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Alternate Ballast Water Exchange Zones for the Newfoundland and Labrador Region – An Aquatic Invasive Species Risk Assessment Based on Oceanographic Modelling, Ecologically and Biologically Significant Areas and the Sustainability of Fisheries and Aquaculture

Zones alternatives de renouvellement de l'eau de ballast pour la région de Terre-Neuve-et-Labrador – Une évaluation du risque pour les espèces aquatiques envahissantes fondée sur la modélisation océanographique, les zones d'importance écologique et biologique et la durabilité des pêches et de l'aquaculture

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ABSTRACT

The scientific advice on alternate ballast water exchange zones (ABWEZ) for the Newfoundland and Labrador region is based on oceanographic modelling (dispersion results), ecologically and biologically significant areas (EBSAs) and the sustainability of fisheries and aquaculture. Potential exchange zones are based on individual vessel routes approaching the Newfoundland and Labrador region and areas of the northwest Atlantic Ocean. The spatial distribution of the surface concentration and the temporal and spatial variation of the dispersion area are all taken into account. EBSAs, identified as part of the Integrated Management strategy for the Placentia Bay - Grand Bank (PBGB) Large Ocean Management Area (LOMA), have also been considered in this risk assessment; as have the areas significant to commercial fisheries and aquaculture. This study presents a first quantitative assessment of ballast water exchange off Newfoundland based on verified model circulation patterns and extensive numerical drift experiments. The potential exchange zones are based on the monthly-mean circulation fields fixed at the 1-m depth. The sensitivity study has indicated some evident impacts of vertical turbulence, while inclusion of the vertical current, weather-band currents and diel migration have limited effects on horizontal dispersion patterns.

Based on the review of the current navigation conditions and the ecological sensitivities of the areas for potential ABWEZs on the east coast of Newfoundland and Labrador, no ABWEZ's are being recommended at this time. For the northeastern coast of Newfoundland an ABWEZ could be located at least 50 nautical miles offshore and in depths greater than 500 m; but further research is needed before any formal recommendation is made.

The scientific review of marine traffic around Newfoundland and Labrador indicates that domestic and coastal commercial traffic would represent a higher risk of aquatic invasive species invasion than international commercial traffic under the current regulations.

RÉSUMÉ

L’avis scientifique sur les zones alternatives de renouvellement de l’eau de ballast (ZAREB) pour la région de Terre-Neuve-et-Labrador repose sur la modélisation océanographique (résultats de la dispersion), les zones d’importance écologique et biologique (ZIEB) et la durabilité des pêches et de l’aquaculture. L’établissement des zones de renouvellement potentielles s’appuie sur les trajectoires des navires individuels qui s’approchent des côtes de Terre-Neuve-et-Labrador et des eaux de l’Atlantique Nord-Ouest. La distribution spatiale des concentrations en surface et la variation spatiale et temporelle de l’aire de dispersion sont autant d’éléments pris en compte. Les ZIEB, déterminées dans le cadre de la stratégie de gestion intégrée de la zone étendue de gestion des océans (ZEGO) de la baie Placentia et du Grand Banc, ont également été prises en considération dans cette évaluation du risque, tout comme les zones d’importance pour l’aquaculture et les pêches commerciales. Cette étude constitue la première évaluation quantitative du renouvellement de l’eau de ballast au large de Terre-Neuve reposant sur les modes de circulation vérifiés par modélisation et des expériences de prévision numérique de la dérive. L’établissement des zones de renouvellement potentielles s’appuie sur les champs de circulation moyenne mensuelle fixés à une profondeur d’un mètre. L’étude de sensibilité a révélé des répercussions évidentes de la turbulence verticale, tandis que l’inclusion du courant vertical, des fourchettes de fluctuations des courants et de la migration nycthémérale a des effets limités sur les modes de dispersion horizontale.

