A preliminary assessment of risks for the ballast water–mediated introduction of nonindigenous marine organisms in the Estuary and Gulf of St. Lawrence

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ABSTRACT

Harvey, M., M. Gilbert, D. Gauthier, and D.M. Reid. 1999. A preliminary assessment of risks for the ballast water–mediated introduction of nonindigenous marine organisms in the Estuary and Gulf of St. Lawrence. Can. Tech. Rep. Fish. Aquat. Sci. 2268: x + 56 p.

Risks for the introduction of nonindigenous marine species into the Estuary and Gulf of St. Lawrence (EGSL) by foreign commercial shipping activities were evaluated by conducting three different surveys to characterize 1) the vessel traffic of foreign origin in the EGSL, 2) ballasting operations of foreign vessels entering ports of the EGSL, and 3) the biodiversity and species richness of protistan and metazoan taxa found in ballast water and sediment of incoming foreign vessels. A total of 709 vessels originating from 49 countries and 11 Food and Agriculture Organization (FAO) ocean regions visited 23 different ports of the EGSL in 1995, resulting in the discharge of about 11.5×10^6 tonnes (t) of ballast water from a foreign origin. Respectively 66% and more than 97% of foreign arrivals and associated ballast water discharges in the EGSL occurred in ports of the Estuary and northwestern Gulf, mainly those of Baie-Comeau, Port-Cartier, and Sept-Îles, because of their use by bulk carriers for the exportation of minerals and cereals. However, it is estimated that 86.5% of the foreign ballast water discharged in the EGSL originates from the Northwest Atlantic as a result of an apparent high level of compliance to the *Voluntary Guidelines for the Control of Ballast Water Discharges from Ships Proceeding to the St. Lawrence River and Great Lakes* (GLBWCG), while only 13.5% originates from previous ports of call. These ports are mainly located in the northwest, northeast, and western central Atlantic and the Mediterranean Sea, particularily around the North Sea and Baltic Sea area and along the eastern and southern coasts of the United States. Except for the Baltic Sea, all these areas exhibit warmer environmental conditions than those prevailing in the EGSL, particularily in the northern Gulf. A total of 292 phytoplanktonic and 89 zooplanktonic species were identified in ballast water of 94 ships from a foreign origin that were sampled and a total of 65 protistan taxa in ballast sediments collected in 8 of these ships. Respectively 60% and 57% of the phytoplanktonic and zooplanktonic species observed in the ships' ballast waters were nonindigenous species that are not yet found or reported in the EGSL, and some of them were found at densities as high as 100,000 cells or ind.$\cdot m^{-3}$. Although mid-ocean ballast water exchanges as prescribed by the GLBWCG appear to be efficient in reducing the number and density of zooplankton taxa in ballast tanks, unusually high zooplankton densities in ballast water of a number of incoming sampled ships having reported complete exchanges indicate that these exchanges were in fact not complete or conducted in unsuitable areas. Nevertheless, observations suggest that risks for the ballast water–mediated introduction of nonindigenous marine species into the EGSL do not appear to be as high as in other areas of the world with documented introductions related to ballast water transport. However, some areas of the Gulf of St. Lawrence do present significant risks for such introductions, particularily in the southern Gulf area — mainly Chaleur Bay and Northumberland Strait — where incoming foreign ships are not subjected to the GLBWCG and where warmer conditions prevail in summer and fall. While additional studies are needed to complete this risk assessment, results point out the necessity to reevaluate and better implement the existing guidelines for offshore ballast water exchange in order to provide better protection for the marine environment of the Estuary and Gulf of St. Lawrence. Some modifications to the current GLBWCG are proposed in this regard as well as the potential use of some community characteristics in ballast waters to monitor compliance to the guidelines.

RÉSUMÉ

Harvey, M., M. Gilbert, D. Gauthier, et D.M. Reid. 1999. A preliminary assessment of risks for the ballast water–mediated introduction of nonindigenous marine organisms in the Estuary and Gulf of St. Lawrence. Rapp. tech. can. sci. halieut. Aquat. 2268 : x + 56 p.

Les risques d'introduction d'espèces marines non indigènes dans l'estuaire et le golfe du Saint-Laurent (EGSL) par les activités maritimes commerciales étrangères ont été évalués par le biais de trois études visant à caractériser : 1) le trafic maritime en provenance de l'étranger dans l'EGSL; 2) les déversements d'eau de lest par les navires étrangers visitant les principaux ports de l'EGSL; et 3) la richesse spécifique et la biodiversité du phytoplancton et du zooplancton présents dans les eaux et les sédiments de lest de certains navires. Un total de 709 navires en provenance de 49 pays et 11 régions de l'Organisation pour l'alimentation et l'agriculture (OAA) ont visité 23 ports différents dans l'EGSL en 1995, entraînant le déversement d'environ $11{,}5 \times 10^6$ tonnes (t) d'eau de lest provenant de l'étranger. Environ 66% des arrivées en provenance de l'étranger et plus de 97% des déversements conséquents d'eau de lest dans l'EGSL se sont produits dans les ports de l'Estuaire et du Nord-Ouest du Golfe, principalement dans les ports de Baie-Comeau, Port-Cartier et Sept-Îles en raison de leur utilisation par des vraquiers pour l'exportation de minerai et de céréales. Cependant, on estime que 86,5% des eaux de lest étrangères déversées dans l'EGSL proviennent de l'Atlantique Nord-Ouest en raison d'un niveau apparemment élevé de conformité aux *Lignes directrices facultatives visant le contrôle du déchargement du lest liquide des navires* selon les rapports des officiers, tandis que seulement 13,5% proviennent des derniers ports visités. Ces ports sont principalement situés dans le nord-ouest, nord-est et centre-ouest de l'Atlantique de même que dans la mer Méditerranée, particulièrement aux environs des mers du Nord et Baltique et le long des côtes est et sud des États-Unis. À l'exception de la mer Baltique, toutes ces régions présentent des conditions environnementales généralement plus chaudes que celles prévalant dans l'EGSL, particulièrement dans le Nord du Golfe. On a identifié un total de 292 espèces phytoplanctoniques et 89 espèces zooplanctoniques dans les eaux de lest de 94 navires en provenance de l'étranger qui ont été échantillonnés, et un total de 65 espèces de protistes dans les sédiments prélevés dans les réservoirs de 8 de ces navires. Respectivement 60% et 57% des espèces phytoplanctoniques et zooplanctoniques observées dans les eaux de lest des navires constituent des espèces non indigènes qui sont absentes ou non encore rapportées dans l'EGSL, et l'abondance de certaines de ces espèces atteignait 100 000 cell.-ind.$\cdot$m^{-3}. Les échanges d'eau de lest en haute mer tels que prescrits par les Lignes directrices sont apparemment efficaces pour réduire le nombre d'espèces zooplanctoniques et leur abondance dans les réservoirs d'eau de lest. Cependant, des densités anormalement élevées d'organismes observées dans un certains nombre de navires ayant rapporté des échanges complets indiquent que ces échanges n'étaient en fait pas complets ou ont été effectués dans des régions inappropriées. Néanmoins, les observations suggèrent que les risques d'introduction d'espèces non indigènes par les déversements d'eau de lest dans l'EGSL ne semblent pas aussi élevés que dans d'autres régions du monde où des introductions reliées au transport d'eau de lest ont été documentées. Certaines régions du golfe du Saint-Laurent présentent des risques significatifs pour de telles introductions, particulièrement dans le sud du Golfe — principalement la baie des Chaleurs et le détroit de Northumberland — où les navires en provenance de l'étranger ne sont pas assujettis aux Lignes directrices et où des conditions environnementales plus chaudes prévalent en été et en automne. Bien que des études additionnelles soient requises afin de compléter cette évaluation, les résultats indiquent la nécessité de réévaluer et de mieux appliquer les directives actuelles visant des échanges en haute mer afin de mieux protéger l'environnement marin de l'estuaire et du golfe du Saint-Laurent. Des modifications aux directives actuelles sont proposées dans ce contexte, de même que l'utilisation potentielle de certaines caractéristiques des communautés présentes dans les eaux de lest afin de vérifier la conformité aux directives.

1.0 INTRODUCTION

Ballast water taken on by vessels for stability has been identified as an important vector for the transfer of exotic species worldwide (Medcof 1975, Carlton 1985, Williams et al. 1988, Carlton and Geller 1993, Hallegraeff 1995). If the ballast water is taken in a shallow port in very turbid waters, sediments and associated organisms as well as those suspended in the water column may be transferred into the ballast tanks. The discharge of ballast water in subsequent ports of call has sometimes resulted in the introduction of non-native species, some with major ecological and economic consequences with respect to human health, fishing, and aquaculture activities (see review in Carlton 1985). As total water ballast tonnage can range from a few hundred to over 100,000 tonnes (t), considerable amounts of water and accompanying viable organisms are being rapidly transported worldwide on a continuous basis (Gauthier and Steel 1996).

The estuary and Gulf of St. Lawrence together form the marine part of the Great Lakes–St. Lawrence drainage basin, which is the thirteenth largest in the world. The current St. Lawrence Seaway system, opened in 1959, provides a navigational link between the Great Lakes and the Atlantic Ocean through a series of locks and canals that allow ships to proceed up as fas as the western tip of Lake Superior, 3,770 km from the Atlantic Ocean. As a result, more than 2,000 foreign vessels per year enter the St. Lawrence system towards numerous ports of the estuary and Gulf, the St. Lawrence River, and the Great Lakes (Bourgeois et al., in prep.).

At present, the only Canadian regulation on nonindigenous species introductions through ballast water in the St. Lawrence is provided by the *Voluntary Guidelines for the Control of Ballast Water Discharges from Ships proceeding to the St. Lawrence River and Great Lakes* (Appendix 1), hereafter called Great Lakes Ballast Water Control Guidelines (GLBWCG). These guidelines were established by the Canadian Coast Guard in 1989, in collaboration with the United States Coast Guard, the Great Lakes Fishery Commission, and representatives of the commercial shipping industry. They apply to all vessels transiting the ECAREG–VTS (Eastern Canada Region – Vessel Traffic Service) zone and proceeding up the St. Lawrence Seaway to ports west of 63° W longitude (Figure 1). All vessels that are subjected to the GLBWCG are requested to conduct ballast water exchanges offshore in the Atlantic Ocean, where depths exceed 2,000 m, before entering the Gulf of St. Lawrence. The primary objective in exchanging ballast water for open ocean water is to reduce the risk of further introductions of freshwater species into the Great Lakes, which have previously been invaded by nonindigenous species including the European zebra mussel (*Dreissena polymorpha*), the spiny water flea (*Bythotrephes cederstroemi*), and the round goby (*Neogobius melanostomus*). If ballast water exchanges in the Atlantic Ocean are not feasible due to safety concerns such as weather conditions and ship stability, foreign ships are allowed to conduct these exchanges in a "backup exchange zone" within the Gulf of St. Lawrence, to the east of 63° W longitude and where depths exceed 300 m. Compliance with the GLBWCG in the Estuary and Gulf of St. Lawrence is first reported to ECAREG–VTS when foreign vessels enter Canadian waters. Compliance monitoring is also carried out through a Ballast Water Exchange Report Form that is provided to foreign ships when they pick up a pilot at Les Escoumins before proceeding up the seaway. These forms are to be carefully completed by the ship's master and given to responsible authorities, either at lock # 1 in St. Lambert, Québec, for

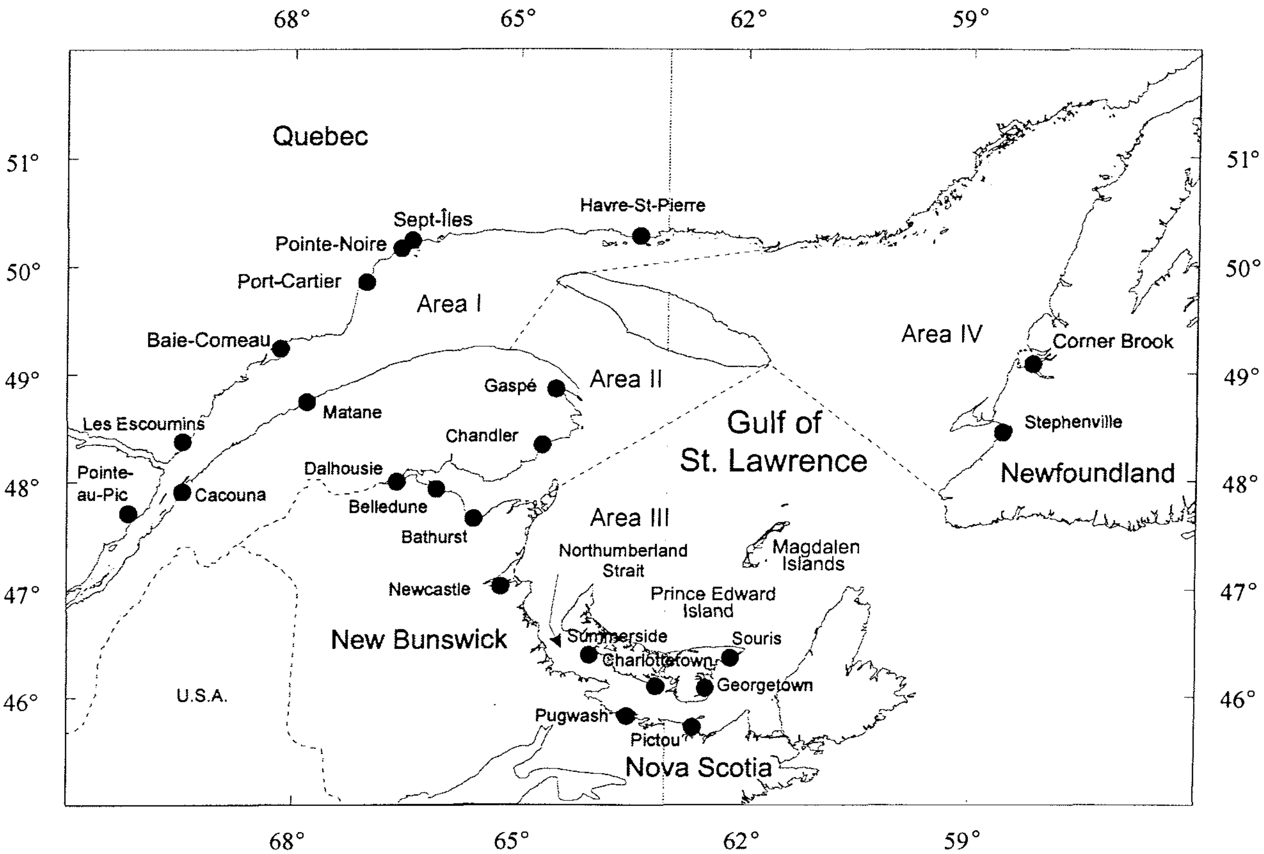


Figure 1. Major ports of the estuary and Gulf of St. Lawrence that receive foreign maritime traffic. See section 2.1 for geographical subdivisions. The 63° W eastern limit of the area covered by the GLBWCG is indicated by a dotted line.

ships proceeding up to the Great Lakes, in destination ports, or by mail. Further monitoring may also be carried out by means of ballast water sampling.

Although these guidelines provide some protection for the freshwaters of the Great Lakes and the St. Lawrence River, they may not be adequate to reduce the risk for ballast water–mediated introductions of marine organisms into the Estuary and Gulf of St. Lawrence (EGSL). Foreign vessels that enter ports of the Gulf located east of 63° W are not subjected to the GLBWCG. In addition, the guidelines do not make provisions for compliance monitoring in foreign ships that are bound for ports located within the Estuary and Gulf east of Les Escoumins, including the major ports of Baie-Comeau, Port-Cartier, and Sept-Îles. In fact, the guidelines may increase the potential for ballast water–mediated introductions of nonindigenous species in the Gulf because they allow and even support backup exchanges in this region. Thus, the risks for such introductions must be assessed to evaluate the pertinence of current guidelines from an Estuary and Gulf perspective and, ultimately, to provide scientific advice for the management of ballast water practices in this marine ecosystem.

In this context, the present study aims at providing a preliminary assessment of the risk for the introduction of nonindigenous marine species in the EGSL by commercial maritime shipping activities through the characterization of 1) the foreign vessel traffic in the EGSL, 2) ballasting operations of foreign vessels bound for selected ports in the EGSL, and 3) the biodiversity and abundance of protistan and metazoan taxa found in water and sediment of ballast tanks in foreign vessels at selected ports of the EGSL.

2.0 METHODS

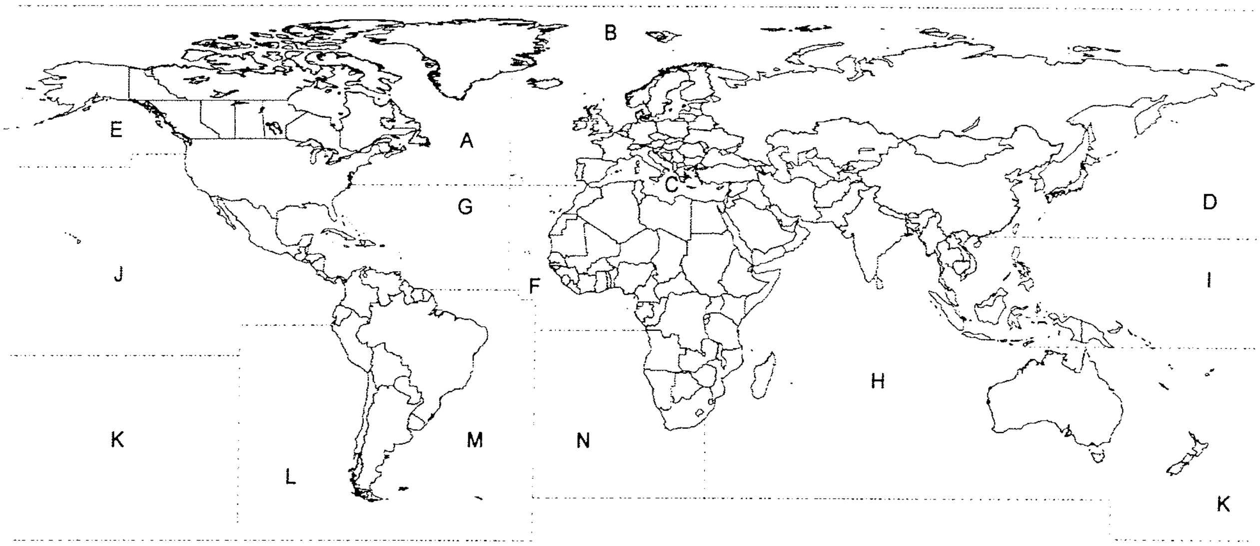
2.1 Vessel traffic in the Estuary and Gulf of St. Lawrence

The analysis of the maritime traffic was made using information supplied by the Eastern Canada Region – Vessel Traffic Services (ECAREG–VTS) database of the Canadian Coast Guard. This database was analyzed to obtain information on 1) the vessel name; 2) the vessel type, such as bulk carriers, general cargo carriers, tankers, and container carriers; 3) the vessel's Gross Register Tonnage (GRT); 4) the name of the last country visited; 5) the ballast condition — in ballast or in cargo; 6) the destination port in the EGSL, and 7) the expected date of arrival at the destination port. Only foreign vessels bound for ports in the EGSL in the 1995 shipping season were considered in this study.

These vessels were first classified by destination port and ballast condition before being regrouped into four geographic areas corresponding to: 1) the estuary and northwestern Gulf area (Area I), 2) the Gaspé – Chaleur Bay area (Area II), 3) the southern Gulf area (Area III), and 4) the northeastern Gulf area (Area IV) (Figure 1). These areas were defined according to the geographical distribution of international ports in the Estuary and Gulf, and are more or less representative of oceanographic subdivisions of the region. Vessels were further categorized by vessel type and season: winter (January-March), spring (April-June), summer (July-September), and fall (October-December). Finally, the vessels having visited at least one port in the EGSL in 1995 were classified by the country of their last port of call. The latter variable was then converted to the standardized ocean region of the world as used by the United Nations' Food and Agriculture Organization (FAO; Figure 2, to determine the general transport routes between the Estuary and Gulf and other regions of the world.

2.2 Vessel ballasting operations

A remote survey consisting of a one-page ballast questionnaire (Appendix 2) to be completed by ships' officers was carried out in the nine most active ports of the EGSL, namely: Sept-Îles, Pointe-Noire, Port-Cartier, Baie-Comeau, Gaspé, Dalhousie, Stephenville, Cornerbrook, and Charlottetown. These ports were selected according to the ECAREG–VTS database for the 1993 shipping season, which showed that these nine ports represented the destination of about 83% of the foreign vessels bound for the EGSL (Reid 1995a). The survey was carried out from 1 February 1995 to 31 January 1996 with the assistance of the vessel agents in each selected port. A total of 140 questionnaires were completed by ships' officers and returned. Given that this survey was conducted as a remote survey with the voluntary assistance from shipping industry personnel, the return rate could not be calculated since there was no record kept of how many vessels were supplied with questionnaires.



A = Northwest Atlantic
B = Northeast Atlantic
C = Mediterranean and Black Sea
D = Northwest Pacific
E = Northeastern Pacific
F = Eastern Central Atlantic
G = Western Central Atlantic
H = Indian Ocean
I = Western Central Pacific
J = Eastern Central Pacific
K = Southwest Pacific
L = Southeast Pacific
M = Southwest Atlantic
N = Southeast Atlantic

Figure 2. Standardized ocean regions of the world as used by the United Nations' Food and Agriculture Organization (FAO).

