from the Gulf and these positions were recorded at 15-day intervals during these simulations.

RESULTS AND DISCUSSION

PHYTOPLANKTON AND ZOOPLANKTON DISPERSION SIMULATIONS

Phytoplankton Surface Dispersion Simulations

The results of animations of two simulations of the surface dispersion of phytoplankton with contrasting results were presented to illustrate the large seasonal variability of transport and dispersion patterns. The first one started in April and shows the transport of particles first toward the Magdalen Islands, then upstream to coastal areas of Anticosti Island, and further upstream where some particles are caught up by the Anticosti Gyre. The patch is then transported downstream again with the arrival of the fresh-water pulse around mid-May. The second started in September and shows a net downstream transport of inoculated particles, first towards the Magdalen Islands then further downstream to Cape Breton Island, as a result of typically dominant northwesterly winds at this time of the year. Most particles are ultimately flushed out of the Gulf through Cabot Strait and only a few remained at the end of the simulation.

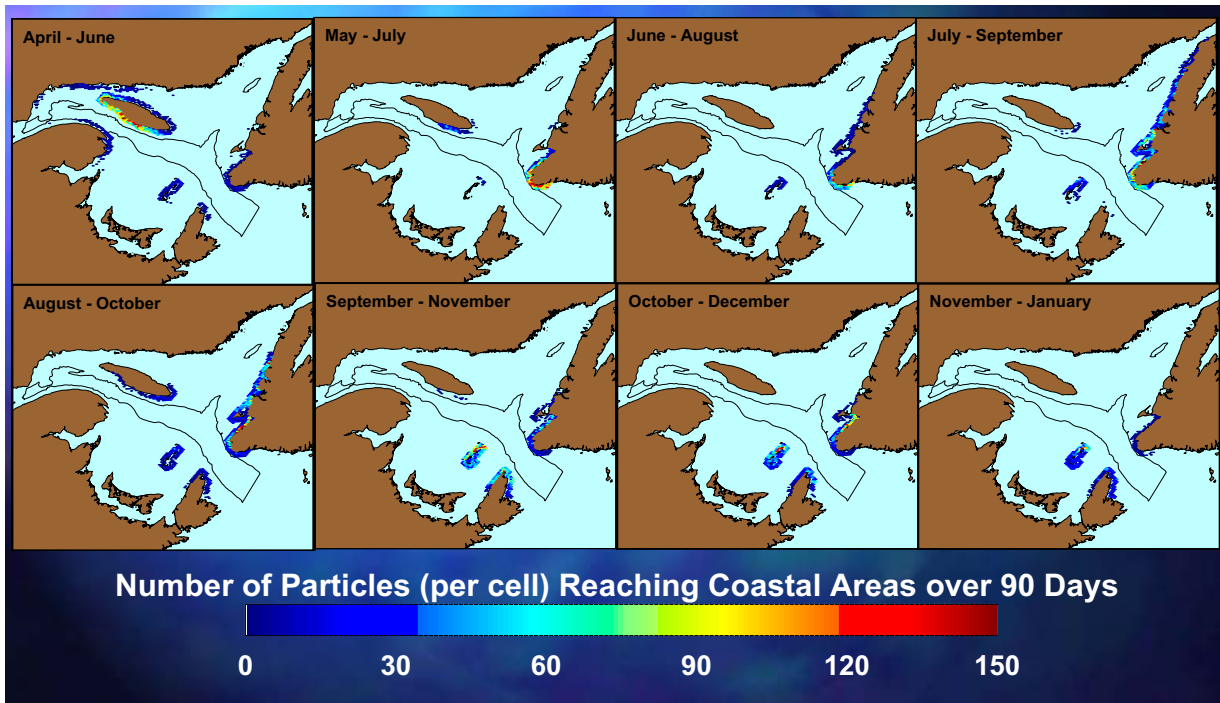


Figure 2. Estimated number of particles reaching coastal areas for 8 phytoplankton surface dispersion simulations.