D’après l’examen des conditions de navigation actuelles et de la sensibilité écologique des ZIEB à des ZAREB potentielles, il est recommandé de ne pas établir de ZAREB sur la côte est de Terre-Neuve-et-Labrador. Sur la côte nord-est de Terre-Neuve, une ZAREB pourrait être établie à une distance d’au moins 50 milles marins du rivage, par plus de 500 m de fond. Des recherches supplémentaires doivent toutefois être menées avant qu’une recommandation officielle puisse être formulée.

L’examen scientifique du trafic maritime dans les eaux de Terre-Neuve-et-Labrador indique que le trafic intérieur et le trafic commercial côtier constitueraient un risque plus élevé d’invasion par des espèces aquatiques envahissantes que le trafic commercial international en vertu du règlement actuel.

RATIONALE FOR NEWFOUNDLAND AND LABRADOR REGION ALTERNATE BALLAST EXCHANGE ZONE STUDY

Many potential vectors act to transport and inoculate aquatic invasive species (AIS) into a non-indigenous enviro nment. Exchange of ballast waters and sediments, and hull fouling are thought to be the principal causes for introductions of marine AIS, although other human activities may also facilitate transfer of organisms (Pederson et al. 2005). The recent discovery of the European green crab (*Carcinus maenas*) in Placentia Bay, Newfoundland and Labrador and the popular belief that this invasive species was introduced through ballast water from a ship or ships arriving in ballast at Placentia Bay ports have increased the awareness of the AIS risk associated with shipping transport in the Newfoundland region (McKenzie et al. 2007).

Analysis of ballast samples in 2001 (Carver and Mallet 2002) from Atlantic Canada confirmed the presence of a wide range of phytoplankton and zooplankton species with high species densities. Species contained in ballast samples may range from single-celled microscopic organisms to larger invertebrate and vertebrate animals (Gollasch et al. 2007). Once AIS are released and become established in a given area, they can continue to spread to other areas by secondary vectors such as localized currents, hull fouling and sea chests of recreational and commercial fishing vessels, aquaculture nets and rigging, and other man-made structures which act to provide additional new substrates for colonization (Coutts et al. 2003).

Mid-ocean exchange (MOE) of ballast water is the currently accepted standard management option for vessels that discharge ballast water under Canadian jurisdiction (Transport Canada Tp13617E 11/2007), following the International Maritime Organization (IMO) recommendation (Gollasch et al. 2007). In the Newfoundland and Labrador region mid-ocean has been defined to approximate the Exclusive Economic Zone (EEZ) extending 200 nautical miles from the coastline, with a minimum depth of 2000 m and salinity ≥ 30 parts per thousand (Fig. 1). The rationale for MOE is that coastal organisms uplifted into ballast tanks at port departure are exchanged with oceanic waters that are unlikely to favour growth and survival of the inshore inhabitants, and likewise during ballast exchange of oceanic species to coastal areas. The observation of live coastal marine organisms in ballast water tanks, including mid-ocean exchanged tanks that would presumably remove coastal dwelling species, indicates problems with efficiency and suggests vessels may pose a significant risk in terms of AIS introductions (Hay and Tanis 1998). In the event that MOE could not take place due to weather situations or safety issues, Transport Canada requested alternative ballast water exchange zones (ABWEZs) be recommended for Canadian waters.

Canadian regional ABWEZs have been developed for the Maritimes (Scotian Shelf, Gulf of Maine; Brickman et al. 2005), the Pacific west coast (Levings and Foreman 2005), and the Laurentian Channel (Simard and Hardy 2005). These documents focused on the following three aspects: 1) ABWEZs that have been identified already by other gover nment departments or agencies; 2) risks that the identified zones may pose to fisheries resources and to the marine ecosystem; and 3) other zones that may pose a lower risk to fisheries resources and to the marine ecosystem.