The questionnaire covered information concerning both the vessel traffic in the EGSL, such as vessel name, type, GRT, last port and country of call, present port of call, and date of arrival at this port, as well as information on the vessel ballasting operations, ballast tank and cargo hold capacity, quantity of ballast carried on arrival, quantity of ballast discharged in the Gulf before arrival, and quantity of ballast to be discharged in port before departure. Moreover, other information concerning the source of ballast water carried on arrival and the proportion of ballast exchanged *en route* in mid-ocean or in the Gulf of St. Lawrence was also gathered in this survey. The latter information was further used to calculate quantities (t) of ballast water originating from the previous ports of call, which was calculated as:

$$QPPOC = QARR - (QARR \times PE) \tag{1}$$

where $QPPOC$ = quantity of ballast water from previous ports of call; $QARR$ = quantity of ballast water carried at arrival at the present port of call; and PE = proportion of ballast water exchanged in mid-ocean or in the Gulf of St. Lawrence. In doing so, it was assumed that ballast waters carried by a given ship upon departure from the last port of call were mostly made up of waters originating from its vicinity, and that minor amounts of residual ballast water from previous ballasting operations remained in ballast tanks.

Regressions relating 1) the ship's ballast capacity, 2) the quantity of ballast carried on arrival, 3) the quantity of ballast water to be discharged in port before departure, and 4) the quantity of ballast water to be discharged originating from the last port of call, onto the vessel's GRT were calculated for bulk carriers and general cargo ships to estimate the total budget of ballasting operations in the EGSL for 1995. Given that only 18 of the 140 ships from which questionnaires were received — 17 bulk carriers and 1 general cargo carrier — were reported in cargo condition, these regressions were calculated for all other vessels in that were in ballast condition. In all cases where a significant ($P \leq 0.05$) linear relationship was obtained between the GRT and any of the dependent variables mentioned above, the regression equation and the GRT of other vessel entries recorded in the ECAREG–VTS database in 1995 were used to extrapolate a foreign ballast water budget for the entire Estuary and Gulf. In cases where the regression was not significant as well as for tanker ships and ships in cargo, the mean value of the above variables were used in the extrapolation.

2.3 Biodiversity and species richness in ballast water and ballast sediment

A survey consisting of a two-page ballast questionnaire, completed during on-board interviews with ships' officers, and a ballast water and sediment sampling program was carried out in four selected ports in the EGSL: Baie-Comeau, Port-Cartier, Sept-Îles, and Gaspé, from 20 July to 9 December 1995. In 1993, the ports of Baie-Comeau, Port-Cartier, and Sept-Îles received about 75% of the international commercial bulk vessel traffic in the EGSL; Baie-Comeau was also active in general cargo vessel traffic, and Gaspé was active in international tanker traffic (Reid 1995a). A schedule of planned boardings based upon vessel type and region of origin, derived from ECAREG–VTS data for 1993 (Reid 1995a), was used as a guide in targeting vessels to be boarded. Vessels were boarded shortly after their arrival at dock. A total of 94 vessels, comprising 89 bulk carriers, one general cargo carrier, and four tankers, were boarded during the survey, 45 in summer and 49 in fall. These vessels originated from FAO regions A, B, C, and G (Figure 2) and were sampled for phytoplankton and zooplankton in ballast water. In addition, sediments were sampled in recently deballasted cargo holds of eight vessels and in the upper wing tank of one vessel; six of these samples were collected in summer and three in fall, and eight vessels sampled originated from FAO region B and one from FAO region C.

Ballast questionnaires were filled using the information provided by ship officers and included information on ship characteristics, origins and destinations, departure and arrival dates, and detailed ballast operations (capacity, amount carried on arrival, amount discharged before docking and to be discharged in port, ballast water exchange information — extent, location, and date — and original ballast water source). In many cases, the reported extent of exchanges (in percent) was less than 100% while the information provided on ballasting operations suggested complete offshore exchanges. For these ships, it was assumed that the reported extent of exchanges was a broad approximation that took into account the amount of umpumpable ballast water and, as a result, that complete exchanges had been performed.

2.3.1 Ballast water sampling program

Two separate sets of sampling equipment (i.e. nets, tow lines, bottles; to avoid cross-contamination between ballast tanks and/or holds) were used to collect one or two sets of samples from one or two ballasted cargo holds or ballast tanks (Reid 1995b). Plankton nets had 30 cm diameter openings with mesh sizes varying from 45 to 110 μm; 75% of the samples were collected with 80 μm mesh nets. Water depth in the tanks was determined by weighted sounding tape. Vertical tows were made from approximately 1 m off the bottom of the tank/hold, to prevent the resuspension of bottom sediments; towing depth was often less than 1 m in ballast tanks but reached 20 m in cargo holds. Typically one to four quantitative vertical tows and one to three qualitative tows were carried out in each accessible ballasted cargo hold and ballast tank of each vessel. Quantitative tows consisted of one vertical tow from 1 m off the bottom to the surface. For qualitative tows in ballast tanks, the plankton nets were repeatedly raised and lowered until a minimum of approximately 10 m of depth was filtered, or until the same water column had been filtered a maximum of five times. For qualitative tows in cargo holds, where water depth exceeded 10 m, single vertical tows in the same location as the quantitative tow were conducted. In cargo holds with open hatches, four quantitative tows could be obtained from different locations. In all cases, nets were towed at about 0.5 $m \cdot s^{-1}$ and samples were placed in marked 250 mL collection sample jars and fixed in 10% buffered formalin immediately upon departure from the vessel.

In the laboratory, one to four days after fixing, the samples were filtered through 53 μm sieves, back-washed into the same collection jars, and preserved in 70% alcohol for later identification and counting of phytoplanktonic cells and zooplanktonic organisms. Identification and counting of phytoplankton cells were made using the technique of Lund *et al.* (1958) while zooplankton samples were sorted under a dissecting microscope (20X) and all animals identified to the lowest possible taxonomic level. In the case of zooplankton, larger samples were subsampled using a Folsom splitter or a Stemple pipet.

Only quantitative tows were considered in the data analysis. The density, expressed in individuals$\cdot m^{-3}$, of each zooplankton species and/or taxon found in each ballast tank and/or hold were added to obtain: 1) the total density of each zooplankton species and/or taxon in each vessel; and 2) the total density of the whole zooplankton community in each vessel. The same calculations were made for the total density of copepods—the most common organisms—as well as for the total number of zooplankton taxa and the total number of copepod taxa. These variables were considered as dependent variables in subsequent statistical analyses. The mean values of dependent variables were compared for summer and fall using a Student's *t*-test on $\log_{(10)}$ - transformed data. Based on the results of these tests (Appendix 3), data were regrouped and regressions were calculated that related each dependent variable to 1) the GRT, 2) the quantity of ballast water carried at arrival by each vessel, and 3) the transit time, *i.e.*, the time elapsed between the departure date from the last port of call to the arrival date at the current port of call.

The number of species and total density of zooplankton and copepods found in ballast water were also used to determine the effectiveness of open-ocean exchanges in reducing risks for ballast water–mediated introductions of nonindigenous marine organisms in the EGSL. This was done by examining the relation between these variables and the extent of ballast water exchanges offshore in the Atlantic Ocean, assuming that zooplanktonic communities would be richer in ballast water originating from shallow inshore areas of the previous ports of call than from deep offshore areas where ballast water exchanges are to be conducted. First, the proportion of ballast water originating from the previous ports of call was calculated for 23 vessels sampled that had reported incomplete exchanges of their ballast water in mid-ocean, using the following equation:

$$PPPOC = \frac{QPPOC}{QARR} \qquad (2)$$

where $PPPOC$ = proportion of ballast water originating from the previous ports of call, $QPPOC$ = quantity of ballast water originating from the previous ports of call as calculated in equation (1), and $QARR$ = quantity of ballast water carried upon arrival at the present port of call. Second, the relationship between the density and total number of zooplankton and copepod taxa found in these 23 ships and the proportion of their ballast waters originating from the previous ports of call ($PPPOC$) was examined to determine the effects of the varying extent of offshore exchange on the zooplanktonic community.

The total density of phytoplankton cells found in each vessel was also calculated, but although the samples were collected quantitatively, many phytoplankton cells were undersampled by the 80 μm mesh net that was used. Thus, all phytoplankton samples were treated as semi-quantitative: species were separated into six categories from very rare to very abundant based upon the estimated density of phytoplankton cells per vessel. No other statistical test was carried out with this data matrix.

2.3.2 Ballast sediment sampling program

Sediment samples were collected from recently deballasted cargo holds except in one case, where they were collected in an upper wing tank. Approximately 10 mL of sediment were collected with a tablespoon throughout the depth of the sediment layer, which ranged in depth from near 0 cm to about 2 cm. Two sediment samples were collected in each case: one sample was preserved in 10% buffered formalin, the other was wrapped in aluminum foil to ensure a dark environment and kept refrigerated. The second sampling procedure aimed at minimizing the excystment of dinoflagellate cysts while keeping them alive for later germination and identification. Identification and counting of protistan and metazoan taxa present in the formalin-treated sediment samples were made using the technique proposed by Anderson and Wall (1978). The diameter of the material examined was between 15 and 70 μm. The refrigerated sediment samples were used for cyst germination experiments. Potentially viable dinoflagellate cysts were isolated using the method described in Matsuoka *et al.* (1989) and washed five times in a sterile culture medium. The medium consisted of filtered seawater (ca. 27 salinity) autoclaved in Teflon containers, with nutrients added according to the *f*-2 medium of Guillard and Ryther (1962). Cysts were placed individually into the wells of a tissue culture plate (Falcon # 3078) that had been previously filled with 0.5 mL of medium. The cysts were incubated at 15 ± 1 °C (14:10 h light:dark) at an irradiance of 180 μmol photons$\cdot$m$^{-2}\cdot$s^{-1} and were examined for germination after two or three weeks.

3.0 RESULTS

3.1 Vessel traffic in the Estuary and Gulf of St. Lawrence

A total of 709 foreign vessels visited 23 ports in the Estuary and Gulf of St. Lawrence in 1995 (Figure 3). The majority of the vessels (66%) were bound for ports of Area I, mainly Port-Cartier (185 ships), Sept-Îles (132 ships), and Baie-Comeau (105 ships). Eighty percent of vessels arriving at these three ports were in ballast. Other areas of importance for the foreign maritime traffic in the Gulf are Chaleur Bay (100 ships), Northumberland Strait (55 ships), and the west coast of Newfoundland (73 ships). Respectively 49%, 80%, and 59% of vessels bound for these areas were in ballast (Figure 3).

The vessel traffic was dominated by bulk carriers in Area I and by general cargo carriers in Areas II, III, and IV (Figure 4). Respectively 24% and 27% of ships bound for Areas II and III were tankers. The vessel traffic in most areas varies little between seasons (Figure 5) except in the southern Gulf, where the maritime traffic was less intense in winter and spring than in summer and fall.

The foreign vessel traffic in the EGSL in 1995 originated from 49 countries from 11 FAO regions (Figure 6). The majority of foreign ships came from four FAO regions: the northwest and

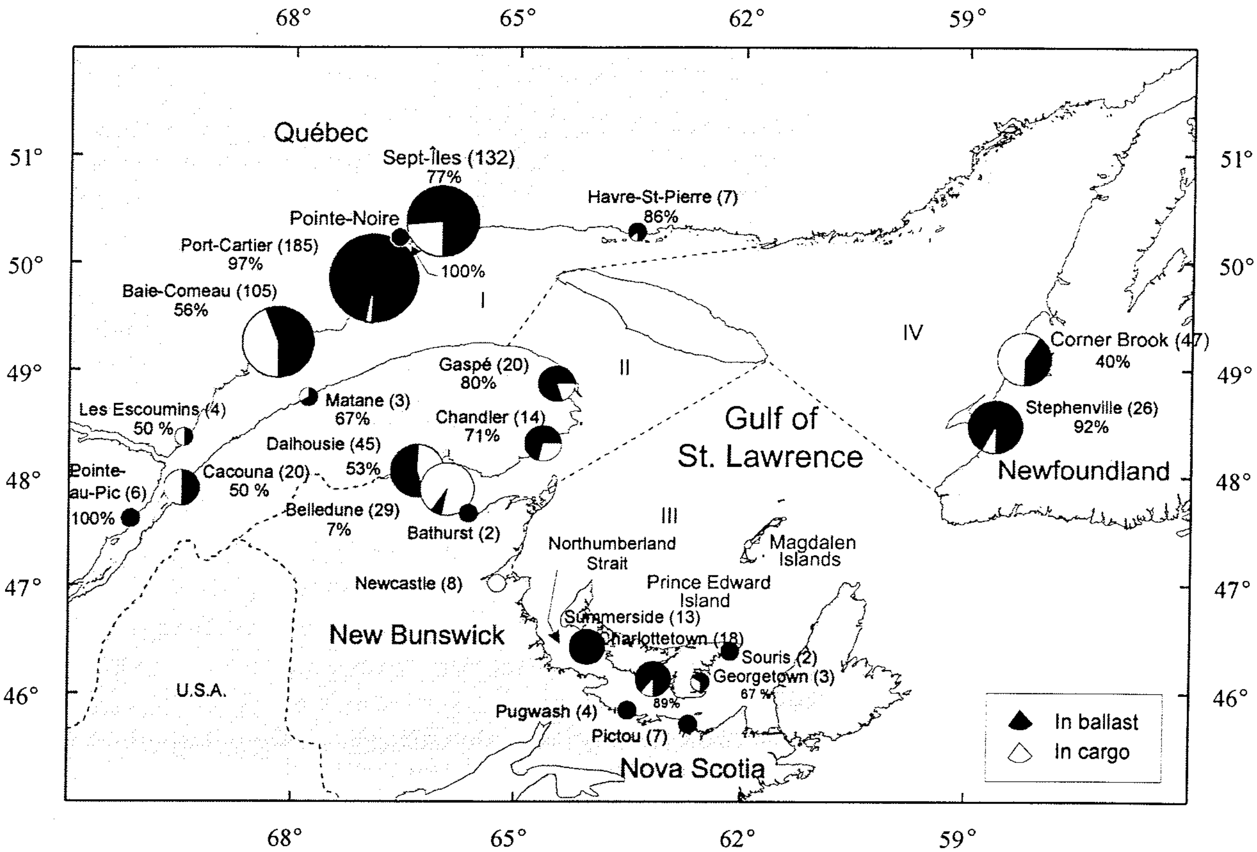


Figure 3. Vessel arrivals of foreign origin in ports of the Estuary and Gulf of St. Lawrence in 1995 from ECAREG–VTS data. The total number of arrivals for each port is given in parentheses. Percentages indicate the proportion of ships arriving in ballast.

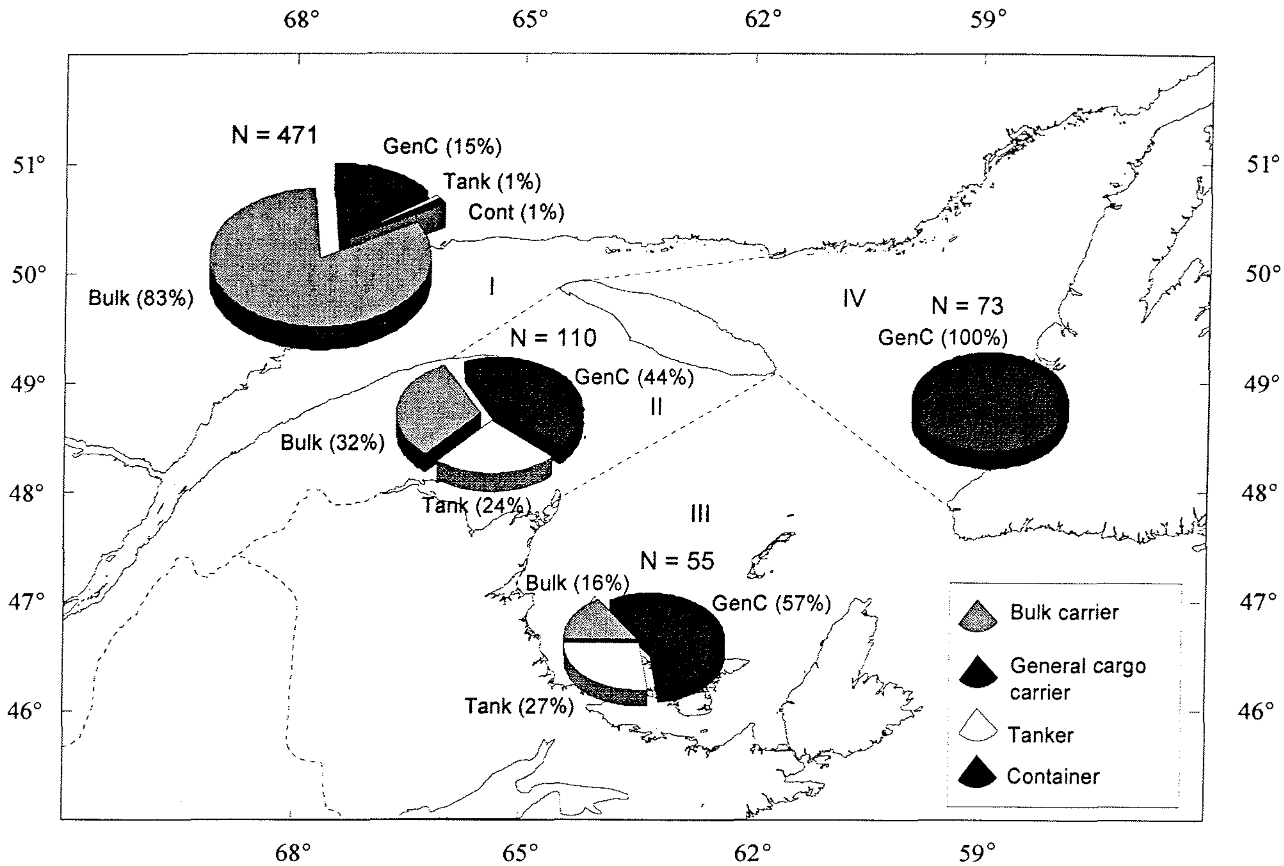


Figure 4. Relative importance, in percentage of numbers of vessels, of the types of vessels bound for the four major areas of activity in the Estuary and Gulf of St. Lawrence.

western central Atlantic (FAO regions A and G respectively; mainly the east coast of the USA), the northeast Atlantic (FAO region B; mainly the North Sea), and the Mediterranean and Black seas (FAO region C). Other FAO regions were only minor contributors to the EGSL shipping traffic in 1995. The breakdown of the vessel traffic in the four areas of activity in the EGSL based on vessel origin is given in Figure 7. This figure shows that about 70% of ships arriving in ports of the estuary and northwestern Gulf (Region I) come from the North Atlantic, mainly FAO region B (northeast Atlantic). In other areas of the Gulf, ships originating from the North Atlantic (A and B) also predominate, but ships from the western central Atlantic region (G) are of greater importance than in the estuary and northwestern Gulf (Figure 7).

3.2 Ballasting operations of foreign vessels

All ballast water parameters of foreign ships were highly correlated to the GRT. Most linear regressions relating the GRT of bulk and general cargo carriers to 1) the vessel ballast water capacity, 2) the ballast water carried at arrival, 3) the total ballast water to be discharged in port, and 4) the total ballast water originating from the last port of call were significant ($P \leq 0.05$) except for the total ballast water originating from the last port of call in general cargo carriers (Figure 8). Using the GRT of ships of foreign origin, these regressions were used to estimate the total ballast water budget for all the maritime traffic in the EGSL during 1995.

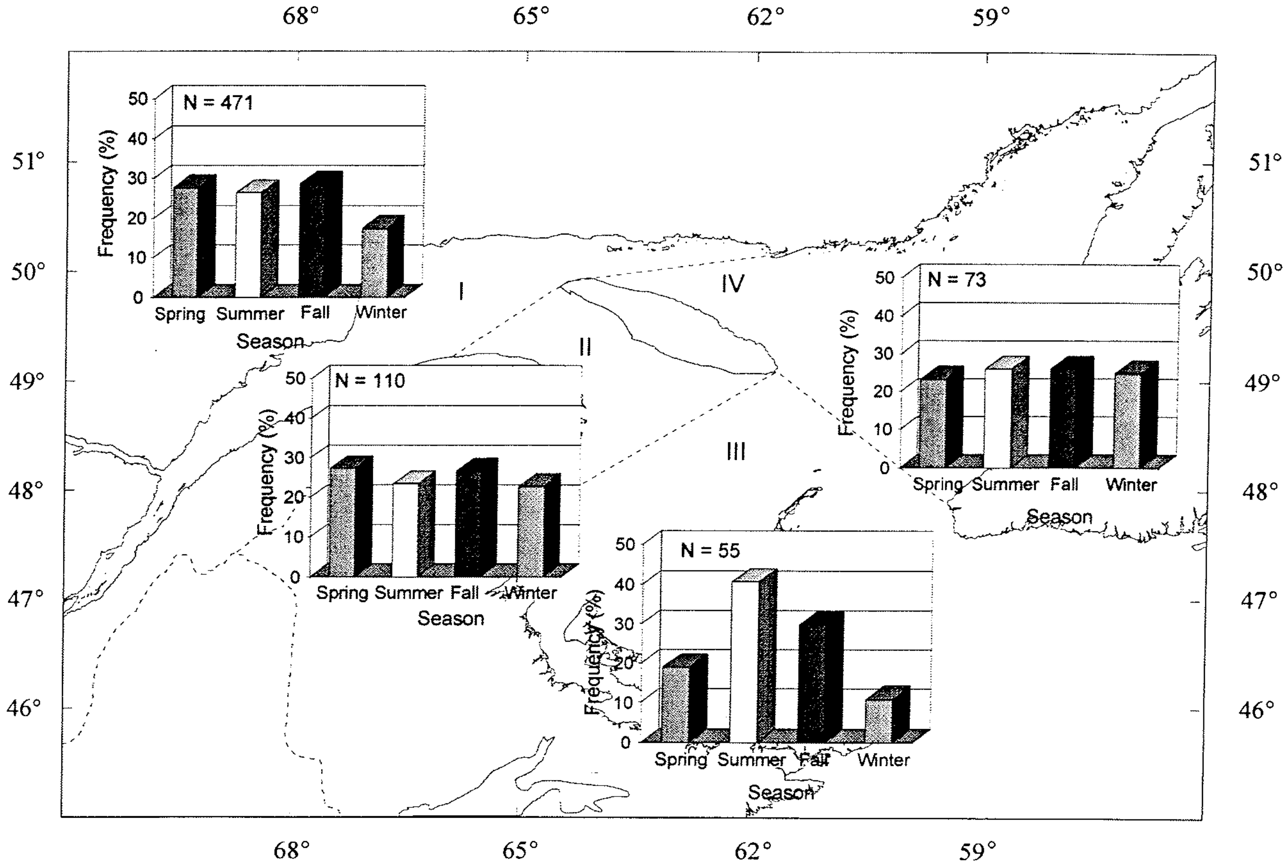


Figure 5. Seasonal variations in the foreign maritime traffic in each of the four areas of activity in the Estuary and Gulf of St. Lawrence.