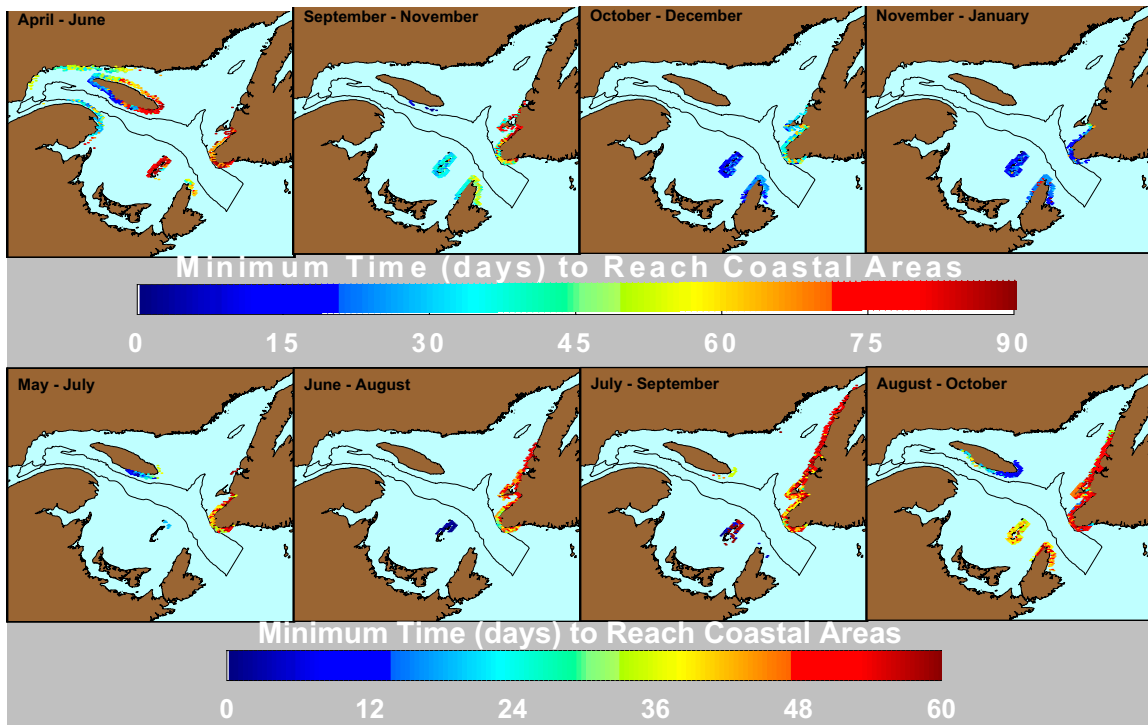


Figure 3. Estimated time needed to reach coastal areas for 8 phytoplankton surface dispersion simulations.

To illustrate coastal areas at risks in the Gulf of St. Lawrence, results of the eight simulations were summarized using three parameters: (1) the total number of particles reaching cells of the model that are adjacent to coastlines, (2) the minimum time required to reach the cells of the model that are adjacent to coastlines, and (3) the number of particles that are retained in the Gulf throughout the simulation.

- 1) Total number of particles. Results of all 8 phytoplankton surface dispersion simulations show that several coastal areas would be reached, some quite intensively, at different times of the year (Figure 2). Dispersion towards upstream areas such as Anticosti Island would occur in spring and late summer while downstream areas, namely the Magdalen Islands, southwestern Newfoundland and Cape Breton Island, would be reached in almost all cases. The entire west coast of Newfoundland would be particularly at risk in summer.
- 2) Time to reach coastal areas. In several cases, inoculated particles would reach coastal areas after 60 days, particularly on the west coast of Newfoundland (Figure 3). However,

this is not the case in the fall and early winter for the Magdalen Islands and Cape Breton Island, which would be reached generally within 30 days. Anticosti Island would be reached within 45 days in spring/early summer and in early fall.