One of the recommendations from a national peer review of Canadian ABWEZs was for the development of an ABWEZ(s) for the Newfoundland and Labrador region (DFO 2004). This report begins the process for the formal development of ABWEZs in the

Newfoundland and Labrador region (Fig. 1). These potential ABWEZs will be assessed using the ecosystem approach designed to limit impact on existing and potential EBSAs and the sustainability of fisheries and aquaculture; while providing scientific advice to assist in the development of ABWEZs that will pose a relatively low risk of AIS introduction.

In order to provide recommended ABWEZs several elements consistent with the ecosystem approach in determining effects on the enviro nment through human activities, will be considered and evaluated. The first element considered is the vectors of introduction. The shipping traffic analyses included traffic patterns and primary routes from international traffic, ballast status upon arrival in Newfoundland ports as well as information which would include high risk (presence of known AIS species) ports of origin (Baines 2007). Also considered are naturally occurring current vectors, and physical enviro nmental conditions in the Newfoundland Shelf region, with a focus on seasonal circulation patterns.

The second element used in the ballast water risk analysis is ocean current modelling based on numerical dispersion experiments using selected shipping corridors (Han et al., 2008). The drift model and modelling strategy is discussed in detail including the overall monthly-mean model circulation features and dispersion patterns. The model is applied to determine the sensitivity of the dispersion to the vertical current, vertical eddy diffusivity and high-frequency wind forcing.

The third element is the potential impact of AIS on the enviro nment and resources. Of particular concern to the Newfoundland and Labrador region is the risk of ballast water exchange on the Grand Banks and EBSAs recently identified (Templeman 2007) through the PBGB LOMA integrated management (IM) process. Another area of particular concern is the risk of ballast water exchange in the Laurentian Channel and Placentia Bay approach to finfish aquaculture on the south coast, as well as AIS risk to shellfish aquaculture along the northeast coast.

The fourth element used in the assessment is the status of known AIS in Newfoundland and their risk of re-introduction and spread. The knowledge gaps encountered during the assessment and recommendations for future research direction in the region will also be discussed. Finally, advice and recommendations for ABWEZs in the Newfoundland and Labrador region are provided.

INTRODUCTION AND TRANSFER VECTORS

VESSEL TRAFFIC PATTERNS AND HIGH RISK PORTS

Determining the risk associated with the introduction of AIS involves the consideration of many variables. The first step in determining risk of species introduction is an analysis of the pathway for species arrival.

Argentia, Come by Chance and Whiffen Head were the primary areas visited by international shipping traffic. A study by Balaban (2001) indicated that 11%, 85% and 100% of shipping traffic entering Argentia, Come by Chance and Whiffen Head, respectively, were in ballast (Table 1).

The Eastern Avalon region (St. John's and surrounding) received 13% of incoming vessels, with approximately one quarter of those vessels entering the port of St. John's. The vessels entering the St. John's region reported in ballast in the 2000 shipping year accounted for 20 % of the traffic (Balaban 2001).

Table 1. List of Newfoundland ports showing percentage of vessels arriving in ballast. Table adapted from Vessel Traffic/Vessel Shipping Patterns on the East Coast of Canada 2000 Shipping Season (Balaban 2001).

Newfoundland Ports	Percent (%) Vessels Arriving in Ballast
Argentia ***Placentia Bay***	11
Bay Roberts ***Conception Bay***	9
Botwood ***Bay of Exploits***	93
Bull Arm ***Trinity Bay***	8
Come by Chance ***Placentia Bay***	85
Conception Bay ***Conception Bay***	80
Corner Brook ***Bay of Islands***	47
Harbour Grace ***Conception Bay***	56
Holyrood ***Conception Bay***	0
Lower Cove ***St. Georges Bay***	100
Marystown ***Placentia Bay***	0
St. John's ***East Avalon***	20
Stephenville ***St. Georges Bay***	85
Whiffen Head ***Placentia Bay***	100