For the entire EGSL area in 1995, the combined ballast water capacity of the incoming foreign maritime traffic reached 18 million t (Table 1). Over 89% of this volume (16,043,576 t) was associated with bulk carriers bound for ports in the estuary and northwestern Gulf (Area I). There were no important seasonal variations in the estimated combined ballast water capacity of the foreign maritime traffic in any area of the Gulf except for a slight decrease in winter for Area I and a three-fold increase in summer in Area III. The total volume of ballast water carried on arrival was estimated to reach 12 million t for the entire Estuary and Gulf ecosystem (Table 2). Again, over 95% of this volume (ca 11.6 million t) came from bulk carriers bound for ports in Area I. General cargo carriers and tankers contributed only 4% of the total ballast water carried on arrival in the entire EGSL.

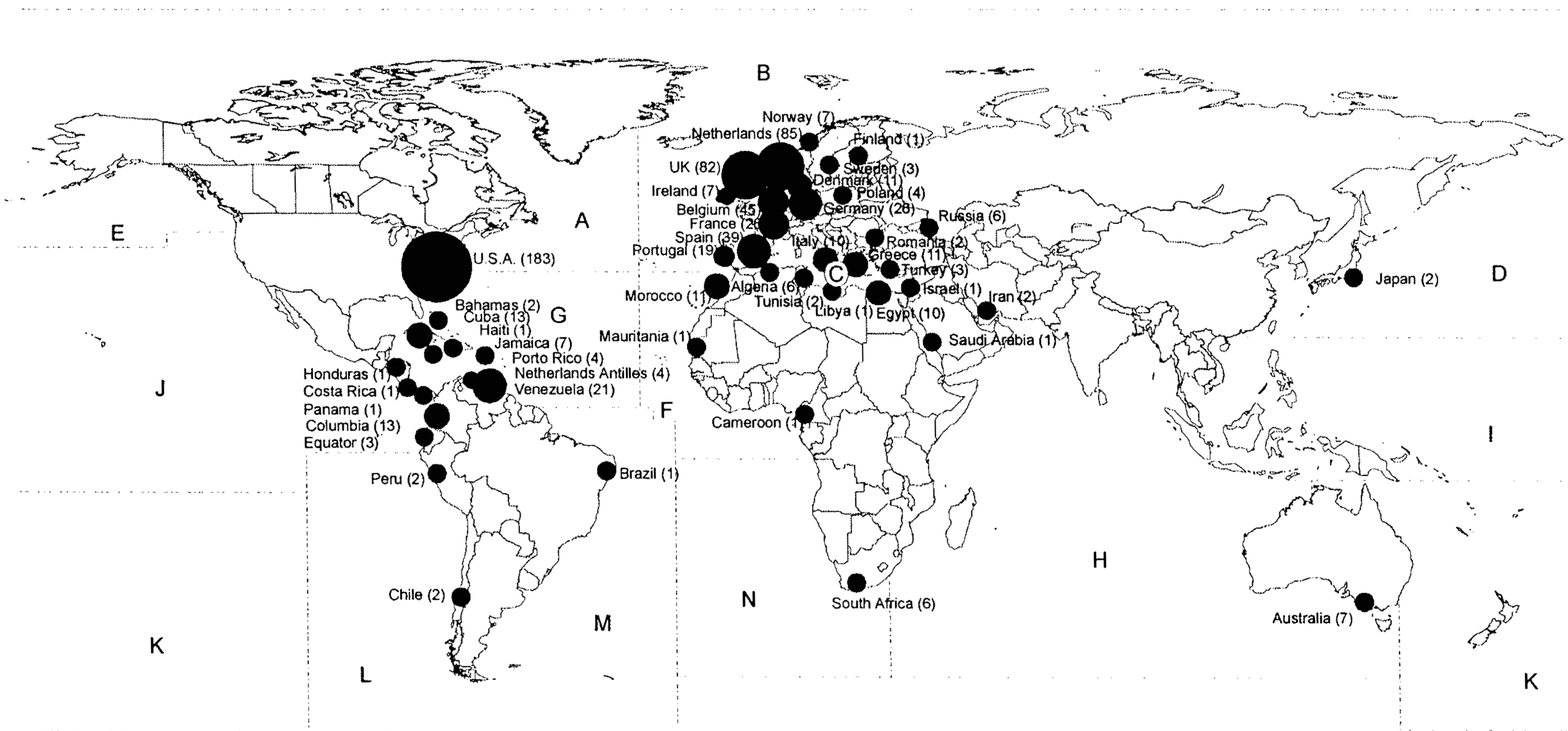


Figure 6. FAO standardized ocean regions, country of origin, and number (in parentheses) of vessels having visited ports of the Estuary and Gulf of St. Lawrence in 1995.

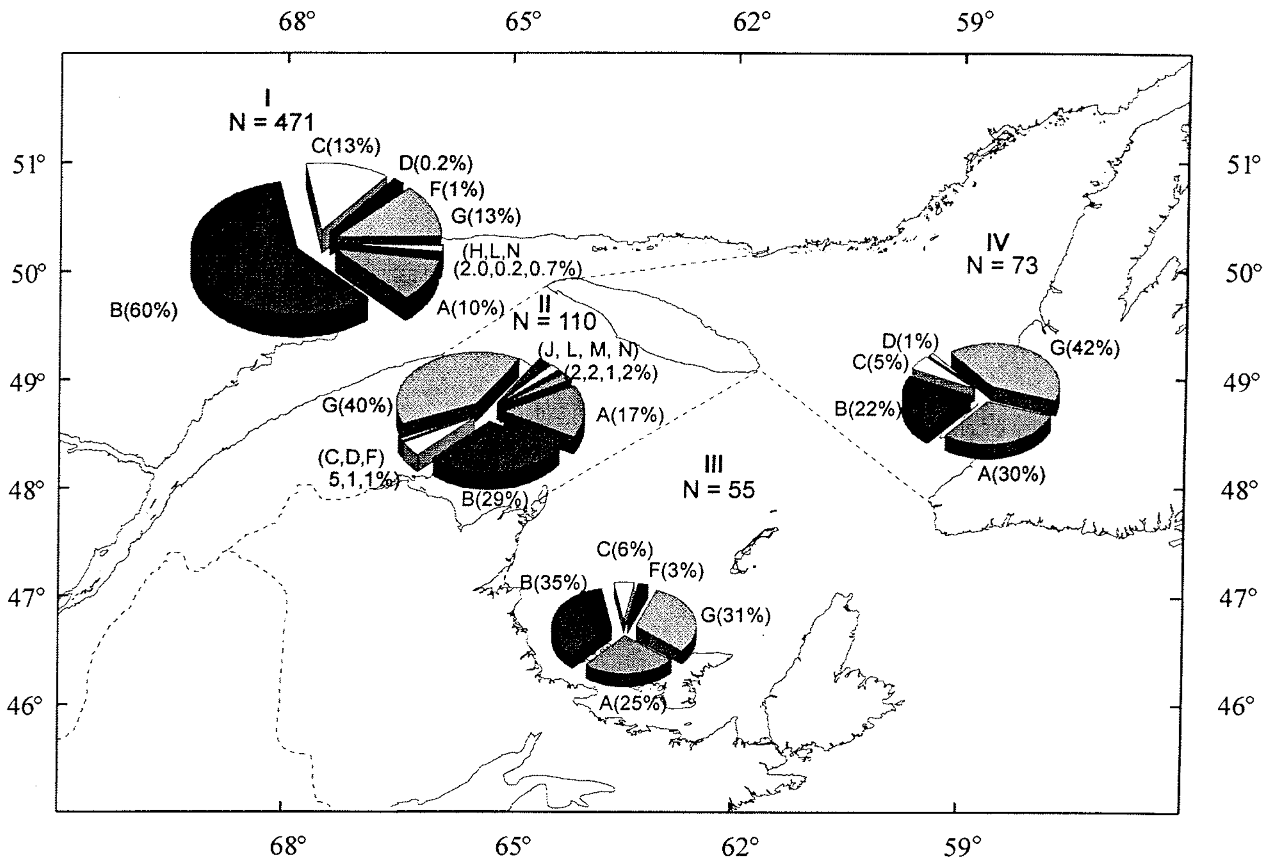


Figure 7. FAO standardized ocean regions of origin (in percentage) of vessels bound for the four major areas of activity in the Estuary and Gulf of St. Lawrence in 1995. See Figure 2 for FAO Regions.

Most of the ballast water transported by incoming ships of foreign origin was to be discharged upon arrival in ports of the EGSL in 1995 (Table 3). About 11,772,829 m^3 of the 12,280,839 m^3 of ballast water transported by these ships were estimated to be discharged in ports of the EGSL in 1995. Over 97% of this water was discharged from ballast tanks and/or cargo holds of bulk carriers in ports of Area I (Table 3). In general, bulk carriers discharged most of their ballast water while general cargo carriers discharged less than 50 % of the ballast water carried on arrival.

Because of a high level of compliance to the GLBWCG, only 13.5% (1,588,170 t) of the ballast water discharged in the entire Estuary and Gulf is estimated to have originated from previous ports of call (Table 4). Over 90% of this volume was contained in bulk carriers bound for ports of the Estuary and northwestern Gulf (Area I). Areas II, III and IV together received only 9% of the ballast water originating from the previous ports of call that was discharged in ports of the EGSL in 1995.

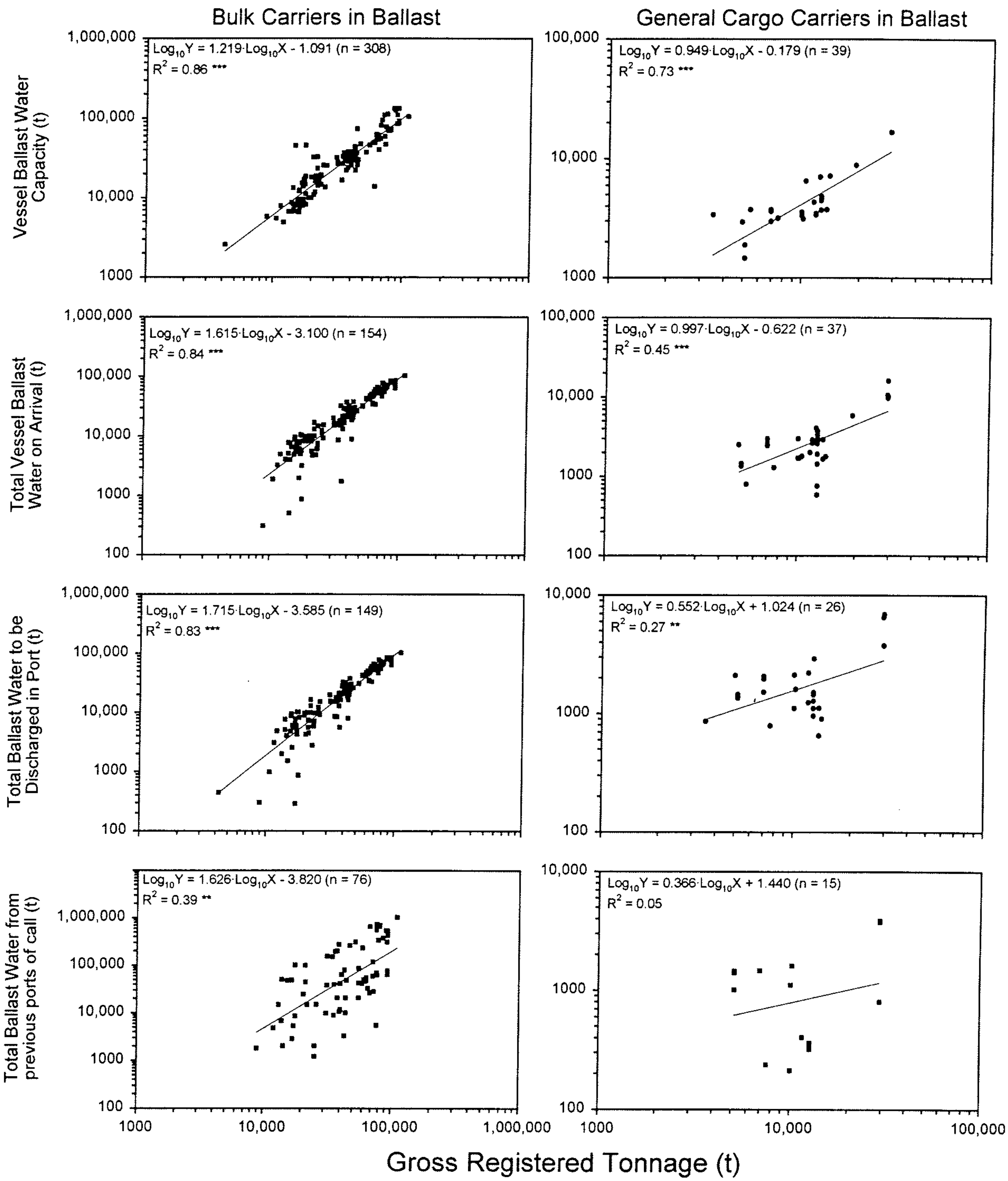


Figure 8. Linear regressions between total ballast water capacity (in tonnes), total ballast water carried on arrival, total ballast water to be discharged in port, and total ballast water from the last port of call regressed onto the gross registered tonnage of in ballast bulk and general cargo carriers surveyed. Variables were log10-transformed prior to analysis (** $P < 0.01$; *** $P < 0.001$; ns = not significant).

Table 1. Total ballast water capacity (in tonnes) per vessel type (Bulk: bulk carrier; Tank: tanker; GenC: general cargo carrier), season, and area (see Figure 1) of the Estuary and Gulf of St. Lawrence, estimated from 1995 ECAREG–VTS data.

Area	Vessel type	Spring	Summer	Fall	Winter	Total
I	Bulk	4,034,093	4,418,334	4,696,936	2,894,213	16,043,576
	GenC	88,774	76,721	86,641	76,868	329,004
	Tank	4,554	9,108	4,554	9,615	27,831
	All	**4,127,420**	**4,504,163**	**4,788,131**	**2,980,696**	**16,400,411**
II	Bulk	227,417	182,376	153,378	165,682	728,853
	GenC	48,808	33,045	61,587	36,459	179,899
	Tank	67,305	76,920	86,535	67,305	298,065
	All	**343,530**	**292,341**	**301,500**	**269,445**	**1,206,817**
III	Bulk	9,839	18,366	0	0	28,205
	GenC	6,466	20,724	22,998	8,647	58,835
	Tank	9,615	48,075	9,615	19,230	86,535
	All	**25,920**	**87,165**	**32,613**	**27,877**	**173,575**
IV	Bulk	0	0	0	0	0
	GenC	67,351	72,419	64,898	65,464	270,132
	Tank	0	0	0	0	0
	All	**67,351**	**72,419**	**64,898**	**65,464**	**270,132**
EGSL	**All**	**4,564,221**	**4,956,089**	**5,187,142**	**3,343,482**	**18,050,935**

Table 2. Total ballast water (in tonnes) carried on arrival at the present port of call, per vessel type (Bulk: bulk carrier; Tank: tanker; GenC: general cargo carrier), season, and area (see Figure 1) of the Estuary and Gulf of St. Lawrence calculated from 1995 ECAREG–VTS data.

Area	Vessel type	Spring	Summer	Fall	Winter	Total
I	Bulk	2,857,756	3,288,031	3,348,574	2,155,838	11,650,200
	GenC	45,259	31,925	30,551	28,590	136,325
	Tank	580	1,160	580	580	2,900
	Total	**2 ,903,595**	**3,321,116**	**3,379,705**	**2,185,008**	**11,789,424**
II	Bulk	52,216	35,854	25,541	34,717	148,328
	GenC	21,014	17,434	38,433	20,318	97,199
	Tank	11,572	11,572	11,572	11,012	45,728
	Total	**84,802**	**64,861**	**75,546**	**66,046**	**291,256**
III	Bulk	6,603	12,699	0	0	19,302
	GenC	5,125	17,387	18,728	7,211	48,452
	Tank	560	3,733	0	560	4,853
	Total	**12,288**	**33,819**	**18,728**	**7,771**	**72,607**
IV	Bulk	0	0	0	0	0
	GenC	30,101	31,130	31,492	34,830	127,553
	Tank	0	0	0	0	0
	Total	**30,101**	**31,130**	**31,492**	**34,830**	**127,553**
EGSL	**Total**	**3,030,787**	**3,450,926**	**3,505,471**	**2,293,656**	**12,280,839**

Table 3. Total ballast water (in tonnes) to be discharged in port before departure per vessel type (Bulk: bulk carrier; Tank: tanker; GenC: general cargo carrier), season, and area (see Figure 1) of the Estuary and Gulf of St. Lawrence calculated from 1995 ECAREG–VTS data.

Area	Vessel type	Spring	Summer	Fall	Winter	Total
I	Bulk	2,803,928	3,211,294	3,318,798	2,103,264	11,437,285
	GenC	18,345	7,666	8,492	11,200	45,703
	Tank	0	0	0	0	0
	Total	**2,822,274**	**3,218,960**	**3,327,290**	**2,114,464**	**11,482,988**
II	Bulk	41,116	27,340	16,460	31,817	116,733
	GenC	9,959	8,337	16,977	11,185	46,458
	Tank	8,856	8,856	8,856	8,856	35,424
	Total	**59,931**	**44,533**	**42,293**	**51,858**	**198,616**
III	Bulk	4,810	9,468	0	0	14,278
	GenC	2,713	6,579	9,261	3,455	22,008
	Tank	0	2,214	0	0	2,214
	Total	**7,523**	**18,261**	**9,261**	**3,455**	**38,500**
IV	Bulk	0	0	0	0	0
	GenC	8,444	14,055	14,997	15,228	52,725
	Tank	0	0	0	0	0
	Total	**8,444**	**14,055**	**14,997**	**15,228**	**52,725**
EGSL	**Total**	**2,898,172**	**3,295,810**	**3,393,842**	**2,185,005**	**11,772,829**

Table 4. Total ballast water (in tonnes) from the last port of call per vessel type (Bulk: bulk carrier; Tank: tanker; GenC: general cargo carrier), season, and area (see Figure 1) of the Estuary and Gulf of St. Lawrence calculated from 1995 ECAREG–VTS data.

Area	Vessel type	Spring	Summer	Fall	Winter	Total
I	Bulk	346,241	413,319	410,140	248,557	1,418,257
	GenC	6,090	6,090	6,090	3,654	21,924
	Tank	0	0	0	0	0
	Total	**352,331**	**419,409**	**416,230**	**252,211**	**1,440,181**
II	Bulk	20,981	16,098	4,875	4,875	46,829
	GenC	4,787	4,434	9,232	6,500	24,952
	Tank	4,428	6,642	6,642	4,428	22,140
	Total	**30,195**	**27,174**	**20,749**	**15,803**	**93,921**
III	Bulk	4,810	1,870	0	0	6,679
	GenC	2,977	6,579	2,378	1,399	13,334
	Tank	0	2,214	0	0	2,214
	Total	**7,787**	**10,662**	**2,378**	**1,399**	**22,227**
IV	Bulk	0	0	0	0	0
	GenC	4,265	10,068	8,081	9,427	31,841
	Tank	0	0	0	0	0
	Total	**4,265**	**10,068**	**8,081**	**9,427**	**31,841**
EGSL	**Total**	**394,578**	**467,314**	**447,438**	**278,840**	**1,588,170**

The ballast water originating from the last port of call that was discharged in ports of Area I in 1995 originated from six different FAO areas (Figure 9). More than 78% (1,123,341 t) of this water was from ports of the northeast Atlantic (FAO Area B) whereas 13% (187,224 t) was from ports of the Mediterranean and Black seas (FAO Area C). Other FAO areas (F, G, H, A) were only minor contributors. Likewise, Area II received water from seven FAO areas, with 42% (39,446 t) from ports of the northwest and west-central Atlantic (FAO areas A and G; mainly the east coast of the USA) and 33% from the northeast Atlantic (FAO Area B; mainly the North Sea). The relative contribution of ports in other FAO areas (C, D, J, L, N) to the total volume of ballast water discharged in Area II ports varied between 1 and 7%. Ballast waters from the last port of call that were discharged in ports of areas III and IV originated from five and four FAO areas respectively. Area III received 11,114 t and 7,557 t from FAO Area B and from the east coast of the USA (FAO areas A and G) respectively, whereas the inverse situation was true in Area IV, where more water originating from the east coast of the USA (FAO areas A and G) was discharged compared to those from the northeast Atlantic (FAO Area B), that is, 20,059 t versus 8,279 t respectively.