- 3) Retention in the Gulf. These figures show the change in retained particles with increasing time of simulation for the 8 seasonal runs (Figure 4). Most of the particles are still present in the Gulf after 45 days in spring and late summer, and at least half of the inoculated particles remain after completion of the 90-day simulations. This indicates that significant retention within the Gulf would occur for phytoplankton cells that would be inoculated with ballast water discharges in the upstream part of the ABWEZ during these periods. However, a significant number of surface particles would be flushed rapidly out of the Gulf in early summer and in fall; in extreme conditions (late fall), almost all of the inoculated particles would be lost to Atlantic waters. These times of the year are characterized by the passage of the spring freshwater runoff pulse in early summer, and

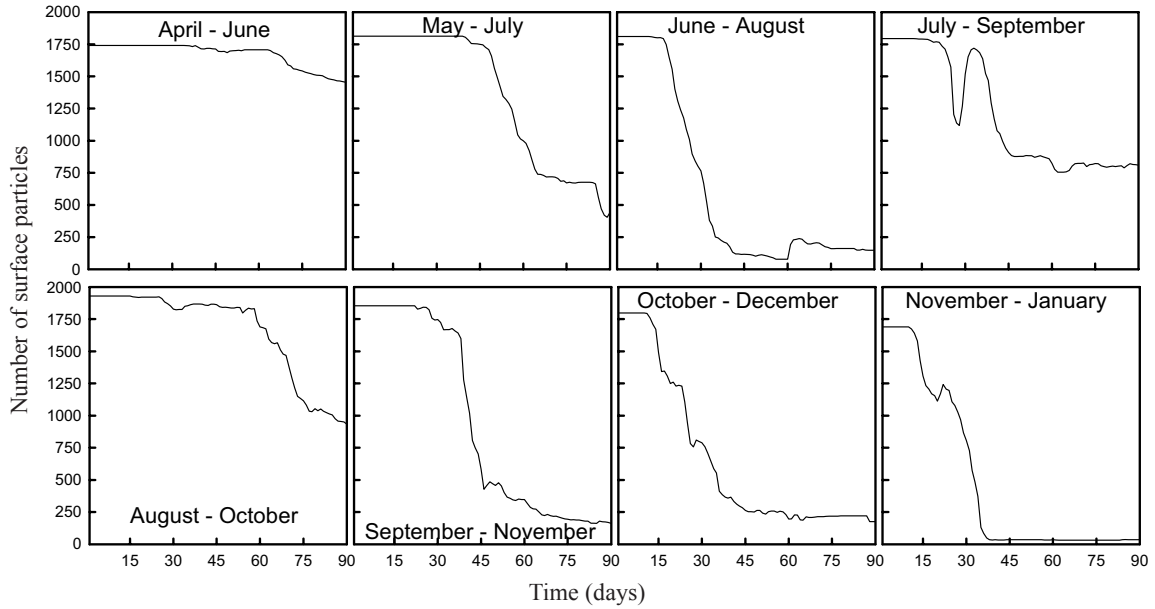


Figure 4. Estimated number of surface particles retained in the Gulf of St. Lawrence for 8 phytoplankton surface dispersion simulations.