Carver and Mallet (2002) sampled six Newfoundland ports and 32 ships for ballast water-mediated introduction of non-indigenous phytoplankton and zooplankton. There are several species of toxic and harmful phytoplankton that can survive long voyages as resting cysts or spores and can be introduced, germinate and spread in the appropriate enviro nment. Carver and Mallet (2002) give a detailed list of the plankton content of ballast water being transported into Atlantic Canada, including several ports in Newfoundland. The majority of these ships were tankers at Come by Chance and Whiffen Head. Approximately 50% of the tankers sampled had conducted ballast exchange in either coastal or oceanic waters. The ships that discharged ballast in Newfoundland were from the northeastern United States. Carver and Mallet found that the greatest volume of ballast water discharged (max 46,407 m^3) during their study (September-December 2001) was at Come-by-Chance and Whiffen Head by docked Oil Tankers. The source water was listed as coming from Riverhead, NY; New Haven, CT; Providence, RI; New York, NY; and Portland, ME. As this study was conducted in 2002, it is suggested that a post regulation study be conducted to determine the effectiveness of the ballast exchange from the northeastern ports south of Cape Cod, given the high traffic into Placentia Bay from these areas.

The ship's point of origin or the ports of call that the vessel makes are also very important factors in determining risk. The concept of "red listed" ports was suggested in the 2004 Alternative Ballast Water Exchange Zones CSAS document (DFO 2004) and is also recommended in this document. The likelihood of introduction is based on the risk that invasive species are present in the waters of origin, the length of time the species can survive through the voyage and the enviro nmental characteristics of the receiving waters. Therefore key factors in "red listing" a source port would be the presence of an invasive species that can survive long voyages and have wide enviro nmental tolerances. The most successful invaders have met these criteria. An example of an AIS that meets these criteria is the European green crab whose larval stage can survive months in ballast tanks and remain viable (Klassen and Locke 2007).

Shipping data provided by Transport Canada for international traffic entering 18 Newfoundland ports in 2003 listed 646 vessels from 43 different locations (5 different continents) (Fig. 2). Of all Newfoundland ports Fortune, Fortune Bay received the largest number of international vessels (271 - all from St. Pierre & Miquelon). Argentia, Placentia Bay received the second largest number of vessels from international ports of origin (142). The majority of these vessels traveled from the European region (primarily Iceland) and North America (USA, South of Massachusetts). Come by Chance, Placentia Bay also received a large number of vessels (111). Most of these (52%) traveled from North American ports, primarily the United States (~38% from South of Massachusetts and 10% North of Cape Cod, MA). All other Newfoundland ports received less than 25 international vessels in the 2003 season.

Tonnage of product taken onboard these international vessels during their visit to the 18 Newfoundland ports was also provided. Of the 18 ports, 14 were used to load products (from household necessities and foods, to oil and gas products) (Fig. 3). Traffic entering Come by Chance loaded more than 17.6 million tons in oil and gas products. Most of these vessels originated in North America (primarily Maine, New York, Pennsylvania, Virginia and New Jersey in the United States). 488 thousand tons of product was loaded onto vessels from Europe (~33% originating from Pallice, France). Fortune had more than 1.5 million tons of product (food, appliances and household items) loaded onto vessels visiting from St. Pierre & Miquelon. Corner Brook traffic (primarily from North and South American ports) took on greater than 450 thousand tons of product.

Vessels loading large quantities of product may require the release of ballast while in port to compensate for the increased load. Vessels which were exempt from the current regulations or those in which the required 95% volumetric exchange was not 100% effective may have released harmful organisms upon release of the ballast water.

Kelly (2002, 2003) documented and analysed vessel traffic patterns off eastern Canada. The present study determined relevant vessel routes based on Kelly's results, similar to Brickman et al. (2005). The selected corridors along which the dispersion experiments were simulated in this report are provided in Figure 4.