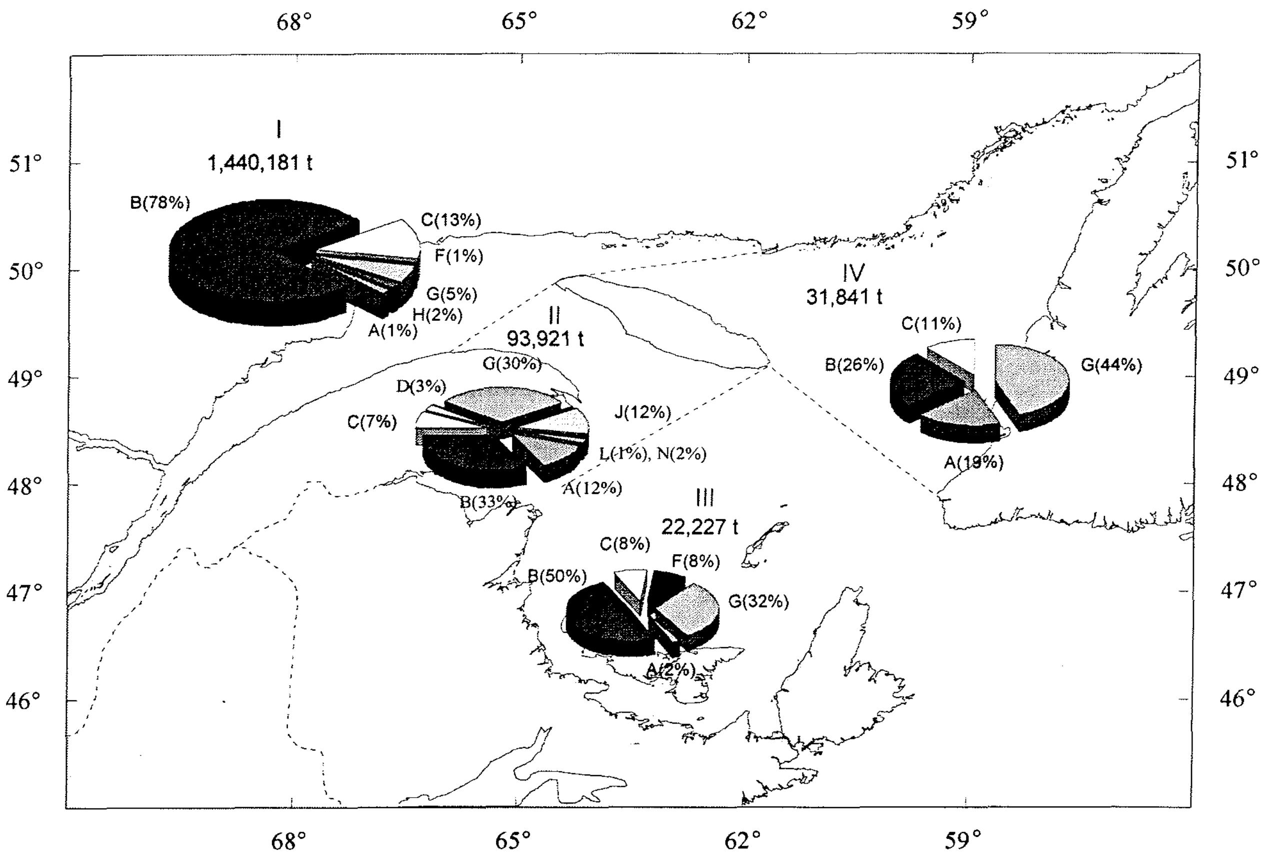


Figure 9. FAO area of origin (in percentage) of ballast water from the last port of call that were estimated to be discharged in each of the four major areas of maritime traffic in the Estuary and Gulf of St. Lawrence in 1995. See Figure 2 for the identification of the letters indicating the FAO areas.

3.3 Biodiversity and species richness in ballast water and ballast tank sediment

3.3.1 Phytoplankton

A total of 292 species of phytoplankton were recorded from the ballast water of the 94 vessels sampled in four ports of the EGSL in 1995 (Appendix 4). This species list comprises 115 centric and 72 pennate diatoms, 13 flagellates (1 cyanophyte, 9 chlorophytes, 3 chrysophytes), 49 dinoflagellates, and 43 tintinnids. Forty-three species (25 centric and 2 pennate diatoms, 10 dinoflagellates, and 6 tintinnids) were found in the ballast waters of 10 vessels or more. Of these 43 species, 4 were very rare (mean abundance < 100 cells·m^{-3}), 12 rare (101 to 1000 cells·m^{-3}), 16 uncommon (1,001 to 10,000 cells·m^{-3}), 9 common (10,001 to 100,000 cells·m^{-3}), 1 abundant (100,001 to 1,000,000 cells·m^{-3}), and 1 very abundant (> 1,000,000 cells·m^{-3}). Of the 249 species found in the ballast waters of 9 vessels or less, 1 species was very abundant and 3 were abundant; the others were either common (20 species), uncommon (22 species), rare (91 species), or very rare (112 species). The species with the highest frequency of occurrence in ships were the dinoflagellates *Ceratium fusus*, *C. tripos*, *C. macroceros*, *C. arcticum*, and *C. longipes*, and the most abundant species were the diatoms *Chaetoceros affinis*, *Chaetoceros constrictus*, *Chaetoceros diadema*, *Asterionellopsis glacialis*, *Licmophora* sp., and *Pseudonitzschia pungens* (Appendix 4).

According to the zoogeographic affiliation of the 292 species found, 97 species are endemic to the EGSL waters (35.9 and 31.9% of the centric and pennate diatoms, 30.6% of the dinoflagellates, and 25.6% of the tintinnids), 178 species have never been observed in the EGSL, and 17 were not identified to a taxonomic level that allowed the determination of their zoogeographic affiliation (Appendix 4). Species endemic to the EGSL were found in a mean number of seven vessels and 55% of them were very rare or rare. The most frequently observed species endemic to the EGSL were the dinoflagellates *Ceratium fusus*, *C. tripos*, *C. arcticum*, and *C. longipes* and the centric diatoms *Proboscia alata* fo. sp., *Rhizosolenia setigera*, *Chaetoceros decipiens*, and *Rhizosolenia imbricata*. On the other hand, species never recorded in the EGSL were found in a mean number of only four vessels and 86% of them were rare or very rare. However, among species never observed in the EGSL, 15 species were found in more than 10 vessels and they were either uncommon (*Actinocyclus normanii* fo. *normanii*, *Bacteriastrum delicatulum*, *Chaetoceros peruvianus*, *Ditylum brightwellii*, *Ceratium longirostrum*, *Protoperidinium divergens*, *Eutintinnus tubiformis*), rare (*Actinocyclus octonarius* fo. *crassus*, *Odontella sinensis*, *Ceratium extensum*, *C. furca*), or very rare (*Lithodesmium undulatum*, *Odontella mobiliensis*, *Planktoniella sol*, *Eutintinnus lusus-undae*). Finally, most of the phytoplanktonic species never observed in the EGSL have a cosmopolitan distribution and have been observed in the northeast Atlantic (FAO region B; mainly the North Sea), the Mediterranean Sea (FAO region C), and the northwest Atlantic (FAO region A; mainly the east coast of Canada and USA) in the past.

Of the 172 phytoplanktonic species never observed in the EGSL, 25 centric and 19 pennate diatoms, 2 dinoflagellates, and 5 tintinnids are known to be neritic or live in the littoral zone (Appendix 4). On the other hand, only 8 centric diatoms, 10 dinoflagellates, and 10 tintinnids are known to be oceanic. Moreover, of the 31 dinoflagellate species never observed in the EGSL, 13 (41.9%) are known to be both neritic and oceanic. Five centric diatoms (*Actinocyclus octonarius* vr. *crassus*, *Bacteriastrum hyalinum*, *Ditylum brightwellii*, *Lithodesmium undulatum*, *Odontella* *mobiliensis*) and two dinoflagellates (*Ceratium furca*, *Protoperidinium divergens*) known to be neritic were found in more than 10 vessels and were very rare (*L. undulatum*, *O. mobiliensis*), rare (*A. octonarius* vr. *crassus*, *C. furca*), or uncommon (*B. hyalinum*, *D. brightwellii*, *P. divergens*).

Of the 69 centric and the 40 pennate diatoms species never observed in the EGSL, 18 (26%) and 29 (73%) respectively are usually found in fresh and/or brackish water. Nevertheless, all these species were found in fewer than 5 vessels. Several of the 172 phytoplanktonic species never observed in the EGSL are usually found in warm waters. This is the case for 34.7% of the 69 centric diatoms, 10% of the 40 pennate diatoms, 83.3% of the 31 dinoflagellates, and 39.2% of the 28 tintinnids (Appendix 4).

Appendix 4 indicates that of the 292 species found in ballast waters, 11 centric diatoms, two chrysophytes, and two dinoflagellates are known to be harmful species, *i.e.*, species that are non-toxic to humans but harmful to fish and invertebrates by damaging or clogging their gills (Hallegraeff 1993). In addition, two pennate diatoms and two dinoflagellates are known to be toxic species, *i.e.*, species that produce potent toxins that can pass through the food chain to humans, causing a variety of gastrointestinal and neurological illnesses (Hallegraeff 1993). However, except for *Coscinodiscus wailesii*, all harmful and toxic species sampled in this study are endemic to the EGSL.

3.3.2 Zooplankton

3.3.2.1 Biodiversity and species richness of zooplankton found in ballast water

A total of 97 zooplankton taxa were found in the ballast water of the 94 vessels sampled in four ports of the EGSL in 1995 (Appendix 5). This list of species and taxa comprises 1 cnidarian, 1 nematode, 2 molluscs, 7 polychaetes, 3 brachiopods, 1 ostracod, 68 copepods (30 calanoids, 17 cyclopoids, and 21 harpacticoids), 1 cirripedid, 6 malacostracans, 1 chaetognath, 1 echinoderm, and 2 urochordates. Appendix 5 shows that 25 of the 97 taxa recorded were found in ballast water of at least 10 vessels. Of these 25 taxa, 6 were uncommon (mean abundance of 10 to 100 ind.$\cdot$m^{-3}), 15 common (100 to 1000 ind.$\cdot$m^{-3}), and 4 abundant (1000 to 5,000 ind.$\cdot$m^{-3}). Of the 72 taxa found in ballast waters of 9 vessels or fewer, 2 taxa were very abundant (> 5,000 ind.$\cdot$m^{-3}), 2 abundant, 8 common, 34 uncommon, and 26 rare (< 10 ind.$\cdot$m^{-3}). The most frequently observed species were the copepods *Oithona similis*, *Temora longicornis*, and *Microsetella norvegica* (Appendix 5).

According to the zoogeographic affiliation of the 97 taxa found in ballast water, 16 taxa are endemic to the EGSL waters, 25 have never been observed in the EGSL, and 56 were not identified to a taxonomic level permitting the determination of their zoogeographic affiliation (Appendix 5). Except for four species of copepods (*Clausocalanus furcatus*, *Corycaeus* sp., *Cyclopina littoralis*, *Euterpina acutifrons*) that were found in the ballast water of 10 vessels or more, most of the 25 taxa never recorded in the EGSL were from 5 vessels or fewer and were either uncommon or rare. Moreover, most of these taxa are endemic to the northeast Atlantic (FAO Area B; mainly the North Sea), the Mediterranean Sea (FAO Area C), and/or the northwest Atlantic

(FAO Area A; mainly the east coast of Canada and the USA). Only four of the 97 taxa recorded are usually found in fresh and/or brackish water (Appendix 5).

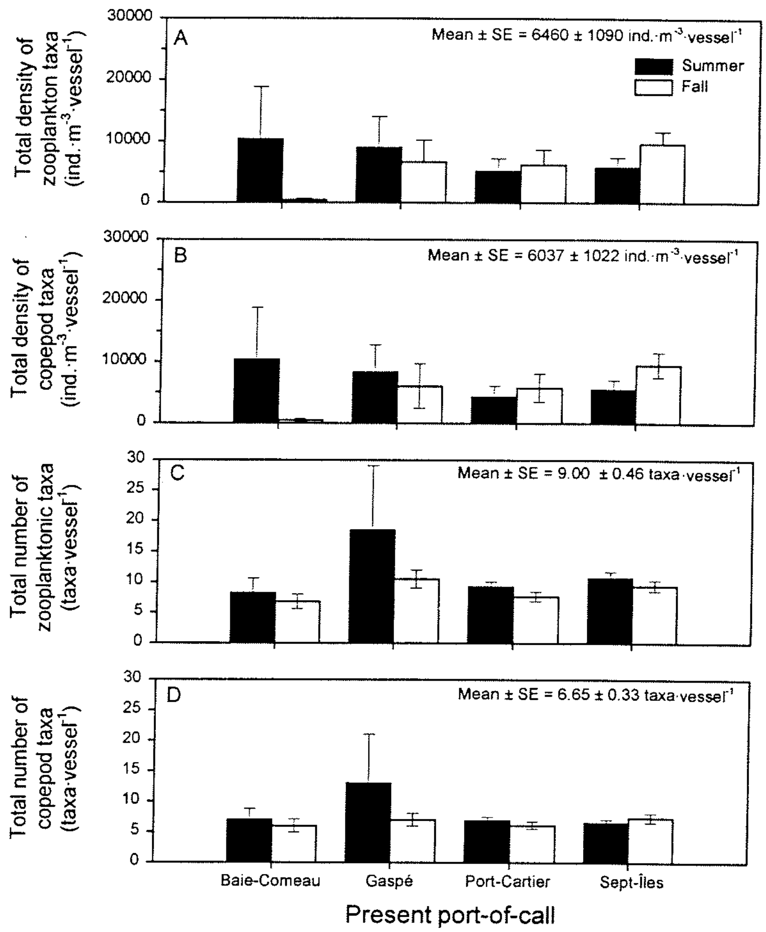


Figure 10. Mean total density (± SE) of zooplankton (A) and copepod (B) taxa and mean total number (± SE) of zooplankton (C) and copepod (D) taxa per foreign vessel bound for the four selected ports in the Estuary and Gulf of St. Lawrence in the summer (black) and fall (white) of 1995.

Figure 10 shows the mean total density and the mean total number per vessel of zooplankton and copepod taxa found in ballast water sampled at the ports of Baie-Comeau, Gaspé, Port-Cartier, and Sept-Îles in the summer and fall of 1995. An average of 6,460 ± 1,085 ind.·m^{-3}·vessel^{-1} were found in the ballast waters of the 94 vessels sampled in the EGSL in 1995. This number showed little variation among ports and seasons except at Baie-Comeau, where densities in ballast water of ships were greater in summer than in fall (Figure 10a). The same pattern of variation was observed in the mean total density of copepod taxa, which constituted 91.3% of the total number of zooplankton taxa (Figure 10b). Likewise, an average of nine different zooplankton taxa per vessel were found in the ballast water of the 94 ships sampled in 1995. This number showed little variation among ports and seasons except at Gaspé in summer, where an average of 17 taxa per vessel were observed (Figure 10c). This number should nevertheless be interpreted with caution given the small number of vessels (4) sampled at this port. Likewise, an average of seven copepod taxa per vessel were found in the 94 vessels sampled. This number showed little variation among ports and seasons except at Gaspé in summer, where a higher number of copepod taxa was observed (Figure 10d).

3.3.2.2 Relationships between biological and physical variables

A Pearson correlation analysis between biological and physical variables showed no correlation between 1) the total density of zooplankton, 2) the total density of copepods, 3) the total number of zooplankton taxa, and 4) the total number of copepod taxa versus the quantity of ballast water carried at arrival or the vessel's GRT. However, these variables were significantly negatively correlated with the transit time (Table 5). The transit time explains respectively 23, 23, 21, and 11% of the variance of the total zooplankton density, the total copepod density, the total number of zooplankton taxa, and the total number of copepod taxa (Figure 11).

Table 5. Pearson correlation coefficients between biological and physical descriptors (n = 94).

Variables	Vessel Gross Register Tonnage (GRT)	Quantity of ballast water carried at arrival (t)	Transit time (days)
Total density of zooplankton (ind.·m^{-3})	0.190 ns	0.205 ns	-0.484 ***
Total density of copepods (ind.·m^{-3})	0.172 ns	0.186 ns	-0.477***
Total number of zooplankton taxa	0.047 ns	0.099 ns	-0.455 ***
Total number of copepod taxa	0.028 ns	0.086 ns	-0.335 ***

*** P ≤ 0.001; ns = not significant

3.3.2.3 Estimation of the proportion of water carried on board from the previous ports of call

There were significant positive relationships between all biological variables and the proportion of ballast water originating from previous ports of call in vessels that reported incomplete exchanges in mid-ocean (Figure 12). These relationships explained respectively 28, 24, 36, and 24% of the variance of the total zooplankton density, the total copepod density, the total number of zooplankton taxa, and the total number of copepod taxa.

The regression equation relating total zooplankton density to the proportion of ballast waters originating from previous ports of call (Figure 12a) was used to verify the claim of ships having reported complete ballast water exchanges in mid-ocean. This was done by estimating the proportion of ballast waters originating from the last port of call that would account for the total density of zooplankton found in ballast water of these vessels. These estimations were made according to the inverse prediction method described by Zar (1984).

Results show that a significant number of ships having reported compliance to the guidelines had an unusually high proportion of their ballast water that originated from previous ports of call (Figure 13). Based upon observed zooplankton densities in ballast waters of the 61 vessels sampled that reported complete offshore exchanges, it is estimated that 13 of these ships had less than 1% of their ballast waters originating from previous ports of call, 31 vessels had between 1 and 50%, seven vessels had between 50 and 100%, and ten vessels appeared to have made no exchange of their ballast waters (Figure 13). Three of these latter vessels had zooplankton densities that exceeded by far the predictions of the model for complete offshore ballast water exchange.

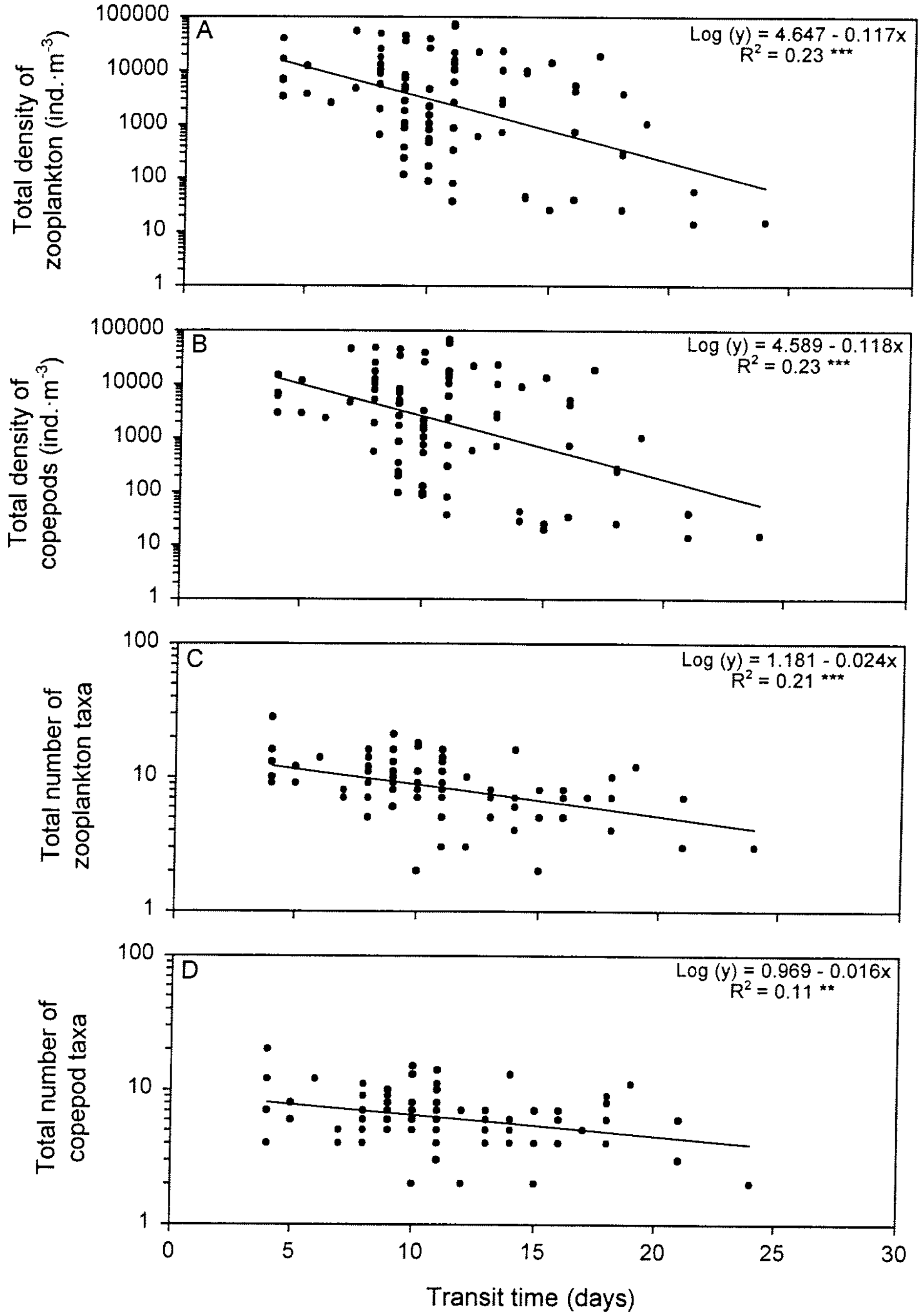


Figure 11. Linear regressions between the transit time and total zooplankton density, total copepod density, total number of zooplankton taxa, and total number of copepod taxa. All dependent variables were $\log_{10}$-transformed prior to analysis. The regression equation and the coefficient of determination for each regression are also presented (** $P \leq 0.01$; *** $P \leq 0.001$).