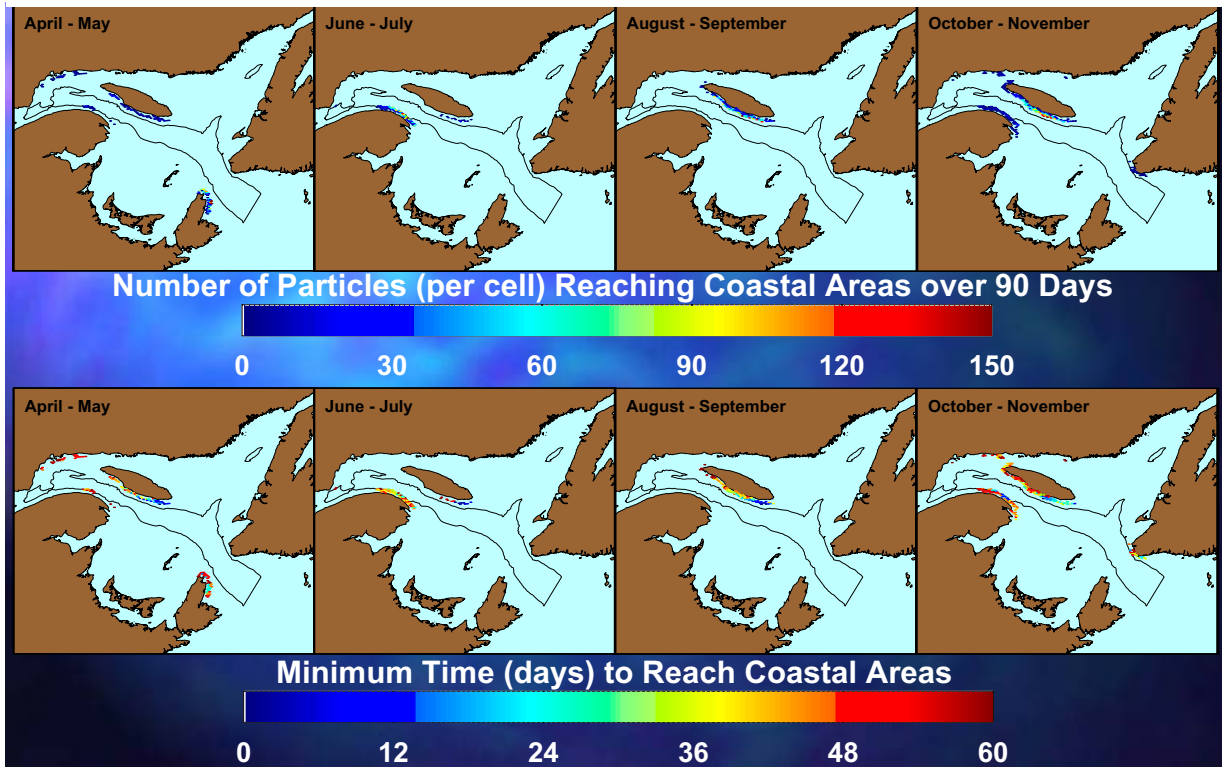


Figure 5. Estimated number of particles reaching coastal areas for 4 zooplankton dispersion simulations.

by strong northwesterly winds in fall which enhance the downstream transport of surface water towards the Atlantic Ocean.

Zooplankton Dispersion Simulations
 The first four maps of the three-dimensional zooplankton dispersion simulations present the number of particles reaching coastal areas over

the 4 simulations (Figure 5). These results show that dispersion patterns for zooplankton are clearly different from those observed for phytoplankton. In all cases, inoculated particles are dispersed upstream towards coastal areas of the Gaspé Peninsula, Anticosti Island and even the northwestern coast of the Gulf, whereas very few particles are dispersed towards downstream coastal areas. In contrast to phytoplankton simulations, the Magdalen Islands do not seem to be threatened by the inoculation of zooplankton in the upstream part of the ABWEZ. The four bottom maps show the minimum time required to reach these coastal areas and indicate that, in most cases, it takes at least 30 to 40 days for the inoculated particles to reach coastal areas except for the southeast coast of Anticosti Island. These different dispersion patterns are clearly related to daily migrations of zooplankton into deep waters of the Laurentian Channel, which show a net inward transport from Cabot Strait up to the head of the Laurentian Channel. This pattern is consistent with the observed zooplankton dynamics in the Gulf of St. Lawrence, where zooplankton is known to passively migrate upstream and accumulate at the head of the Laurentian Channel near Tadoussac. Thus, it can be assumed that zooplankton inoculated in the Laurentian Channel with ballast water discharges would be subjected to this passive upstream transport and ultimately could be incorporated in the observed zooplankton dynamics in this area, if conditions were favorable for their survival and reproduction.

Summary

In summary, phytoplankton dispersion simulations showed that several coastal areas are at risk from phytoplankton inoculation in the Laurentian Channel, including the Magdalen Islands, Southwest Newfoundland, Northern Cape Breton Island, and Anticosti Island. Some of these coastal areas, namely the Magdalen Islands, Anticosti Island, Cape Breton Island, would be reached within 30 days. A significant downstream transport would occur in late spring/early summer, because of the spring freshet, and in fall as a result of predominant northwesterly winds, while a significant retention of surface

phytoplankton within the Gulf would occur in spring and late summer.