GENERAL CIRCULATION AND OTHER PHYSICAL CONDITIONS IN THE NORTHWESTERN ATLANTIC OCEAN

Near-surface ocean circulation off Newfoundland and Labrador is dominated by two primary currents (Fig. 5), the relatively cold and fresh equatorward Labrador Current, and the warmer and saltier poleward Gulf Stream and its extension, the North Atlantic Current (e.g. Loder et al 1998). The Labrador Current has two branches, with the core along the shelf-edge and continental slope and a smaller residual flow along the Newfoundland east coast.

The shelf-edge Labrador Current bifurcates north of the Flemish Pass, with one branch southward through the Flemish Pass and the other eastward along the northern flank of the Flemish Cap. The Flemish Pass branch flows along the southeastern Grand Bank slope with strong retroflection offshore, a portion of which passes around the Tail of the Grand Bank and continues along the southwestern Newfoundland Slope (Petrie and Anderson 1983). The inshore Labrador Current hugs the eastern and south Newfoundland coast. There are significant cross-shelf exchanges between the inshore and offshore currents from place to place.

On the seasonal scale, the Labrador Current is stronger in fall/winter and weaker in spring/summer (Han et al. 2008). There is substantial interannual variability in the Labrador Current. The region is also subject to intensive atmospheric forcing from fall to spring, resulting in significant synoptic variability in the shelf circulation. In addition, sea ice formation, growth, advection and melting in winter and spring can also affect regional circulation.

Over the lower continental slope, the mean currents are equatorward but much weaker than the Gulf Stream and the North Atlantic Current. In addition to variations of the Labrador Current strength and pathway, meanders and eddies pinched from the Gulf Stream and the North Atlantic Current can generate prominent temporal and spatial variability in regional hydrography and circulation, resulting in intense shelf/deep-ocean interactions and exchanges of physical, chemical and biological properties.

Although cold water temperatures that prevail much of the year in this region have been reported to restrict the growth and spread of some AIS species, there is particular concern with the general warming trend that has been reported within the whole of the north Atlantic during the late 1990’s and recent years (Colbourne et al. 2005) and how this may influence future AIS introductions.

NORTHWESTERN ATLANTIC OCEANOGRAPHIC MODELING

CIRCULATION MODEL

A finite-element model QUODDY4 (Lynch et al. 1996; Han and Loder 2003) was used to compute circulation fields. The model has three-dimensional (3-d) nonlinear primitive equations with Boussinesq and hydrostatic approximations, and a level-2.5 turbulence closure scheme (Mellor and Yamada 1982; Blumberg et al. 1992). The vertical eddy viscosity for momentum and vertical diffusivity for temperature, salinity and turbulent kinetic energy and mixing length scale were given a minimum value of 0.0001 m^2/s.

The model's fixed horizontal mesh (Fig. 6) has about 10000 variably spaced nodes. It covers the southern Labrador Shelf (SLS), the Newfoundland Shelf, and adjacent deep oceans, with high resolution in shallow areas and those with steep topography. Typical node spacing is 5 km over the shelf. The vertical mesh has 21 variably spaced nodes with minimum spacing of 1 m near the sea surface and seabed, and adjusts to track the movement of the sea surface during the model simulations. The model uses topography for the shelf from a database with about 7-km resolution and topography for deep oceans from etopo5 (Han et al. 2008).

The initial sea surface elevation and 3-d velocity fields for the prognostic models were taken from the monthly-mean and M_2 tidal solutions of the linear diagnostic model FUNDY5 (Naimie and Lynch 1993). The initial monthly-mean solutions were obtained by specifying baroclinic pressure gradients throughout the model domain, spatially variable wind stresses at the sea surface, elevations at the SLS and offshore boundaries, and depth-integrated normal velocities on the Strait of Belle Isle (SBI) boundary. The baroclinic pressure gradients were derived from the density fields calculated from climatological monthly-mean temperature and salinity fields (Geshelin et al. 1999). The wind stresses are computed from 6-hourly wind data of NCEP-NCAR (National Center for Enviro nmental Prediction – National Center for Atmospheric Research) reanalysis data. The climatological monthly-mean wind stresses have seasonal variations in both magnitude and direction, with the winter stress being stronger and directed more cross-shelf (offshore) than the stresses during the other seasons (Han 2005). For more details of the circulation model see Han et al. (2008).