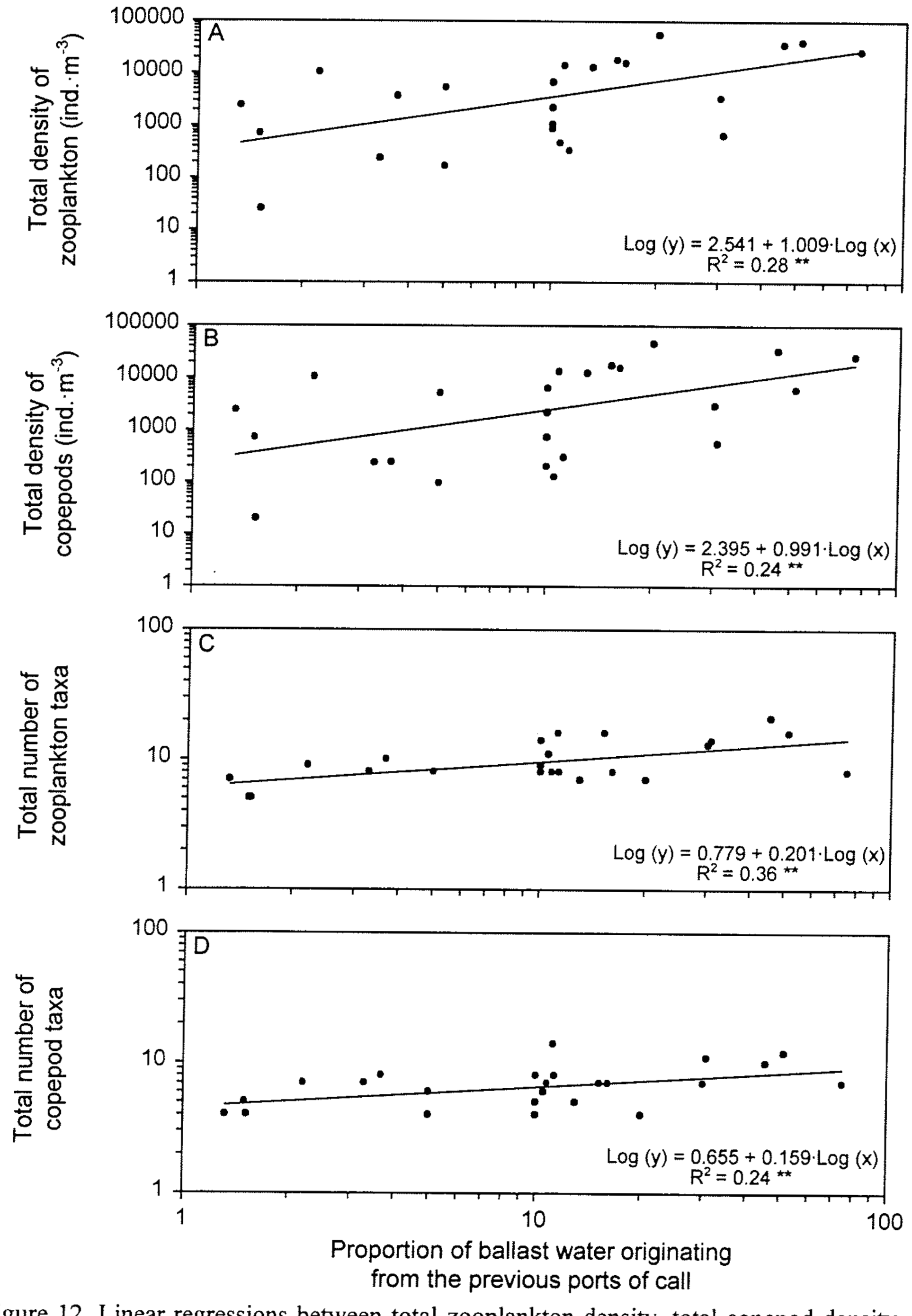


Figure 12. Linear regressions between total zooplankton density, total copepod density, total number of zooplankton taxa, and total number of copepod taxa versus the proportion of ballast water from the last port of call in vessels having reported partial exchanges of their ballast waters in mid-ocean. All variables were $\log_{10}$-transformed prior to analysis. The regression equation and the coefficient of determination for each regression are also presented (** $P \leq 0.01$).

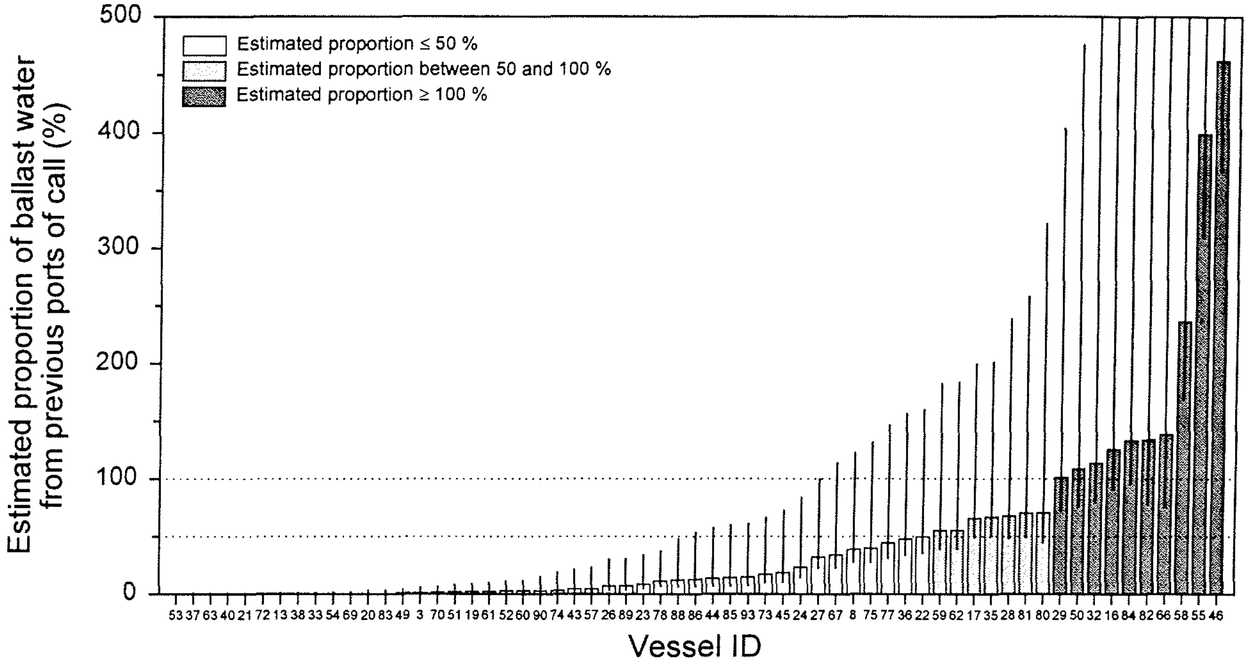


Figure 13. Estimated proportions of ballast waters originating from the previous ports of call (± 95% confidence interval) in vessels that reported complete exchanges of their ballast waters in mid-ocean. These estimations were based upon the regression equation relating the total density of zooplankton to the proportion of ballast water originating from previous ports of call for vessels having reported incomplete exchanges of their ballast water in mid-ocean (see Appendix 6 for voyage date and ballast activity of the vessels used in this analysis).

3.3.3 Ballast sediment sampling program

3.3.3.1 Biodiversity and species richness of protistan taxa found in ballast sediment

A total of 65 protistan taxa were recorded from sediments sampled in eight recently deballasted cargo holds and one upper wing tank from ships sampled in the four selected ports of the EGSL in 1995 (Appendix 7). This list of species comprises 17 centric and 9 pennate diatoms, 13 flagellates (1 prasinophyte, 6 chrysophytes, 6 chlorophytes), 23 dinoflagellates, and 3 tintinnids. Of the 65 taxa observed, 37 (57%), were found only once. Of these 37 taxa, 19 were rare (mean abundance < 100 cells·cm^{-3}), 8 uncommon (100 to 500 cells·cm^{-3}), 4 common (500 to 1000 cells·cm^{-3}), 3 abundant (1001 to 5000 cells·cm^{-3}), and 2 very abundant (> 5,000 cells·cm^{-3}). The taxa with highest frequencies of occurrence were the tintinnid *Tintinnopsis* sp., the centric diatom *Thalassiosira* spp., and the chrysophyte *Dictyocha speculum*; the most abundant taxa were the centric diatoms *Chaetoceros concavicornis* and *Chaetoceros costatus* (Appendix 7). According to zoogeographic affiliations, 41 of the 65 protistan taxa recorded (63%) are endemic to the EGSL. Only 12 taxa have never been previously observed in the EGSL. Finally, freshwater chlorophytes and pollen grains were found in respectively 44 and 55% of the nine vessels sampled.

Of the 65 protistan taxa sampled in ballast sediments, the three centric diatoms *Chaetoceros concavicornis*, *Leptocylindrus minimus*, and *Skelotema costatum*; the dinoflagellate *Ceratium fusus*; and the chrysophyte *Dictyocha speculum* are known to be harmful species. The pennate diatom

Pseudo-nitzschia seriata and the dinoflagellate *Dinophysis norvegica* are known to be toxic species (Hallegraeff 1993) (Appendix 7).

Figure 14 shows the mean total density per vessel and the mean total number of protistan taxa per vessel found in ballast sediment sampled at the ports of Baie-Comeau, Port-Cartier, and Sept-Îles in summer and fall 1995. An average of 3,272 ± 791 cells·cm^{-3}·vessel^{-1} were found in the ballast sediment of the nine vessels sampled in the EGSL in 1995. This number showed little variation among ports and seasons except for three vessels where very low (463 ± 103 cells·cm^{-3}) or very high (56,626 ± 9,073 and 107,625 ± 15,887 cells·cm^{-3}) densities were found (Figure 14a). Likewise, between 16 and 22 different taxa per vessel were found in ballast sediment of the nine vessels sampled except in two vessels, where only six and nine species were observed (Figure 14b).

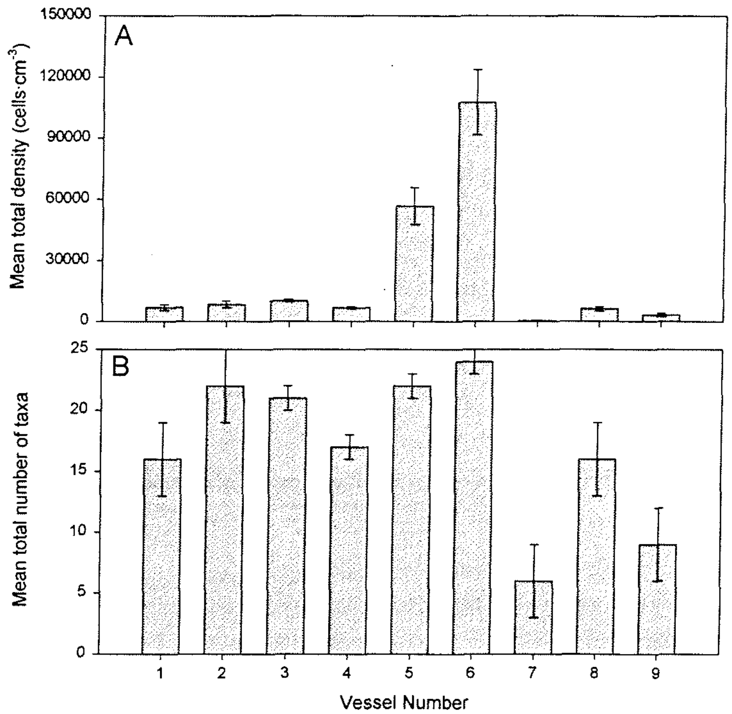


Figure 14. Mean total density (± SE) and mean total number (± SE) of protistan taxa found in the sediment samples obtained in eight recently deballasted cargo holds and one upper wing tank in 1995.

3.3.3.2 Cyst germination experiments

The examination of the refrigerated sediment samples permitted the observation of between 12 and 28 dinoflagellates cysts·cm^{-3} of sediment (mean = 16.2 ± 5.7 cysts·cm^{-3}) for each of the 9 vessels sampled. A total of 1,853 dinoflagellates cysts from 42 different taxa were tested for germination in two different experiments. However, attempts to culture dinoflagellates cysts from sediment collected in ballast tanks were unsuccessful in all cases as a result of insufficient cyst numbers in the first experiment and because of sample deterioration in the second experiment. Nevertheless, two of the cysts that were identified (*Alexandrium excavatum*, *A. minutum*) are known to be toxic or harmful species.

4.0 DISCUSSION

4.1 Foreign vessel traffic and associated ballast water discharges in the Estuary and Gulf of St. Lawrence

The shipping traffic of foreign origin in the Estuary and Gulf of St. Lawrence, although globally comparable to other areas of the world with known ballast water–mediated introduction problems, is not as intense on an individual port basis. With a total of 709 vessels in 1995, the foreign maritime traffic in the EGSL system is as heavy as in Chesapeake Bay (Baltimore and Norfolk), on the east coast of the United States, which was identified as one of the most problematic areas of that country with respect to the potential introduction of nonindigenous species by ship-transported ballast water (Carlton *et al.* 1995). Moreover, vessels of foreign origin that are bound for EGSL ports are more numerous than those proceeding upstream to the Great Lakes (455 ships in 1990; Locke *et al.* 1991), where many introductions of non-native species via ballast water have been reported in the past (Schormann et al. 1990; Mills et al. 1993; Leach 1995; Gauthier and Steel 1996). However, the shipping traffic of foreign origin in the Estuary and Gulf was distributed among 23 different ports in 1995 and did not exceed 185 arrivals in a single port (Port-Cartier). This port-based traffic is much less intense than that of the Chesapeake Bay port of Norfolk (425 ships in ballast in 1991; Carlton *et al.* 1995) and that of the five most important ports of Australia (ca 448 ship visits per port on average in 1991), where several non-indigenous species invasions have been reported (Kerr 1994). This indicates that ballast water discharges associated with the foreign maritime traffic in the EGSL are more scattered within the area than in regions of comparable shipping intensity where ballast water–mediated introductions of non-indigenous species have been documented.

However, there are regions within the EGSL where the foreign shipping traffic and its associated ballast water discharges are relatively intense. The Estuary and northwestern Gulf (Area I; see Figure 3) received 409 international ship visits (357 in ballast) in 1995, resulting in the discharge of 11,789,424 t of ballast water. Most of this traffic was concentrated in three ports located within a 300 km stretch of coastline (Baie-Comeau, Port-Cartier, and Sept-Îles), which accounted for almost 60% of the entire foreign maritime traffic in the EGSL in 1995. Other regions of notable foreign shipping concentration in the Gulf are Chaleur Bay (Area II; 90 ships), Northumberland Strait (Area III; 34 ships), and the southwestern coast of Newfoundland (Area IV; 73 ships). However, the Gulf areas in which these regions are located received only a few vessels of foreign origin and minor amounts of discharged ballast water in 1995 compared to the Estuary and northwestern Gulf area.

In addition to the intensity of the shipping traffic, differences in the types of vessels also contributed to the observed geographical variations in foreign ballast water discharges in the EGSL in 1995. Bulk carriers, with a mean GRT of 42,142 t and a mean ballast water capacity of 38,652 t, dominated in Area I where the major ports of Baie-Comeau, Port-Cartier, and Sept-Îles export more bulk commodities—mostly minerals and grain trans-shipments—than other ports in the EGSL. In contrast, ports located in Areas II, III, and IV of the Gulf are visited mainly by general cargo carriers (mean GRT = 12,399 t; mean ballast capacity = 5,396 t) because of their use by the pulp and paper industry and other first and second transformation industries. As a result, the Estuary and northwestern Gulf receives most of the discharged ballast water of foreign origin into the EGSL.

The apparent high level of compliance to the Great Lakes Ballast Water Control Guidelines (GLBWCG), as reported by ships when entering Canadian waters, appears to substantially reduce the amount of ballast water originating from previous ports of call that is discharged into the EGSL, particularly in the Estuary and northwestern Gulf area. Based on the information obtained during the remote survey, more than 90% of the bulk carriers and 100% of the general cargo carriers bound for ports of the EGSL claim to have exchanged at least part of their ballast water *en route* in mid-ocean or in the backup exchange zone within the Gulf of St. Lawrence. As a result, only 14% of the ballast water discharged in ports of the EGSL would have originated from previous ports of call (1,588,170 t). The extent of exchanges is highest in ships that are bound for ports of the Estuary and northwestern Gulf (1,440,181 t or 12.5% of discharged ballast waters originating from previous ports of call) as all these ships are subjected to the GLBWCG. In contrast, foreign ships arriving in ports of other areas of the Gulf are not subjected to the GLBWCG and, as a result, the proportion of discharged ballast water that originates from previous ports of call exceeds 50% in these ships (147,989 t for Areas II, III, and IV combined). Although results of the present study suggest that compliance to the guidelines may not be adequately reported by some ships (see sections 3.3.2.3 and 4.4), it is not possible to validate the information provided by ship officers regarding ballast water exchanges as there are at present no control measures in place for ships that are bound for most ports of the Estuary and Gulf. As a result, the amount of discharged ballast water that originated from previous ports of call, as reported above, may be underestimated.

Nevertheless, the regions of the world from which the foreign maritime traffic in the EGSL originated in 1995 generally exhibit environmental conditions that are different from those encountered in the EGSL. Outside the northwest Atlantic, the majority of the foreign maritime traffic in the EGSL originates from ports located in the northeast Atlantic (mainly the North Sea), the Mediterraneen Sea, and the western central Atlantic, which all exhibit warmer conditions than in the EGSL. For example, surface temperatures in the North Sea range from 9 to 12 °C on average and usually do not fall below 3 °C during winter (Becker and Wegner 1993). In other such as the western central Atlantic and the Mediterranean Sea, surface temperatures never fall below 10 °C during the year and may exceed 25 °C in summer (Figure 15). By contrast, the EGSL is mostly ice covered in winter and temperatures of less than 1 °C prevail throughout the Gulf to a depth of more than 120 m during that time of the year (Gilbert and Pettigrew 1997). In addition, a cold intermediate layer (CIL) with temperatures of -1.5 to 3 °C persists throughout the year in the EGSL at depths ranging from 20-30 m to 140 m. The presence of this layer in the EGSL originates from the intrusion of the cold Labrador Current through the Strait of Belle-Isle and from the local cooling of surface waters during the winter (Gilbert and Pettigrew 1997).

However, a non negligible part of the foreign shipping traffic originated from areas that match to a certain degree the characteristics of the EGSL. Approximately 20% of the inbound foreign maritime traffic in 1995 entered ports located in the southern Gulf of St. Lawrence, mainly Chaleur Bay and Northumberland Strait, where warmer conditions prevail in summer and fall. In addition, a number of foreign vessels (less than 50) originated from countries bordering the Baltic Sea, which exhibit similar temperature conditions to those prevailing in the EGSL, including the presence of a seasonal ice cover during winter and estuarine conditions. However, the exact number of ships linking the Baltic Sea to the EGSL cannot be determined since 1) some of these countries of origin (Germany, Sweden, and Denmark) also border the North Sea, and 2) the exact port of origin is not recorded in the ECAREG–VTS database.

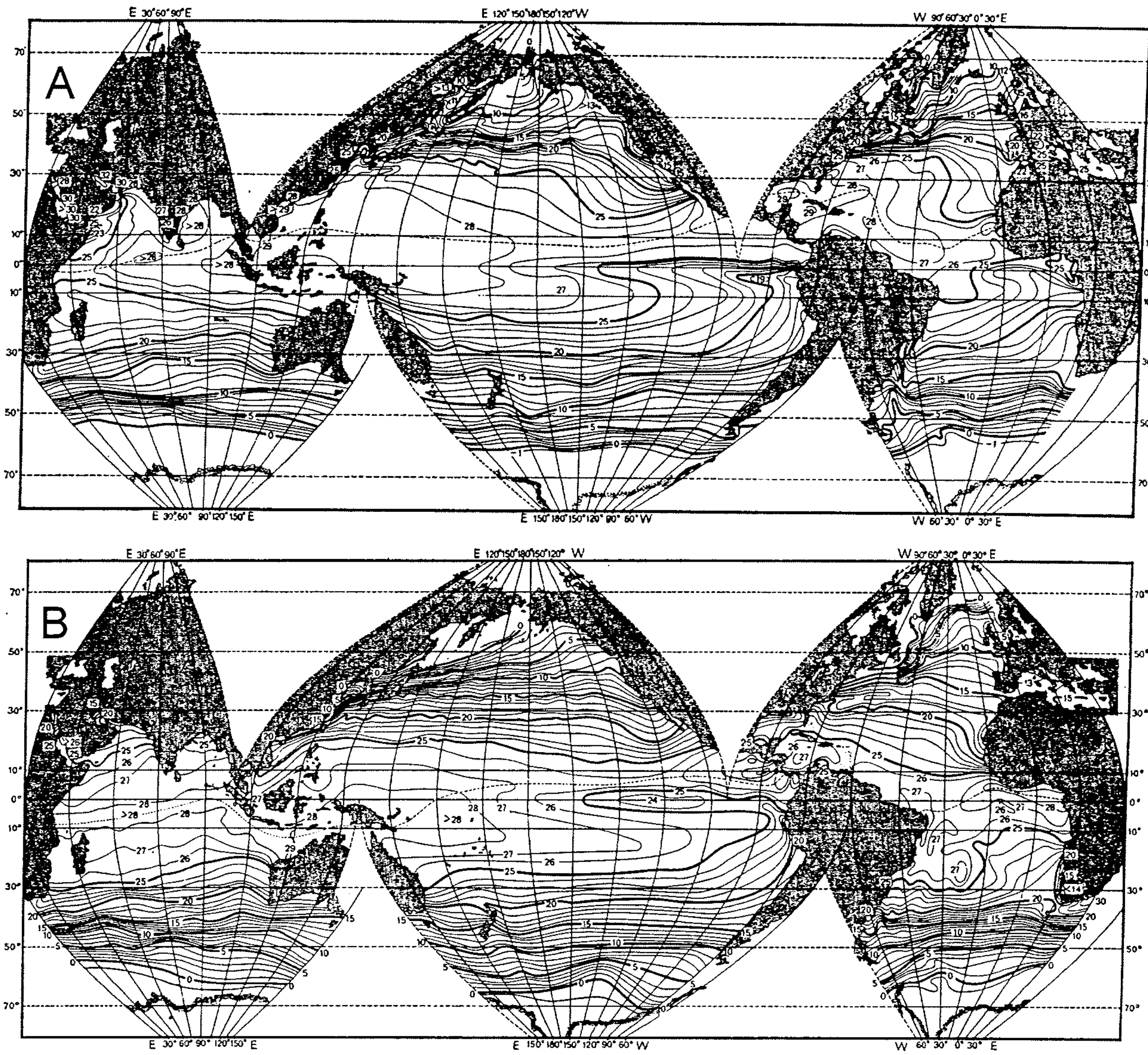


Figure 15. Sea surface temperature distribution in the world oceans in August (A) and in February (B). Taken from McLellan (1965).