Three-dimensional dispersion simulations of zooplankton yielded further retention of particles in the Gulf as a result of the net inward transport of deep waters in the Laurentian Channel. Thus, inoculated zooplankton would be mainly retained within the Laurentian Channel and upstream coastal areas would be particularly at risk (Gaspé Peninsula, Anticosti Island). Ultimately, inoculated zooplankton could be incorporated into the zooplankton dynamics of the Estuary and Gulf ecosystems.

ABWE southeast of Anticosti Island represents a risk from a Gulf perspective, because of the significant retention of inoculated planktonic organisms within the Gulf and for their dispersion towards coastal areas. However, it was recognized that there was a need for ballast water regulating agencies in Canada and the U.S. and for the industry to have an alternate zone in the Gulf of St. Lawrence, and the authors tried to identify such a ABWEZ by looking at areas from where surface waters would be quickly flushed out of the Gulf.

FLUSHING OF SURFACE WATERS OUT OF THE GULF (90 DAYS)

Figure 6 shows the initial position of surface particles that would be flushed out of the Gulf at two week intervals during the simulations for the 8 phytoplankton surface dispersion simulations. Deep blue and blue areas represent areas flushed out within 15 and 30 days respectively, light blue and green areas represent areas flushed after 30 and 45 days, and yellow and red areas are for 75 and 90-day flushing time. These maps clearly show that surface waters in the Cabot Strait area of the Gulf are rapidly flushed out to the Atlantic, usually within 30 days. This is particularly the case in summer, when high surface temperature would allow survival of a greater number of inoculated species, and in late fall when the need for a ABWEZ is highest because of bad weather conditions in the North Atlantic at this time of the year.

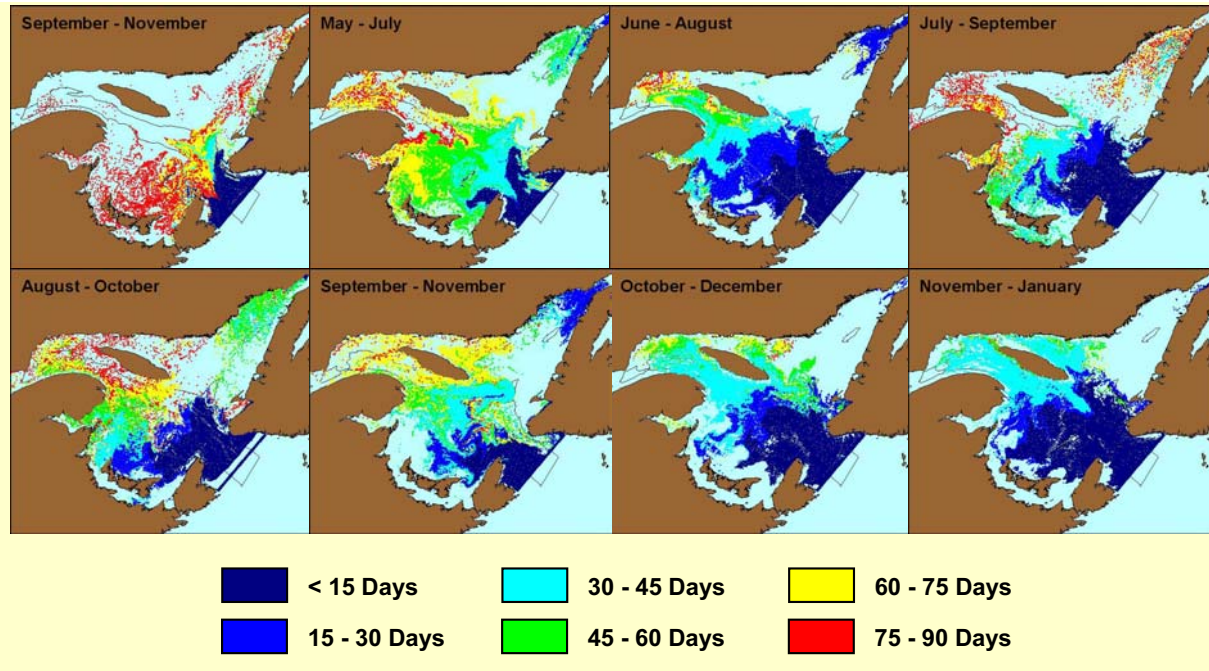


Figure 6. Estimated time required for flushing surface waters out of the Gulf of St. Lawrence for the phytoplankton dispersion simulations.