NUMERICAL DISPERSION EXPERIMENT

Ballast water exchange occurs while a vessel is moving. The exchange takes between 18 - 36 hours, during which the vessel travels about 300-500 km (hereinafter called a route segment). Principal vessel routes were modelled to have curvilinear axes and a finite width of 40 km (Fig. 7). The choice of 40 km is somewhat arbitrary but sufficient to account for the variation of individual vessel routes from the nominal route axis (Also see Brickman et al. 2005). A standard route segment is defined to be 320 km in length. To improve the modelling efficiency we first model dispersion for releases from 40 km by 40 km boxes along vessel routes. Then the results are assembled for each standard segment: a sequence of 8 consecutive boxes (320 km in total). Each segment was assessed according to the surface concentration distribution and the total dispersal area after 15 days from the start of exchange. The surface concentration is evaluated for each 5 km by 5 km grid cell. The dispersal area is defined as the sum of areas of the grid cells within which there is at least one particle.

Organisms in ballast water are highly diverse, from bacteria, phytoplankton, zooplankton, to ichthyoplankton. Both the temporal and spatial variability of the physical enviro nmental and the behaviours of organisms may affect the distribution and survival of these species. The method used tracks passive numerical drifters released in the model monthly circulation fields and the M_2 tidal current fields. The objective is to identify and recommend along-route-locations for exchanging ballast water that may have minimal impacts.

The drifter-tracking method is described by Werner et al. (1993) and Blanton (1995). In addition, estimates of the influence of u nmodeled horizontal motions are obtained assuming a random walk process where additional displacements are calculated using externally specified eddy diffusivities in the horizontal directions (e.g. Berg 1993). The sensitivity of the advective pathways to the effects of u nmodeled horizontal current fluctuations is considered using a horizontal random walk. The horizontal diffusivity is assumed to be homogenous and isotropic. The Smagorinsky formulation in the circulation model indicates that the horizontal eddy viscosity of 130 to 200 m^2/s. Previous studies based on field experiments off the US east coast estimated the eddy mixing coefficients to be 50 - 500 m^2/s (Ketchum and Keen 1955). In this study a baseline value of 150 m^2/s was chosen. Figure 8 shows the relationship between the dispersion area and the horizontal eddy diffusivity for a segment of the Corridor IC.

MODEL CIRCULATION AND DISPERSION RESULTS

The circulation model generated 12 monthly-mean circulation fields and the M_2 tidal current fields. There are strong seasonal variations in the near-surface circulation. For example, the Labrador Current is much stronger in December than in July (Fig. 9). The spatial variability is significant, with the dominant flow along the shelf edge, and along the coast. Cross-shelf advective exchanges are clearly evident, for example, the offshore flow on the northeastern Newfoundland Shelf. The cross-slope exchanges are also revealed, especially along the southeastern Grand Bank slope where the Labrador Current retroreflects northeastward. There is also substantial spatial variability in the M_2 tidal currents, e.g. with strong currents over the Southeast Shoal (Fig. 9).

Figure 10 shows the dispersion area with month and the segments for each corridor. Overall the dispersion area is larger in fall/winter and smaller in summer. For most segments, the dispersion area after 15 d is between 40,000 to 60,000 km^2.

Three corridors (A5, U1 and A3) were selected to illustrate general drifter patterns (Figs. 11-13). Offshore of the 1000 m isobath along the northeastern Newfoundland Slope and offshore of the 200-m isobath on the southeastern Grand Bank, the releases usually drift towards the deep ocean. The drifters released on the inner-shelf routes can affect aquaculture sites and Marine Protected Areas (MPAs). There are non-homogeneous advection and diffusion processes that occur, resulting in higher concentrations in some areas.