4.2 Biodiversity in ballast water and ballast tank sediments of incoming foreign ships

4.2.1 Planktonic communities

There was a taxonomically diverse array of phytoplankton and zooplankton in ballast water of ships entering the EGSL. Despite the large mesh size of the plankton net used (80 μm), this study is the first to present a detailed list of 292 phytoplankton species found in ballast water. With the exception of Pierce *et al.* (1997) and Galil and Hülsmann (1997), most ballast water research efforts have focused on zooplankton (Medcof 1975, Williams *et al.* 1988, Locke *et al.* 1991, Carlton and Geller 1993) or on toxic diatom and dinoflagellate cysts (Hallegraeff and Bolch 1991, Hallegraeff and Bolch 1992, Hallegraeff 1995) found in ballast water and sediments.

With 70 zooplankton species and 27 other zooplankton taxa found in the 94 vessels sampled in this study, the biodiversity of the ballast water zooplanktonic communities is comparable to those observed in many other studies (Williams *et al.* 1988, Carlton and Geller 1993, Locke *et al.* 1993, Gollasch *et al.* 1995). For instance, Williams *et al.* (1988) found 22 zooplankton species and 45 other taxa in the ballast water tanks of 31 vessels sailing between Japan and Australia; Carlton and Geller (1993) found 225 zooplankton species in plankton samples from 159 cargo ships carrying ballast water from 25 Japanese ports; Locke *et al.* (1993) found 57 species and at least 50 other invertebrates taxa in the zooplankton samples taken from 86 vessels transiting the St. Lawrence Seaway locks near Montréal or docked in Montréal Harbor; and Gollasch *et al.* (1995) found 250 zoological species or taxa in 300 vessels calling at German ports over three years. Similarily, estimates of total zooplankton abundance in ballast tanks observed in this study, ranging from 9 to 51,920 ind.$\cdot$m^{-3}, are comparable to those observed by Locke *et al.* (1993) in the region of Montréal in 1991, where densities between 21 and 70,000 ind.$\cdot$m^{-3} were found in the 86 vessels sampled.

Several phytoplankton and zooplankton species found in ballast waters of the 94 ships sampled are known to occur in the ESGL. These similarities between ballast tank and local planktonic communities result from both the nearby origin of the foreign maritime traffic in the EGSL and from offshore ballast water exchanges in the Atlantic Ocean. Several foreign vessels that were sampled in 1995 originated from the northwest or northeast Atlantic, which present some similarities in phytoplankton and zooplankton assemblages with the Estuary and Gulf of St. Lawrence based upon biogeographic subdivisions of the world oceans (summarised in van der Spoel and Heyman 1983). Moreover, most ships that were sampled reported ballast water exchanges in the Atlantic Ocean, where organisms originating from previous ports of call were replaced to some extent by those occurring in surface waters of the northwest Atlantic off Canada. Thus, the relative proximity of the foreign maritime traffic and compliance to the GLBWCG undoubtedly limit the extent to which nonindigenous species are inoculated into the EGSL with foreign ballast water discharges.

However, respectively 60% and 57% of the phytoplankton and zooplankton species found in ballast waters of foreign ships are not known to occur in the EGSL. This indicates that ballast water practices in the EGSL represent a potentially important vector for the accidental introduction of nonindigenous species. However, the majority of nonindigenous species encountered were found in only one or two ships and at very low densities. Only a few nonindigenous species were found in more than 10 vessels and at relatively high densities. While this apparent rareness of nonindigenous species in ballast water somewhat limits the potential for their succesful introduction into the EGSL, it may also reflect the effectiveness of mid-ocean exchanges in reducing the number of species in ballast waters and their inoculation frequency (see section 4.4).

Several of the nonindigenous species found in ballast tanks of incoming foreign ships are neritic or usually found in brackish water, which increases the potential for their survival once inoculated into the EGSL. Neritic species are well adapted to living in the variable environmental conditions of the continental shelf while oceanic species have a relatively low survival capacity in coastal waters. Thus, the presence of nonindigenous neritic species of phytoplankton and zooplankton in ballast waters suggests that mid-ocean exchanges were not totally effective in eliminating species originating from ballasting operations in shallow nearshore areas of previous ports of call. Moreover, the presence of some neritic phytoplankton species such as *Actinocyclus normanii* fo. *normanii*, *Aulacoseira granulata* vr. *granulata*, *Bacteriastrum hyalinum*, *Ditylum brighwellii*, *Ceratinium furca*, *C. macroceros*, and *Protoperidinium divergens*, which were found in at least 15 ships at densities ranging from rare (100 to 1000 cells·m^{-3}) to common (10,000 to 100,000 cells·m^{-3}), confirms that mid-ocean exchange was probably not complete or not conducted in some cases. Although neritic and littoral species undoubtedly remain in residual ballast water and/or tank bottom sediment during mid-ocean exchanges, their numbers are likely insufficient to colonise refilled ballast tanks at densities observed in the present study.

Only 19 harmful or toxic phytoplankton species were found in the ballast water of the 94 vessels sampled, of which only one species (*Coscinodiscus wailesii*) has never been previously observed in the EGSL. This species is known to cause the clogging of fishing nets through an abundant production of mucilage (Boalch and Harbour 1977; Mahoney and Steimle 1980). It is a native species of the Pacific Ocean but it has recently established in the northwest and northeast Atlantic (Boalch and Harbour 1977; Mahoney and Steimle 1980; Rincé and Paulmier 1986; Rick and Dürselen 1995), possibly by spreading through the Panama Canal and/or through oyster imports (Rincé and Paulmier 1986). Although this species is not toxic to humans, its cosmopolitan distributiuon and clogging effects on fishing nets (Rincé and Paulmier 1986) raises concerns for its potential introduction into the Estuary and Gulf of St. Lawrence.

4.2.2 *Protistan taxa in ballast sediment*

Ballast sediment samples collected during the present study contained many protistan taxa at various densities. Except for pollen grains, all of these taxa have been reported in ballast sediment surveys conducted by Australian (Hallegraeff and Bolch 1991, Hallegraeff and Bolch 1992, Hallegraeff 1995) American (Kelly 1993), British (Macdonald 1995) and German (Gollasch *et al.* 1995) researchers. Among the taxa observed in this study, dormant dinoflagellate cysts were present in almost 50% of the samples at densities varying from 18 to 509 cysts·cm^{-3}. Ballast sediments have been identified as a potential source for the introduction of toxic or harmful nonindigenous species in many countries (Hallegraeff and Bolch 1991, Hallegraeff and Bolch 1992, Kelly 1993, Hallegraeff 1995, Macdonald 1995), due to the ability of toxic dinoflagellates to encyst under harsh environmental conditions for a long period of time and to germinate when conditions become favourable (Hallegraeff and Bolch 1992). The present study confirms such risks for the EGSL, although germination experiments failed to provide evidence of the viability of dinoflagellate cysts found in sampled ballast sediments.

4.3 Foreign maritime traffic and planktonic communities in ballast waters

A number of factors are known to influence the survival of planktonic organisms in ballast water. Carlton (1985) first provided a model describing the sequencial events of ballast water transport leading to the successful introduction of nonindigenous species. One of the critical events described in this model is the survival of organisms during transport, which is largely influenced by the prevailing and/or changing conditions in ballast tanks and by the length of time during which organisms are exposed to these conditions. Indeed, the transit time or voyage length has been shown to affect the survival of species found in ballast waters upon arrival. Williams *et al.* (1988) noted a decrease in the number of planktonic species and taxa in ballast waters with increased voyage time (8 to 18 days) between Japan and Australia and attributed this decrease to temperature effects or to the collapse of the food chain in the ballast tanks. The present study also shows the negative effects of transit time on both the number and densitiy of zooplankton and copepods in ballast water, with voyage lengths ranging from 4 to 24 days. However, the majority of ships sampled in our survey had transit times of less than two weeks, due to the nearby origin of most foreign ships entering the Estuary and Gulf of St. Lawrence, which reduces the extent to which voyage length affects the survival of organisms. In addition, offshore ballast water exchanges are also known to affect species numbers and densities (Williams *et al.* 1988, Locke *et al.* 1993; see section 4.4) and the necessary operations to conduct these exchanges may increase voyage lengths. Thus, the observed relations may very well have been biased by compliance to the guidelines, so that the importance of transit time in reducing the number of surviving organisms that are inoculated into the EGSL with ballast water discharges cannot be determined for the present study.

Other characteristics of the foreign maritime traffic in the EGSL were also tested for their effects on species numbers and densities in ballast water, including vessels' gross registered tonnage and the quantity of ballast water carried on arrival, but none of these variables showed significant relationships with biological variables. This indicates that species numbers and densities do not vary with ship size and associated ballast water volume to be discharged. However, the foreign maritime traffic in the EGSL is dominated by large ships such as bulk carriers, particularly in the Estuary and northwestern Gulf. This results in greater volumes of ballast water discharge per ship and greater numbers of organisms being inoculated per discharge than in other areas where the maritime traffic is dominated by general cargo carriers, for example in the Great Lakes. For a given species, the instantaneous inoculation of greater numbers of individuals in local water masses of the Estuary and Gulf may increase its potential for survival and reproduction, and thereby increase the risk for a successful introduction.

4.4 Effectiveness of ballast water exchanges in reducing species numbers and densities

As mentioned earlier (see section 1.0), all foreign ships bound for ports west of 63° W in the St. Lawrence Seaway are subjected to the Great Lakes Ballast Water Control Guidelines (GLBWCG), which recommend ballast water exchanges in the Atlantic Ocean or in the Gulf of St. Lawrence. These guidelines were developed mainly to protect the Great Lakes ecosystem from the introduction of nonindigenous freshwater species, but they also apply to foreign ships bound for ports of the EGSL located west of 63° W, which represented more than 60% of the foreign maritime traffic in the St. Lawrence marine ecosystem in 1995. However, compliance with the guidelines is not monitored (Gauthier and Steel 1996), and foreign vessels entering other ports of the Gulf of St. Lawrence—one third of the foreign maritime traffic in the EGSL in 1995—are not subjected in any way to the GLBWCG. Furthermore, the GLBWCG allow foreign ships bound for ports in the Great Lakes or in the freshwater part of the St. Lawrence—more than 755 ships annually (Gauthier and Steel 1996)—to exchange their ballast waters in the Gulf of St. Lawrence if not feasible in the Atlantic Ocean. Thus, the current guidelines provide only limited protection against potential introductions in the EGSL and may very well increase this risk, depending on the extent of ballast water exchanges in the Gulf.

Yet, ballast water exchanges, as requested by GLBWCG, appear to be effective in reducing the potential for ballast water–mediated introductions of nonindigenous marine species in the Estuary and Gulf of St. Lawrence. The total number and density of zooplankton species as well as of copepod species in ballast water was positively correlated with the proportion of ballast water originating from the last port of call for foreign ships that reported partial exchanges in mid-ocean. This indicates that the biodiversity in ballast waters decreases as the extent of mid-ocean exchanges increases. Williams *et al.* (1988) and Locke *et al.* (1991, 1993) also showed that mid-ocean exchange of ballast water greatly reduced the number of plankton species. However, the presence of some neritic species in ballast waters of incoming vessels who reported complete exchanges indicates that such practices may not be effective in completely eliminating neritic and littoral species. Locke *et al.* (1993) determined the effectiveness of mid-ocean ballast exchange by looking for freshwater-tolerant zooplankton taxa in ballast water of vessels originating from a fresh- or brackish-water port that had reported the exchange of ballast water in compliance with the GLBWCG. They also found that ballast water exchange in vessels that reported compliance to the GLBWCG was not completely effective since freshwater-tolerant zooplankton taxa remained in the ballast tanks after partial or complete exchange. These results indicate that offshore ballast water exchanges cannot be considered as a final solution to reduce or eliminate risks for ballast water–mediated introductions in the Estuary and Gulf of St. Lawrence.

However, while ballast water treatment techniques are being developed, offshore ballast water exchanges remain at present the only valuable control measure to reduce these risks, provided that provisions for such exchanges are developed accordingly and that they are fully complied with by ship officers. In the present study, some ships who reported complete exchanges had unusually high zooplankton densities in their ballast water upon arrival. Based upon the observed relation between density and the proportion of ballast water originating from the last port of call, it was possible to determine that, for at least 17 ships who reported complete exchanges, compliance to the Voluntary Guidelines was not adequately reported in that exchanges were not complete and/or were simply conducted in coastal areas. These observations indicate that the amount of ballast water originating from the last port of call that are discharged annually in the EGSL may be higher than those previously calculated using the values reported by ship officers in the remote survey (1,588,170 t, see sections 3.2 and 4.1). They also point to the necessity of a study on the risk for ballast water–mediated introductions of nonindigenous species and on the efficiency of mid-ocean ballast water exchanges to be based on adequate and reliable information provided by ship officers.

5.0 CONCLUSION

Results of the present study indicate that the risk for ballast water–mediated introductions of nonindigenous marine species in the Estuary and Gulf of St. Lawrence may not be as high as in other areas of the world with documented invasions related to ballast water transport. Foreign ballast water discharges in the EGSL are globally comparable to those occurring in major ports of the United States and Australia but are scattered over a wide region whose marine environmental conditions are generally much colder than in most areas where the foreign maritime traffic originates. As a result, the potential for the survival or proliferation of nonindigenous species usually living under more temperate water conditions is considerably limited in the Estuary and Gulf, particularly planktonic organisms that undergo daily vertical migrations whose inoculation into the EGSL would periodically expose them to temperatures of the cold intermediate layer. In addition, much of the foreign ballast water discharges in the EGSL are made up of water originating from the nearby northwest Atlantic as a result of offshore exchanges conducted in compliance to the GLBWCG, although the information provided by ship officers remains to be validated. Furthermore, the foreign maritime traffic in the EGSL originates mainly from nearby FAO regions which present some similarities with the Estuary and Gulf in terms of phytoplankton and zooplankton assemblages despite geographical differences in temperature regimes. These similarities are mostly made up of those cosmopolitan species that can tolerate a wide range of temperature and salinities.

These conclusions are supplemented by the fact that there is yet no evidence or official reports of successful ballast water–mediated introductions of nonindigenous species in the Estuary and Gulf with environmental or socio-economic impacts that are comparable to those observed in the Great Lakes or elsewhere in the world. At present, there are only a few reported cases of introduced species in the Estuary and Gulf, including the periwinkle *Littorina littorea*, which was likely introduced in the late 19th century (J.T. Carlton, pers. comm.), and the occurrence of the green crab, *Carcinus maenas*, in the southern Gulf of St. Lawrence (Squires 1990). The latter case may have resulted from the introduction and subsequent northward expansion of the species from coastal areas of northeastern United States rather than from a direct introduction through ballast water discharges or any other possible vector. However, the apparent absence of successful ballast water–mediated introductions with noticeable impacts in the Estuary and Gulf does not imply that there have been none. Some introductions may already have occurred locally, around international ports, without being reported. Moreover, nonindigenous species that may have been introduced to the EGSL over the last century could be misleadingly considered as local species because of few existing taxonomic studies for the Estuary and Gulf of St. Lawrence, most of which have only recently been completed.

Despite the above mentioned limitations, some areas of the Estuary and Gulf of St. Lawrence do present significant risks for the introduction of nonindigenous species through foreign ballast water discharges. This is particularily the case in the southern Gulf of St. Lawrence, which received approximately 20% of the incoming foreign maritime traffic in 1995 and where warmer conditions prevail in summer and fall. Moreover, foreign ships that are bound for ports in this area are not subjected to the GLBWCG, which increases risks compared to other areas of the Estuary and Gulf where the GLBWCG apply. In the Estuary and northern Gulf, several nonindigenous species were still found in ballast waters of incoming foreign ships despite an apparently high level of compliance to the GLBWCG. Some of these species may have originated from areas with similar environmental conditions to those prevailing in the EGSL, for example the Baltic Sea. In addition, some ballast water exchanges do occur in the backup exchange zone within the Gulf of St. Lawrence. Thus, there are at present non-negligible risks for ballast water–mediated introductions in the Estuary and Gulf of St. Lawrence that are either not covered or may even be enhanced by the current GLBWCG.

Additional studies are needed to fully assess these risks in order to prevent the introduction of nonindigeneous species with potential socio-economic impacts such as those that have occurred with the introduction of the zebra mussel into the Great Lakes and that of the American comb jelly into the Black and Azov seas. Among others, survival and viability studies on planktonic communities in ballast water are needed to determine the potential for successful introductions of nonindigenous species that are inoculated into the EGSL through existing commercial shipping routes, particularly those linking the Estuary and Gulf with areas exhibiting similar environmental conditions (e.g., the Baltic Sea). The absence of evidence or reports regarding successful ballast water–mediated introductions into the Estuary and Gulf is also a crucial question that needs to be addressed to complement our evaluation of the potential for such introductions.

The existing voluntary guidelines requesting offshore ballast water exchanges should be reevaluated to provide better protection for the marine environment of the Estuary and Gulf of St. Lawrence. Above all, the geographical coverage of the GLBWCG should be extended to the entire Estuary and Gulf ecosystem to minimize risks associated with the foreign maritime traffic in the southern Gulf of St. Lawrence. Although this area receives much less ballast water discharges than the Estuary and northwestern Gulf area, its warmer conditions could be suitable for the introduction of a wider spectrum of nonindigenous species, with potential impacts on local fisheries and aquaculture activities. In addition, the guidelines' provisions for exchanges in a backup zone within the Gulf of St. Lawrence are questionable from an Estuary and Gulf perspective and should be revised considering the known potential impacts of introductions on ecosystem stability and the importance of local fisheries in the EGSL. This issue was also raised during a workshop that was held at DFO's Bedford Institute of Oceanography in 1991 (Smith and Kerr 1992) but has yet to be addressed. Furthermore, compliance to the GLBWCG should be closely monitored for foreign ships that are bound for ports in the Estuary and Gulf. Our assessment suffers in part from the unverified validity of information provided by ship officers and shows that compliance to the GLBWCG was indeed not adequately reported for some ships. The information provided regarding ballast water exchanges and discharges upon arrival in ports of the EGSL and its reliability are critical for a representative assessment of associated risks for the introduction of nonindigenous species. The present study shows that the density of organisms in ballast waters of incoming foreign ships could be useful in this context.

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Appendix 1. Great Lakes Ballast Water Control Guidelines.

VOLUNTARY GUIDELINES FOR THE CONTROL OF BALLAST WATER DISCHARGES FROM SHIPS PROCEEDING TO THE ST. LAWRENCE RIVER AND GREAT LAKES

1.0 Introduction

1.1 The purpose of these voluntary Guidelines is the protection of Great Lakes waters from non-native fish and other aquatic organisms, that can be harmful to the balance of nature that now exists. When a new organism is introduced to a balanced ecosystem, negative changes may result. In the Great Lakes, there have been many aquatic organisms introduced by accident, and several of these have been very harmful. These Guidelines should reduce the probability of additional non-native species being introduced.

1.2 The best method of protecting Great Lakes waters from foreign organisms that may exist in ballast water collected in foreign harbours and near-shore areas, is for the ballast water to be exchanged in the open ocean, beyond any continental shelf or fresh water current effect. Harbour and coastal waters are often rich in living organisms that could unbalance the Great Lakes fisheries systems. Water in the open ocean contains comparatively fewer organisms. Those organisms that do exist are adapted to life in open salt water and are less likely to survive if accidentally introduced into the Great Lakes fresh water system.

1.3 The intent of these Guidelines is that all ships, bound for river and Great Lakes ports west of 63 degrees west longitude, exchange their ballast, at sea, far enough from any coastline so that there will be few organisms of any kind in the exchanged ballast water.

1.4 These voluntary Guidelines have been developed by the Canadian Coast Guard, in full consultation with the United States Coast Guard, the Great Lakes Fishery Commission, and representatives of commercial shipping. The Canadian Department of Fisheries and Oceans, and the Canadian Department of the Environment were also involved in their development, and fully support their application.

1.5 These Guidelines should not be seen as adding to or detracting from existing statutory or regulatory requirements, which will prevail in the case of conflict with the Guidelines.

2.0 SHORT TITLE

2.1 These Guidelines may be cited by the short title of "Great Lakes Ballast Water Control Guidelines".

3.0 APPLICATION

3.1 The Great Lakes Ballast Water Control Guidelines apply to all vessels transiting the ECAREG VTS Zone that are proceeding toward the St. Lawrence River beyond 63 degrees west longitude.*

3.2 The effective date for introduction of these Guidelines is May l, 1989.

4.0 IMPLEMENTATION

4.1 Applicable ships will be requested to provide ECAREG with the following information, as part of the ECAREG interrogative:

4.2 (i) Whether ballast water is being carried;

4.3 (ii) If the answer to (i) is affirmative, the minimum ocean depth and location where the ballast water was taken on or exchanged.

4.4 Vessels, subject to the Guidelines, will be requested by ECAREG to exchange any ballast water that had not been taken on in ocean depths greater than 2000 metres. The exchange should be made, at sea, as far from land as practicable, in a water depth of not less than 2000 metres.

4.5 In exceptional circumstances, where it may be impracticable to exchange ballast water as per paragraph 4.2, and for those ships that have not left the North American continental shelf on their inbound voyage, the exchange may be made in internal Canadian waters, within the Laurentian Channel and in water depths exceeding 300 metres. Such internal waters exchanges should be restricted to the area southeast of 63 degrees west longitude.

4.6 Canada's pollution prevention regulations restrict the discharge of oil or pollutant substances into waters under Canadian jurisdiction. Ballast water being carried in a bunker fuel tank, or in the cargo tank of a tanker, may be discharged only if the concentration of pollutants in the effluent falls within the allowable limits in the appropriate Canadian legislation; otherwise, the discharge must only be to a shore reception facility.

4.7 It should be noted that the stability of the ship, and any other safety considerations, remain the responsibility of the ship's master. Nothing in these Guidelines should be construed as an infringement upon that responsibility.

4.8 When pumping out ballast water, preparatory to an exchange in accordance with these Guidelines, the pump should be run until it loses suction, thus assuring that the tank is reasonably empty before commencing to take on the new ballast water.