CONCLUSION AND RECOMMENDATIONS

CONCLUSION

The Gulf area that is located around Cabot Strait east of the Magdalen Islands could be acceptable for ABWE from a Gulf perspective. However, zooplankton inoculations in this area would probably still be subjected to a net upstream transport and, more importantly, the fate of inoculated organisms that would be flushed out of the Gulf with surface waters is unknown, but may pose a threat to the Canadian Atlantic Coast. This hypothesis has been confirmed with recent studies. However, the approach presented in the present study should be applied to the Atlantic Coast in order to identify alternate zones for ballast water exchange.

RISK ANALYSIS AND DECISION SUPPORT SYSTEM

There is no ideal solution to this problem and some level of risk must be accepted. However, such an acceptable level of risk would have to be minimized as much as possible; the

suitability of ballast water exchanges around Cabot Strait (or other areas) would have to be based also upon other conditions that influence the survival of inoculated organisms, which point to a risk analysis approach and a decision support system. For ships proceeding up the St. Lawrence River and to the Great Lakes, the first factor to be considered would be the salinity of ballast waters transported by ships. Exchanges in the Gulf of St. Lawrence could be allowed in the ABWEZ when ships are transporting freshwater in their ballast tanks. On the other hand, exchanges would not be required for ships transporting marine waters with salinity exceeding 30 PSU, because these exchanges would not further reduce risks for ships proceeding up to freshwater ports but could increase those for the Gulf of St. Lawrence. If brackish waters were transported in ballast tanks, then other factors would have to be considered, the second most important being the time of the year. In this case, the need for ABWEZ would be particularly important during fall and winter because of stormy conditions in the North Atlantic. This is also a time of the year when surface temperature in the Gulf decreases significantly to near freezing temperatures, which

limit the potential for survival of inoculated organisms. As a result, ABWE could be allowed from late fall through spring around Cabot Strait (or other areas) while for the rest of the year, a third factor would be incorporated in the risk analysis, namely the origin of the ship. If ships originate from tropical or subtropical areas, then ABWE would be allowed, whereas for ships originating from temperate and subarctic ports, other means such as storage facilities and treatment options or sealed tanks (exchanges not allowed) would have to be considered. Such a risk analysis, if incorporated in voluntary guidelines in conjunction with ABWEZ around Cabot Strait, would maintain risks for ballast water-mediated introductions in the Great Lakes at a low level, but would significantly reduce these risks for the Estuary and Gulf of St. Lawrence. A similar risk analysis could also be developed for ships proceeding to marine ports of the Estuary and Gulf. In conclusion, this approach would be consistent with a precautionary approach and would definitely facilitate the development of regulations for ballast water exchange at the national level in Canada.

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Risk Assessment for Species Introduced from Ballast Water Exchange

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ABSTRACT

The geographical information system (GIS) mapping of geo-referenced ballast water exchange volume endpoints recorded on Ballast Water Report Forms submitted to Marine Safety, Transport Canada, provides insight in ballast activities reported off Eastern Canada during the year 2002.

Vessel movement tracks and seasonal computer-modelled potential (interpolation) surface thematic maps rendered location information on preferred vessel exchange corridors and delineated high-value areas for ballast exchange volumes (reported endpoints) for vessel traffic approaching Eastern Canada from the United States, Europe and other international departure points.

The same Transport Canada ballast water data provided for a comparative, statistical analysis of shipping trends and patterns for Eastern Canada, with years 1998 and 2000.

Please see the full 85-page report, *GIS Mapping of Marine Vessel Ballast Water Exchange Endpoint Data in Atlantic Canada, for the 2002 Shipping Season*, which appears in these proceedings as Appendix VII.