4.9 A record of the salinity of the ballast water to be discharged in the Great Lakes and the location, date and time of the ballast water exchange should be entered in the ship's log book, or in other suitable documentation.

5.0 TANK SEDIMENT DISPOSAL

5.1 Sediment from the ballast tanks of foreign-going ships is to be disposed of only in land dumpsites.

6.0 COMPLIANCE MONITORING

6.1 If not already carried on board, ships to which these Guidelines apply will be provided with a copy by the pilot boarding the vessel at Les Escoumins. The Ballast Water Exchange Report Form (Appendix A to the Guidelines) is to be carefully completed by the ship's master. The completed Report Form will be used to verify the information previously provided to ECAREG and as a means of compliance and effectiveness monitoring of the Guidelines. For those ships passing through the St. Lambert Lock, the completed Report Form is to be given to the Lockmaster at the St. Lambert Lock. For those ships not proceeding through the locks, the completed form should be given to a Canadian Coast Guard steamship inspector or the ship's agent and/or forwarded to the Chief, Pollution Prevention, AMSE, Ship Safety Branch, Canadian Coast Guard, 344 Slater Street, Ottawa, Ont. K1A 0N7 (fax 613-954-4916). Samples of ballast water may also be taken for the purpose of assessing the effectiveness of the Guidelines. Any problems encountered should be indicated under Remarks on the Report Form.

6.2 These Guidelines are being introduced on a voluntary compliance basis, in the expectation of customary cooperation from the shipping industry. It is in the interests of all parties to work for their success.

6.3 It should be noted that under the Canada Shipping Act it is an offence, punishable by a fine of up to $50,000 to refuse to provide information, or to knowingly provide false information to a vessel traffic regulator, where such information is requested for the promotion of environmental protection.

Amendment No. 4
31 March 1993

* Eastern Canada Vessel Traffic Services Zones. For detailed information refer to the Annual Edition of Canadian Notice to Mariners, Notice 26.

Appendix 2. Ballast questionnaire to be completed by ships' officers during the remote survey.

GULF OF ST. LAWRENCE AND ESTUARY BALLAST WATER SURVEY
Collected for the Department of Fisheries and Oceans of Canada

Date: ___________

Vessel Name: ____________________ Vessel Type: ______________________________
Flag: _______________ Official No.: ____________________ GRT __________________
Please record the above information as it appears on the ship's specifications.

Present Port of Call: ____
Date of Arrival: _________________ Date of Departure: ______________________
Did the vessel arrive at this port in ballast or with cargo? Circle One: Ballast Cargo

Last Canadian Port and Country of Call: ______________________________ Date of Departure ______________
Last Foreign Port and Country of Call: ______________________________ Date of Departure ______________
Next Canadian Port and Country of Call: ______________________________ Date of Arrival ______________
Next Foreign Port and Country of Call: ______________________________ Date of Arrival ______________

For the following, please record units (metric tons: MT; cubic metres: m^3; or specify other) for all quantities (estimate if necessary; if "no ballast" in some cases, enter 0 or nil).

List the vessel's ballast capacity and quantity of ballast carried on arrival for all ballast tanks and ballastable cargo holds, if any. Record the quantity of ballast discharged in the Gulf of St. Lawrence before arrival and the total quantity to be discharged in port before departure

	Ballast Tanks	Cargo Hold(s)	Total Ballast
Vessel Ballast Water Capacity:	________	________	________
Quantity of Ballast Carried on Arrival at this Port:	________	________	________
Quantity of Ballast Discharged in Gulf Before Arrival:	________	________	________
Total Ballast to be Discharged in Port Before Departure:	________	________	________

Was Ballast water exchanged or flushed before arrival in the present port of call (circle answer)?
Exchanged: Yes No If Yes to either question, where_______________________
Flushed: Yes No If Yes to either question, how much (circle percentage range below)?
Ballast Tanks: 1-25% 26-50% 51-75% 79-100%
Cargo Hold(s): 1-25% 26-50% 51-75% 79-100%

Record the Source (Sources if more than one) of **Ballast Water** Carried on Arrival in the Ballast Tanks and Cargo Holds, date ballasted for each source, and quantity ballasted from each source (record port and country if in port; longitude and latitude if at sea).

	Source(s) of Ballast Water	Date Ballasted	Quantity Ballasted
Ballast Tanks:	____________	________	____________
	____________	________	____________
Cargo Hold(s):	____________	________	____________
	____________	________	____________

Is this vessel capable of exchanging all of its ballast water at sea? Y N
If No, how much cannot be exchanged?______________________________
How much "unpumpable" water is retained in the ballast tanks after complete discharge? __________

Completed by: ______________________________ Rank ____________________

Appendix 3. Student's *t*-tests comparing the mean values of the total zooplankton density, total copepod density, total number of zooplankton taxa, and total number of copepod taxa between seasons (summer and fall).

Variable	Source of variation	df	*t*-value	*P*-value
Total zooplankton density (ind.$\cdot$m$^{-3}\cdot$vessel^{-1})	Season	85	0.157	0.875
Total copepod density (ind.$\cdot$m$^{-3}\cdot$vessel^{-1})	Season	85	0.251	0.802
Total number of zooplankton taxa (No. of taxa$\cdot$vessel^{-1})	Season	85	1.165	0.248
Total number of copepod taxa (No. of taxa$\cdot$vessel^{-1})	Season	85	0.022	0.982

Appendix 4. Identification and abundance of phytoplankton species caught by plankton net hauls in ballast water from vessels sampled in 1995. The zoogeographic affiliation indicates whether the species have been observed in the Estuary and Gulf of St. Lawrence (EGSL). For species that have never been observed in the EGSL, locations/areas (not exhaustive) are indicated where they have been observed in the Atlantic Ocean and/or in the Mediterranean Sea (NEA: northeast Atlantic; ECA: eastern central Atlantic; NWA: northwest Atlantic; MED: Mediterranean). When available, information on the ecological affinity of the species is indicated, such as neritic (N), oceanic (O), or usually found in the littoral zone (L). The frequency of occurrence (No. of vessels) and density range (cells·m^{-3}) are presented with an index of abundance that was calculated by dividing the total number of cells of a given species by the total number of ships where this species was observed (Very rare: 1 to 100; Rare: 101 to 1000; Uncommon: 1,001 to 10,000; Common: 10,001 to 100,000; Abundant: 100,001 to 1,000,000; Very abundant > 1,000,000).

Species	Zoogeographic affiliation	Occurence (No. of vessels)	Density range (Cells·m^{-3})	Index of abundance
Centric Diatoms				
Actinocyclus roperii	NEA (L)	1	0 - 49	Very rare
A. normanii fo. *normanii**	NEA	28	0 - 89,502	Uncommon
A. normanii fo. *subsalsus**	NEA	2	0 - 4,322	Uncommon
A. octonarius	NEA, MED (N)	2	0 - 260	Rare
A. octonarius vr. *crassus*	NEA, MED (N)	10	0 - 781	Rare
A. octonarius vr. *octonarius*	NEA, MED (N)	5	0 - 493	Rare
A. subtilis	NEA	1	0 - 918	Rare
Actinoptychus senarius	EGSL	14	0 - 8 875	Rare
A. splendens	NEA (L)	5	0 - 802	Rare
Aulacodiscus argus	NEA, NWA (L)	2	0 - 208	Rare
Aulacoseira sp.*	?	1	0 - 4	Very rare
*A. ambigu**	?	6	0 - 534,331	Common
A. granulata vr. *angustissim**	?	7	0 - 34,306	Uncommon
A. granulata vr. *granulata**	?	20	0 - 230,766	Common
A. granulata vr. sp.*	?	1	0 - 884	Rare
*A. islandica**	EGSL	3	0 - 39,249	Common
*Azpeitia nodulifera***	NEA	3	0 - 59	Very rare
Bacteriastrum delicatulum	NEA, MED (O)	3	0 - 179	Very rare
*B. elongatum***	NEA (O)	1	0 - 144	Rare
B. hyalinum	NEA, MED (N)	17	0 - 96,492	Uncommon
*Bellarochea horologicalis***	NWA	2	0 - 10,021	Uncommon
B. malleus fo. sp.	EGSL	2	0 - 68	Very rare
Biddulphia alternans	NEA (N)	5	0 - 94	Very rare
*B. reticulum***	NEA (L)	1	0 - 10	Very rare
Cerataulina pelagica Ψ	EGSL	2	0 - 29	Very rare

* Species usually found in fresh or brackish water

** Species usually found in warm water

Ψ Harmful species

ΨΨ Toxic species

Appendix 4. Continued

Species	Zoogeographic affiliation	Occurence (No. of vessels)	Density range (Cells·m^{-3})	Index of abundance
Centric Diatoms				
C. turgidus	NEA (L)	1	0 - 59	Very rare
Chaetoceros sp.	?	1	0 - 14	Very rare
C. affinis	EGSL	15	0 - 46,125,225	Very abundant
C. atlanticus	EGSL	17	0 - 262,075	Common
C. borealis	EGSL	8	0 - 1,008	Rare
C. compressus	EGSL	1	0 - 29	Very rare
C. concavicornis Ψ	EGSL	13	0 - 262,075	Common
C. constrictus	EGSL	5	0 – 2,271,318	Abundant
C. convolutus Ψ	EGSL	14	0 - 87,358	Uncommon
C. curvisetus	NEA (N)	2	0 - 1,175	Rare
C. debilis Ψ	EGSL	5	0 - 363,856	Common
C. decipiens	EGSL	24	0 - 96,492	Common
C. diadema	EGSL	9	0 - 8,823,196	Abundant
C. didymus	EGSL	14	0 - 96,492	Common
C. diversus	NEA (N)	1	0 - 1,835	Uncommon
C. laciniosus	EGSL	6	0 - 4,700	Rare
C. lorenzianus	EGSL	13	0 - 96,492	Uncommon
*C. messanensis***	NEA (O)	5	0 - 648	Rare
C. mitra	EGSL	5	0 - 96,492	Common
*C. peruvianus***	NEA (O)	11	0 - 96,492	Uncommon
C. pseudocurvisetus	NEA (N)	1	0 - 39	Very rare
*C. rostratus***	NWA	1	0 - 77	Very rare
C. teres	EGSL	1	0 - 8,875	Uncommon
C. wighamii	EGSL	1	0 - 8,875	Uncommon
C. cf. willei	EGSL	2	0 - 637	Rare
*Climacodium frauenfeldianum***	?	2	0 - 26	Very rare
Corethron criophilum Ψ	EGSL	1	0 - 6	Very rare
Coscinodiscus sp.**	?	1	0 - 521	Rare
C. asteromphalus vr. *asteromphalus*	EGSL	11	0 - 3,677	Rare
C. centralis Ψ	EGSL	10	0 - 96,492	Common
C. concinnus Ψ	EGSL	1	0 - 11	Very rare
C. granii	NEA (N)	4	0 - 49	Very rare
C. jonesianus vr. *commutatus**	NEA (L)	6	0 - 208	Very rare
C. jonesianus vr. *jonesianus***	NEA	5	0 - 712	Rare
C. oculus-iridis	NEA (O)	4	0 - 220	Very rare
C. radiatus	EGSL	1	0 - 918	Rare
*C. wailesii*** Ψ	NEA	1	0 - 73	Very rare
*Cyclostephanus dubius**	?	2	0 - 469	Rare
Cyclotella sp.*	?	2	0 - 260	Rare

* Species usually found in fresh or brackish water

** Species usually found in warm water

Ψ Harmful species

ΨΨ Toxic species

Appendix 4. Continued

Species	Zoogeographic affiliation	Occurence (No. of vessels)	Density range (Cells·m^{-3})	Index of abundance
Centric Diatoms				
*C. atomus**	NEA	1	0 - 28,654	Common
C. meneghiniana vr. sp.*	NEA	2	0 - 4,116	Uncommon
C. stelligera	EGSL	2	0 - 208	Rare
C. striata	EGSL	3	0 - 469	Rare
Ditylum brightwellii	NEA (N)	22	0 - 96,492	Uncommon
Eupodiscus radiatus	NWA, NEA	1	0 - 41	Very rare
Guinardia flaccida	NEA (N)	5	0 - 220	Very rare
G. striata	NEA, NWA	1	0 - 72	Very rare
*Helicotheca tamesis***	?	4	0 - 144	Very rare
*Hemidiscus cuneiformis***	NEA(N)	2	0 - 5	Very rare
Hyalodiscus scoticus	EGSL	1	0 - 96,492	Common
Leptocylindrus danicus Ψ	EGSL	1	0 - 370	Rare
L. minimus Ψ	EGSL	14	0 - 61,365	Uncommon
Lithodesmium undulatum	NEA (N)	13	0 - 556	Very rare
*Melosira lineata**	?	4	0 - 1,927	Rare
M. nummuloides	EGSL	1	0 - 23	Very rare
*M. varians**	?	1	0 - 116	Rare
Odontella mobiliensis	NEA, NWA (N)	10	0 - 260	Very rare
O. regia	NEA, NWA (N)	4	0 - 75	Very rare
O. rhombus fo. *rhombus*	NEA (N)	7	0 - 96,492	Common
O. sinensis	NEA (O)	40	0 - 8,875	Rare
Paralia sulcata fo. *radiata*	NEA, NWA (N)	2	0 - 93	Very rare
P. sulcata fo. sp.	EGSL	18	0 - 1,666	Rare
*Planktoniella sol***	NEA	10	0 - 220	Very rare
Proboscia alata fo. *indica*	NEA	1	0 - 6	Very rare
P. alata fo. sp.	EGSL	25	0 - 96,492	Uncommon
*Pseudosolenia calcar-avis***	NEA	4	0 - 8,875	Uncommon
*Rhizosolenia bergonii***	NEA	4	0 - 87,358	Commun
*R. castracanei***	NEA	1	0 - 72	Very rare
R. hebetata fo. *semispina*	EGSL	1	0 - 72	Very rare
R. imbricata	EGSL	22	0 - 96,492	Uncommon
R. robusta	NEA (O)	3	0 - 49	Very rare
R. setigera	EGSL	24	0 - 578,954	Common
R. styliformis	NEA (O)	4	0 - 918	Rare
Roperia tessellata	NEA	1	0 - 43	Very rare
Skeletonema costatum Ψ	EGSL	9	0 - 24,391	Uncommon
*Stephanodiscus hantzschii**	NEA	3	0 - 1,511	Rare
S. rotula vr. *minutula**	NEA	1	0 - 29	Very rare
S. rotula vr. sp.*	?	1	0 - 185	Rare

* Species usually found in fresh or brackish water

** Species usually found in warm water

Ψ Harmful species

ΨΨ Toxic species

Appendix 4. Continued

Species	Zoogeographic affiliation	Occurence (No. of vessels)	Density range (Cells·m^{-3})	Index of abundance
Centric Diatoms				
*Stephanopyxis palmeriana***	NEA (N)	1	0 - 128	Rare
S. turris	NEA (N)	5	0 - 96,492	Common
Thalassiosira sp.	?	2	0 - 2,605	Uncommon
T. anguste-lineata	EGSL	2	0 - 356	Rare
*T. baltica**	NEA	2	0 - 220	Rare
*T. eccentrica***	NEA	9	0 - 192,985	Common
*T. hyperborea vr. pelagica***	NEA	1	0 - 2,032	Uncommon
T. leptopus	NEA	1	0 - 20	Very rare
T. nordenskioeldii	EGSL	1	0 - 87,358	Common
*T. punctigera***	NEA	8	0 - 40	Very rare
T. weissflogii	EGSL	1	0 - 5,210	Uncommon
Triceratium favus	NEA (N)	8	0 - 469	Very rare
Pennate Diatoms				
Achnanthes sp.	?	1	0 - 729	Rare
A. lanceolata vr. *elliptica* *	NEA	2	0 - 938	Rare
A. lanceolata vr. sp.*	NEA	1	0 - 260	Rare
Amphora ovalis fo. sp.	EGSL	3	0 - 469	Rare
Asterionella bleakeleyi	?	3	0 - 358	Rare
A. gracillima	?	2	0 - 1 338	Rare
Asterionellopsis glacialis	EGSL	3	0 - 103,536,302	Very abundant
Caloneis amphisbaema fo. sp.*	NEA (N)	1	0 - 521	Rare
Cocconeis pediculus	EGSL	4	0 - 364	Rare
C. placentula vr. *euglypta*	EGSL	3	0 - 729	Rare
C. placentula vr. sp.**	NEA (N)	2	0 - 72	Very rare
Ctenophora pulchella	EGSL	1	0 - 10	Very rare
Cymatopleura elliptica vr. *nobilis**	NEA (L)	1	0 - 208	Rare
*Cymatopleura librile**	NEA	2	0 - 469	Rare
Cymbella aspera vr. sp.*	NEA	1	0 - 29	Very rare
C. cistula vr. sp.*	NEA	1	0 - 260	Rare
C. prostrata vr. *auerswaldii**	NEA	2	0 - 469	Rare
Delphineis surirella	NEA (N)	3	0 - 208	Rare
Diatoma tenue vr. *elongatum**	EGSL	1	0 - 260	Rare
D. tenue vr. *tenue**	NEA (N)	1	0 - 208	Rare
D. vulgare vr. sp.*	EGSL	2	0 - 417	Rare
D. vulgare vr. *vulgare**	NEA (N)	1	0 - 208	Rare
*Encyonema silesiacum***	NEA (N)	3	0 - 1,436	Rare
Eunotia sp.*	NEA	1	0 - 32	Very rare
Fragilaria sp.	?	4	0 - 729	Rare
Fragilaria construens vr. *venter**	NEA	1	0 - 58	Very rare

* Species usually found in fresh or brackish water

** Species usually found in warm water

Ψ Harmful species

ΨΨ Toxic species

Appendix 4. Continued

Species	Zoogeographic affiliation	Occurence (No. of vessels)	Density range (Cells·m^{-3})	Index of abundance
Pennate Diatoms				
*F. crotonensis**	NEA (N)	7	0 - 2,604	Rare
F. striatula	EGSL	6	0 - 87,358	Common
F. vaucheriae vr. *vaucheriae**	NEA (N)	1	0 - 208	Rare
Frustulia rhomboides vr. sp.	EGSL	1	0 - 208	Rare
Gomphonema angustatum vr. sp.	EGSL	1	0 - 208	Rare
G. parvulum vr. sp.	EGSL	1	0 - 469	Rare
Grammatophora. serpentina	?	1	0 - 49	Very rare
Gyrosigma sp.	NEA	1	0 - 208	Rare
*G. acuminatum**	NEA (N)	1	0 - 260	Rare
G. acuminatum vr. sp.*	NEA (N)	1	0 - 1,848	Uncommon
G. balticum	EGSL	1	0 - 6	Very rare
Hantzschia amphioxys vr. sp.*	NEA	2	0 - 208	Rare
Licmophora sp.	?	1	0 - 771,939	Abundant
*Lioloma pacificum***	MED (N)	1	0 - 96,492	Common
Lyrella lyra	NEA (N)	1	0 - 21	Very rare
Navicula sp.	?	2	0 - 1,979	Rare
N. radiosa vr. sp.*	NEA (N)	1	0 - 58	Very rare
*Neidium bisulcatum vr. subundulatum**	?	1	0 - 260	Rare
Nitzschia sp.	?	2	0 - 12,397	Uncommon
N. amphibia vr. sp*.	NEA	1	0 - 260	Rare
N. hungarica	NEA, MED (N)	1	0 - 208	Rare
*N. sigmoidea**	NEA	2	0 - 469	Rare
Pinnularia sp.	NEA	1	0 - 208	Rare
Pleurosigma formosum	EGSL	1	0 - 96,492	Common
P. strigosum	EGSL	1	0 - 1	Very rare
Pseudo-nitzschia pungens ΨΨ	EGSL	12	0 - 4,921,110	Abundant
Pseudo-nitzschia seriata ΨΨ	EGSL	1	0 - 8,875	Uncommon
Rhabdonema minutum	EGSL	1	0 - 49	Very rare
*Rhaphoneis amphiceros**	NEA (N)	5	0 - 469	Rare
Rhoicosphenia abbreviata	EGSL	1	0 - 2,032	Uncommon
Stauroneis phoenicenteron vr. sp.*	NEA (N)	1	0 - 208	Rare
Surirella biseriata vr. sp*.	NEA	1	0 - 469	Rare
S. ovata vr. sp.	EGSL	1	0 - 677	Rare
S. robusta vr. sp.*	NEA	1	0 - 208	Rare
*Synedra ulna**	NEA (N)	2	0 - 5,210	Uncommon
S. ulna vr. *aequalis**	?	1	0 - 260	Rare
S. ulna vr. *amphirhynchus**	?	1	0 - 208	Rare
S. ulna vr. *danica**	NEA	1	0 - 469	Rare
S. ulna vr. sp.*	NEA	4	0 - 417	Rare

* Species usually found in fresh or brackish water

** Species usually found in warm water

Ψ Harmful species

ΨΨ Toxic species

Appendix 4. Continued

Species	Zoogeographic affiliation	Occurence (No. of vessels)	Density range (Cells·m^{-3})	Index of abundance
Pennate Diatoms				
Synedra parasitica vr. *subconstricta**	NEA	1	0 - 260	Rare
Tabellaria sp.*	NEA	1	0 - 58	Very rare
*T. fenestrata**	EGSL	2	0 - 90	Very rare
T. flocculosa vr. sp.*	EGSL	6	0 - 8,875	Uncommon
*Thalassionema frauenfeldii***	NEA (N)	2	0 - 614	Rare
T. nitzschioides	EGSL	6	0 - 87,358	Common
Thalassiothrix longissima	EGSL	13	0 - 174,717	Common
Cyanophytes				
Lyngbya majuscula (colony)*	?	1	0 - 17	Very rare
Chlorophytes				
Coelastrum sp.*	?	1	0 - 260	Rare
Cosmarium sp.*	?	1	0 - 185	Rare
Pediastrum boryanum (colony)*	?	4	0 - 469	Rare
P. boryanum vr. *longicorne* (colony)*	?	1	0 - 30	Very rare
P. clathratum (colony)*	?	3	0 - 83	Very rare
P. duplex vr. *pulchrum* (colony)*	EGSL	2	0 - 781	Rare
P. simplex (colony)*	?	1	0 - 1	Very rare
Scenedesmus sp. (colony)*	EGSL	1	0 - 260	Rare
*Staurastrum paradoxum**	?	1	0 - 208	Rare
Chrysophytes				
Dictyocha fibula	EGSL	7	0 - 96,492	Common
Distephanus speculum Ψ	EGSL	6	0 - 96,492	Common
Ebria tripartita Ψ	EGSL	1	0 - 96,492	Common
Dinoflagellates				
Ceratium arcticum Ψ	EGSL	48	0 - 87,358	Uncommon
*C. arietinum***	NEA, NWA (N,O)	6	0 - 96,492	Common
*C. azoricum***	NEA, NWA (N,O)	1	0 - 29	Very rare
*C. concillans***	NEA, NWA (N,O)	2	0 - 31	Very rare
*C. contortum***	NEA, NWA (N,O)	1	0 - 167	Rare
*C. contrarium***	NEA, MED (O)	8	0 - 32	Very rare
*C. declinatum***	NEA, NWA (O)	1	0 - 220	Rare
*C. euarcuatum***	NEA, MED (O)	3	0 - 72	Very rare
*C. extensum***	NEA, MED (O)	19	0 - 12,883	Rare
*C. falcatum***	NEA, NWA, MED	1	0 - 38	Very rare
C. furca	NEA (N)	15	0 - 1,569	Rare
C. fusus Ψ	EGSL	82	0 - 436,792	Common
*C. gibberum***	NEA (N,O)	5	0 - 260	Very rare
*C. gravidum***	NEA (O)	1	0 - 11	Very rare
C. hexacanthum	NEA (N,O)	9	0 - 264	Very rare

* Species usually found in fresh or brackish water

** Species usually found in warm water

Ψ Harmful species

ΨΨ Toxic species

Appendix 4. Continued

Species	Zoogeographic affiliation	Occurence (No. of vessels)	Density range (Cells·m^{-3})	Index of abundance
Dinoflagellates				
Ceratium horridum	NEA (N,O)	4	0 - 127	Very rare
*C. inflatum***	NEA (O)	8	0 - 1,937	Rare
C. longipes	EGSL	41	0 - 174,717	Uncommon
*C. longirostrum***	NEA, MED	13	0 - 15,689	Uncommon
*C. macroceros***	NEA, MED (N,O)	48	0 - 3,897	Rare
C. macroceros vr. *gallicum***	NEA, MED (N, O)	3	0 - 377	Rare
*C. massiliense***	NEA (N,O)	4	0 - 45	Very rare
*C. pentagonum***	NEA (O)	1	0 - 6	Very rare
C. platycorne vr. sp.**	NEA (O)	1	0 - 72	Very rare
*C. symmetricum***	NEA	1	0 - 918	Rare
*C. trichoceros***	NEA (N,O)	2	0 - 216	Rare
C. tripos	EGSL	61	0 - 96,492	Uncommon
Dinophysis norvegica ΨΨ	EGSL	2	0 - 7	Very rare
Dissodinium pseudocalanni	NEA	3	0 - 163	Rare
*Dissodinium pseudolunula***	NEA (O)	1	0 - 12	Very rare
Gonyaulax rostratum	NEA	1	0 - 1	Very rare
Gonyaulax sp. (cysts)	?	3	0 - 8,875	Uncommon
*Ornithocercus steinii***	NEA (O)	1	0 - 6	Very rare
Phalacroma rotundatum ΨΨ	EGSL	1	0 - 18	Very rare
Prorocentrum compressum ΨΨ	EGSL	1	0 - 3	Very rare
Prorocentrum lima ΨΨ	EGSL	1	0 - 1	Very rare
Protoperidinium sp. 1	?	2	0 - 67	Very rare
Protoperidinium sp. 2	?	2	0 - 26	Very rare
P. claudicans	EGSL	1	0 - 1	Very rare
P. curtipes	NEA	2	0 - 72	Very rare
P. denticulatum	EGSL	10	0 - 8,875	Rare
P. depressum	EGSL	2	0 - 69	Very rare
*P. divergens***	NEA (N)	24	0 - 87,358	Uncommon
*P. leonis***	NEA, NWA (N,O)	1	0 - 18	Very rare
*P. oceanicum***	NEA, NWA (N,O)	2	0 - 14	Very rare
P. ovatum	EGSL	1	0 - 9	Very rare
P. pallidum	EGSL	3	0 - 8,875	Uncommon
P. pentagonum	EGSL	2	0 - 8,875	Uncommon
Pyrophacus horologium	EGSL	1	0 - 141	Rare
Tintinnids				
Codonellopsis sp.	EGSL	1	0 - 5	Very rare
Coxliella annulata	EGSL	1	0 - 15	Very rare
C. cf. *annulata*	NEA	1	0 - 15	Very rare
Epiorella sp.**	?	1	0 - 1	Very rare

* Species usually found in fresh or brackish water

** Species usually found in warm water

Ψ Harmful species

ΨΨ Toxic species

Appendix 4. Continued

Species	Zoogeographic affiliation	Occurence (No. of vessels)	Density range (Cells·m^{-3})	Index of abundance
Tintinnids				
Eutintinnus sp.	EGSL	4	0 - 19	Very rare
E. fraknoi	NEA, NWA (O)	1	0 - 43	Very rare
E. lusus-undae	NEA, MED (O)	10	0 - 139	Very rare
E. macilentus	NEA, MED(O)	1	0 - 6	Very rare
E. tubiformis	NEA (O)	13	0 - 87,358	Uncommon
Favella sp.	?	3	0 - 56	Very rare
F. fistulicauda	ECA, MED (N)	3	0 - 45	Very rare
F. panamensis	NEA (N)	5	0 - 127	Very rare
F. serratus	EGSL	10	0 - 8,875	Rare
Helicostomella sp.	?	1	0 - 3	Very rare
H. edentata	ECA, NEA (N)	3	0 - 6	Very rare
H. subulata	EGSL	2	0 - 14	Very rare
Parafavella sp.	?	15	0 - 87,358	Uncommon
P. curvata	NEA (O)	1	0 - 41	Very rare
P. denticulata	EGSL	1	0 - 45	Very rare
P. edentata	NEA, NWA (O)	2	0 - 161	Very rare
P. media	NEA, NWA (O)	3	0 - 9	Very rare
Ptychocylis acuta	NEA, NWA (O)	1	0 - 1	Very rare
P. drygalskii	EGSL	1	0 - 87,358	Common
P. obtusa	EGSL	11	0 - 8,875	Rare
P. urnula	NEA, NWA (O)	1	0 - 7	Very rare
*Rhabdonella conica***	NEA, NWA, ECA	2	0 - 7	Very rare
*R. cuspidata***	?	6	0 - 260	Very rare
*R. henseni***	NWA, ECA	1	0 - 1	Very rare
*R. torta***	?	2	0 - 47	Very rare
Salpingacantha undata	NEA, NWA (O)	2	0 - 5	Very rare
Salpingella acuminata	EGSL	1	0 - 212	Rare
S. attenuata	MED	3	0 - 87,358	Common
Tintinnopsis beroidea	EGSL	1	0 - 19	Very rare
T. campanula	EGSL	1	0 - 8,875	Uncommon
T. campanula	EGSL	1	0 - 8,875	Uncommon
T. lobiancoi	NEA, NWA (N)	1	0 - 82	Very rare
T. strigosa	NEA (N)	2	0 - 5	Very rare
Undella hyalina	NEA, NWA, MED	1	0 - 14	Very rare
*Xystonella lanceolata***	MED	1	0 - 19	Very rare
*X. lohmanni***	NEA, NWA, MED	3	0 - 72	Very rare
*X. longicauda***	MED	11	0 - 963	Rare
*X. minuscula***	?	1	0 - 3	Very rare
*X. treforti***	NEA, NWA, MED	1	0 - 32	Very rare
X. cf. *treforti***	?	5	0 - 72	Very rare

* Species usually found in fresh or brackish water

** Species usually found in warm water

Ψ Harmful species

ΨΨ Toxic species

Appendix 5. Identification and abundance of zooplankton species and taxa caught by plankton net hauls in ballast water from vessels sampled in 1995. The zoogeographic affiliation indicates whether the species or taxa has been observed in the Estuary and Gulf of St. Lawrence (EGSL). For species or taxa that have never been observed in the EGSL, locations/areas (not exhaustive) are indicated where they have been observed (NEA: northeast Atlantic; ECA: eastern central Atlantic; NWA: northwest Atlantic; MED: Mediterranean). The frequency of occurrence (No. of vessels) and density range (ind.·m^{-3}) are presented along with an index of abundance, which was calculated by dividing the total number of individuals of a given taxa by the total number of ships where this taxa was observed (Rare: 1 to 10; Uncommon: 11 to 100; Common: 101 to 1000; Abundant: 1001 to 5,000; Very abundant: > 5,000 ind.·m^{-3}).

Species	Zoogeographic affiliation	Occurrence (No. of vessels)	Density range (ind.·m^{-3})	Index of abundance
Phylum Cnidaria	?	11	0-7,967	Common
Phylum Nematoda	?	7	0-9	Rare
Phylum Mollusca				
Class Gastropoda	?	28	0-825	Common
Class Pelecypoda	?	38	0-6,767	Common
Phylum Annelida				
Class Polychaeta				
Nepthyidae (larvae)	?	3	0-90	Uncommon
Phyllodocidae (larvae)	?	2	0-2	Rare
Nereidae (larvae)	?	3	0-764	Common
Polynoidae (larvae)	?	1	0-13	Uncommon
Spionidae (larvae)	?	20	0-698	Uncommon
Syllidae (larvae)	?	1	0-2	Rare
Terebellidae (larvae)	?	1	0-26	Uncommon
Phylum Arthropoda				
Class Crustacea				
Subclass Branchiopoda				
Evadne sp.	?	6	0-177	Uncommon
Podon sp.	?	5	0-177	Uncommon
Daphniidae	?	5	0-8 679	Abundant
Subclass Ostracoda	?	1	0-1	Rare
Subclass Copepoda				
Copepoda unidentified	?	2	0-80	Uncommon
Order Calanoida				
Acartia clausi	EGSL	31	0-3,698	Common
Acartia longiremis	EGSL	4	0-170	Common
Acartia tonsa	EGSL	20	0-11,966	Abundant
Acartia sp.	?	15	0-535	Common
Calanus finmarchicus	EGSL	17	0-2,306	Common
*Calanus tenuicornis***	ECA, MED	1	0-18	Uncommon
Calanus sp.	?	8	0-226	Uncommon
Calocalanus contractus	NEA	1	0-2	Rare
Candacia sp.	EGSL	1	0-2	Rare

* Species usually found in fresh or brackish water

** Species usually found in warm water

Appendix 5. Continued

Species	Zoogeographic affiliation	Occurrence (No. of vessels)	Density range (ind.·m^{-3})	Index of abundance
Centropages hamatus	EGSL	19	0-6,189	Common
Centropages typicus	EGSL	16	0-21,645	Abundant
Centropages sp.	?	8	0-330	Uncommon
Clausocalanus furcatus	NEA, MED, NWA	15	0-2,812	Common
Euchaeta sp.	?	2	0-150	Uncommon
Eurytemora affinis	EGSL	4	0-25,583	Very abundant
Eurytemora sp.	?	3	0-5	Rare
Labidocera sp.	?	1	0-5	Rare
Metridia lucens	EGSL	1	0-1	Rare
Metridia sp.	?	1	0-71	Uncommon
Microcalanus pygmaeus	EGSL	3	0-40	Uncommon
Paracalanus parvus	EGSL	20	0-5,583	Common
Paracalanus sp. A	?	4	0-94	Uncommon
Paracalanus sp.	?	9	0-781	Uncommon
Pleuromamma gracilis	NEA, MED, NWA	1	0-4	Rare
Pontella sp.	NEA, MED,NWA	1	0-35	Uncommon
Pontellopsis sp.	NEA, MED, NWA	1	0-2	Rare
Pseudocalanus cf. elongatus	EGSL	26	0-3,157	Common
Temora longicornis	EGSL	50	0-6,463	Common
Temora sp.	?	3	0-2,150	Common
Calanoid sp.	?	26	0-1,087	Common
Order Cyclopoida				
Corycaeus sp.	NEA, MED, NWA	11	0-47	Uncommon
*Cyclopina littoralis**	NEA, MED	10	0-177	Uncommon
Cyclopina sp. A	?	1	0-7	Rare
Cyclopinae sp. 1	?	1	0-52	Uncommon
Cyclopinae sp. 2	?	1	0-78	Uncommon
Cyclopoida sp. A*	?	17	0-146	Uncommon
Cyclopoida sp. B*	?	1	0-6	Rare
Cyclops sp.	?	2	0-18,064	Very abundant
*Oithona similis**	EGSL	80	0-41,326	Abundant
Oithona sp. 1	?	15	0-8,224	Abundant
Oithona sp. 2	?	15	0-6,329	Common
Oncaea media	NEA, MED	8	0-4,448	Common
Onceae mediterranea	NEA, MED	1	0-25	Uncommon
Onceae tenella	ECA	3	0-163	Uncommon
Onceae venusta	NEA, MED, NWA	4	0-83	Uncommon
Onceae sp.	?	30	0-249	Uncommon
Sapphirina sp.	ECA, MED, NWA	1	0-1	Rare
Order Harpacticoida				
Amphiascus sp.	?	1	0-14	Uncommon
Alteutha sp.	?	5	0-35	Uncommon
Acrenhydrosoma sp.	NWA	1	0-1	Rare
Bradya sp.	NEA	1	0-2	Rare
Canuella sp.	NEA, NWA	5	0-415	Common
Cletotidae sp.	?	1	0-2	Rare

* Species usually found in fresh or brackish water

** Species usually found in warm water

Appendix 5. Continued

Species	Zoogeographic affiliation	Occurrence (No. of vessels)	Density range (ind.·m^{-3})	Index of abundance
Dactylopodia sp.	?	2	0-28	Uncommon
Ectinosoma sp.	?	1	0-1	Rare
Euterpina acutifrons	NEA, MED	30	0-2,892	Common
Leptocaris tricetosus	NEA	1	0-12	Uncommon
Longipedia sp.	NEA	4	0-94	Uncommon
Macrosetella gracilis	ECA, MED, NWA	2	0-5	Rare
Microsetella norvegica	EGSL	44	0-3,307	Common
Microarthridion sp.	?	1	0-7	Rare
Occulosetella gracilis	NEA, NWA	8	0-3,784	Common
Parathalestris sp.	?	1	0-5	Rare
Pseudobradya beduina	NEA	1	0-2	Rare
Pseudobradya sp.	NEA	2	0-51	Uncommon
Schizopera sp.*	NWA	4	0-12	Rare
Stenhelia gibba	NEA	1	0-1,330	Abundant
Tisbe sp.	EGSL	4	0-403	Common
Subclass Cirripedia				
Cypris larvae	?	29	0-485	Uncommon
Subclass Malacostraca				
Order Amphipoda				
Hyperiidae	?	1	0-28	Uncommon
Caprellidae	?	2	0-85	Uncommon
Order Decapoda	?	9	0-50	Rare
Order Euphausiacea	?	4	0-94	Uncommon
Order Isopoda	?	1	0-16	Uncommon
Order Mysidacea	?	9	0-245	Uncommon
Phylum Chaetognata	?	8	0-186	Uncommon
Phylum Echinodermata	?	8	0-902	Common
Phylum Urochordata				
Class Thaliacea	?	2	0-42	Uncommon
Class Appendicularia	?	3	0-28	Uncommon
Fish larvae	?	1	0-1	Rare
Eggs, unidentified	?	2	0-14	Rare

* Species usually found in fresh or brackish water
** Species usually found in warm water

Appendix 7. Protistan taxa in ballast sediment samples obtained from recently deballasted cargo holds of nine vessels. The zoogeographic affiliation indicates whether the taxa have been observed in the Estuary and Gulf of St. Lawrence (EGSL). For taxa that have never been observed in the EGSL, we indicate locations/areas (not exhaustive) where they have been observed in the Atlantic Ocean and/or in the Mediterranean Sea (NEA: northeast Atlantic; ECA: eastern central Atlantic; NWA: northwest Atlantic; MED: Mediterranean). The frequency of occurrence (No. of vessels) and range (cells·cm^{-3}) are presented along with an index of abundance that was calculated by dividing the total number of cells of a given taxa by the total number of ships where this species was observed (Rare: 1 to 100; Uncommon: 101 to 500; Common: 501 to 1000; Abundant: 1,001 to 5,000; Very abundant > 5,000).

Species	Zoogeographic affiliation	Occurence (No. of vessels)	Density range (Cells·cm^{-3})	Index of abundance
Centric Diatoms				
Biddulphia sp.	?	2	0 - 131	Rare
Chaetoceros spp.	EGSL	2	0 - 56	Rare
C. affinis	EGSL	1	0 - 71	Rare
C. concavicornis Ψ	EGSL	1	0 - 5,783	Very abundant
C. costatus	NEA	1	0 - 85,798	Very abundant
C. diadema	EGSL	1	0 - 4,447	Abundant
Leptocylindrus minimus Ψ	EGSL	1	0 - 29	Rare
Lithodesmium sp.	NEA	3	0 - 415	Uncommon
Melosira spp.	EGSL	4	0 - 3,135	Abundant
M. arctica	EGSL	1	0 - 83	Rare
Odontella aurita	EGSL	1	0 - 94	Rare
Paralia sulcata	EGSL	1	0 - 178	Uncommon
Rhizosolenia sp.	EGSL	1	0 - 71	Rare
Skeletonema costatum Ψ	EGSL	1	0 - 964	Common
Thalassiosira spp.	EGSL	6	0 - 1,150	Uncommon
T. nitzschioides	EGSL	2	0 - 1,846	Abundant
T. gravida	EGSL	1	0 - 606	Common
Pennate Diatoms				
Amphiprora sp.	EGSL	1	0 - 85	Rare
Asterionellopsis glacialis	EGSL	3	0 - 1,000	Uncommon
Cymatosira lorenziana	?	2	0 - 56	Rare
Gyrosigma sp.	EGSL	2	0 - 290	Uncommon
Navicula sp.	EGSL	2	0 - 589	Uncommon
Nitzschia sp.	EGSL	2	0 - 586	Uncommon
Pseudo-nitzschia seriata ΨΨ	EGSL	3	0 - 142	Rare
Pleurosigma sp.	EGSL	1	0 - 99	Rare
Unidentified diatoms	?	2	0 - 310	Uncommon
Dinoflagellates				
Ceratium sp.	?	1	0 - 32	Rare
C. fusus Ψ	EGSL	1	0 - 67	Rare
C. longipes	EGSL	1	0 - 106	Uncommon

* Species usually found in fresh or brackish water

Ψ Harmful species

ΨΨ Toxic species

Appendix 7. Continued

Species	Zoogeographic affiliation	Occurence (No. of vessels)	Density range (Cells·cm^{-3})	Indexe of abundance
Dinophysis sp.	?	1	0 - 33	Rare
D. diegensis	?	1	0 - 71	Rare
D. norvegica ΨΨ	EGSL	1	0 - 1,344	Abundant
Dinoflagellates				
Diplopeltopsis minor	?	1	0 - 383	Uncommon
Gonyaulax sp.	EGSL	4	0 - 1,875	Common
G. spinifera (cysts)	EGSL	1	0 - 30	Rare
Heterocapsa triquetra	EGSL	2	0 - 356	Uncommon
Peridinium sp.	EGSL	4	0 - 167	Rare
P. cinctum		1	0 - 29	Rare
P. crassipes	EGSL	1	0 - 208	Uncommon
Prorocentrum spp.	EGSL	2	0 - 233	Uncommon
P. micans	EGSL	4	0 - 2,389	Abundant
Protoperidinium spp.	EGSL	1	0 - 1,453	Abundant
P. conicum (cysts)	EGSL	2	0 - 318	Uncommon
P. divergens	EGSL	1	0 - 29	Rare
P. pellucidum	EGSL	1	0 - 58	Rare
Scrippsiella sp. (cysts)	?	1	0 - 442	Uncommon
S. trochoidea (cysts)	EGSL	2	0 - 509	Uncommon
Dinoflagellates spp. (cysts)	?	4	0 - 200	Rare
Dinoflagellates spp.	?	4	0 - 34,292	Very abundant
Prasinophytes				
Pterosperma sp.	EGSL	1	0 - 505	Common
Chrysophytes				
Dictyocha antarctica	?	3	0 - 288	Uncommon
D. fibula	EGSL	2	0 - 149	Rare
D. speculum ΨΨ	EGSL	5	0 - 583	Uncommon
Distephanus sp.	?	1	0 - 292	Uncommon
Uroglena sp.(cysts)*	?	1	0 - 77	Rare
Unidentified Chrysophytes	?	1	0 - 30	Rare
Chlorophytes				
*Characium limneticum**	?	1	0 - 29	Rare
*Pediastrum boryanum**	?	2	0 - 143	Rare
*P. duplex**	EGSL	1	0 - 167	Uncommon
*Scenedesmus acuminatus**	?	1	0 - 200	Uncommon
Staurastrum sp.*	?	1	0 - 82	Rare
Unidentified Chlorophytes	?	5	0 - 903	Uncommon
Tintinnids				
Parafavella denticulata	EGSL	1	0 - 833	Common
Favella composita	?	2	0 - 963	Uncommon
Tintinnopsis sp.	?	7	0 - 1,317	Common

* Species usually found in fresh or brackish water

Ψ Harmful species

ΨΨ Toxic species

Appendix 7. Continued

Species	Zoogeographic affiliation	Occurence (No. of vessels)	Density range (Cells·cm^{-3})	Indexe of abundance
Pollen				
Pinus spp.*	?	1	0 - 25	Rare
Unidentified Pollen *	?	4	0 - 461	Uncommon
Unknown		9	146 - 16,918	Very abundant

* Species usually found in fresh or brackish water

Ψ Harmful species

ΨΨ Toxic species