SENSITIVITY TO ADDITIONAL PROCESSES

To explore the influence of additional physical processes and biological behaviour assumptions, the following sensitivity cases were considered. A segment of the IC corridor was chosen to conduct numerical experiments in April to investigate effects of the vertical current, vertical diffusion, weather-band wind-driven current and vertical behaviour. The results are briefly summarised in this subsection.

Vertical Current

The results presented in the preceding section were obtained under zero vertical velocity, with the discharged ballast water fixed at the prescribed depth of 1 m. In reality, ocean water moves up and down in the vertical, though in most cases the vertical current is very slow compared with the horizontal current. To examine the impacts of the vertical current on the dispersion pattern, the ballast water is allowed to move both horizontally and vertically following the 3-d model circulation fields. A comparison of results indicates the addition of the vertical water current has little effect on the horizontal dispersion pattern within 15 days of release.

Vertical Diffusion

The effect of vertical turbulence is considered in this subsection. A vertical random walk approach based on the model turbulence field is used. In the approach, the Langevin equation is used to derive a Markov equation for the vertical velocity in inhomogeneous turbulence (Legg and Raupach 1982). The offshore (southwestward) movement is much reduced, because the turbulence brings the ballast water significantly below the sea surface and the horizontal current at depth is much weaker.

Weather-band Wind-forced Current

To include the effect of the weather-band wind-driven circulation, the wind-driven model circulation forced under the 12-h nowcast winds from Enviro nment Canada's regional numerical weather prediction model is included. It is shown that the wind-driven current has limited advective effect in changing the horizontal pattern. However, the horizontal and vertical mixing effects of the weather-band wind forcing can be significant. The horizontal mixing effect is empirically accounted for in the baseline simulations. The vertical mixing effect is not considered here.

Vertical Behaviour

A diel migration pattern between 0.5 m and 100 m, or the bottom with an ascent (surface seeking at dusk) and descent (bottom seeking at dawn) speed of 0.02m /s, was used. The result indicates that the diel migration has a similar effect on the dispersion pattern in the horizontal to the vertical turbulent diffusion.

POTENTIAL IMPACT OF AQUATIC INVASIVE SPECIES ON NEWFOUNDLAND AND LABRADOR ENVIRO NMENT AND RESOURCES

ECOLOGICALLY AND BIOLOGICALLY SIGNIFICANT AREAS

Through a process outlined in CSAS Ecosystem Status Report (DFO 2004b), eleven Ecologically and Biologically Significant Areas (EBSA) were identified for the Newfoundland and Labrador Placentia Bay Grand Banks Large Ocean Management Area (PBGB LOMA) in the Newfoundland and Labrador Region (Templeman 2007). These areas were identified and evaluated based on their relevance to the primary dimensions of Uniqueness, Aggregation, and Fitness consequences with some consideration to the secondary dimensions of Resilience and Naturalness being noted (see DFO 2004b, Templeman 2007). For the purpose of this assessment these dimensions can be described as the following:

Uniqueness – areas whose characteristics are unique, rare, distinct and for which alternatives do not exist.

Aggregation – areas where i) most individuals of a species aggregated for some part of the year, ii) most individuals use the area for some important function in their life history, and iii) some structural features or ecological process occurs with exceptionally high density.

Fitness Consequences – areas where the life history activity(ies) undertaken make a major contribution to the fitness of the population or species present.

Resilience – areas where the habitat structures of species are highly sensitive, easily perturbed, and slow to recover.

Naturalness – areas which are pristine and characterized by native species.

Significant areas in the PBGB LOMA were identified through an Ecosystem Overview and Assessment Report (EOAR) for the area, other available literature, and input from key scientists within the region based on their knowledge and experiences. Individual features associated with the primary dimensions of Uniqueness, Aggregation and Fitness Consequences for the EBSAs were evaluated to be of 'high', 'moderate' and 'low' biological significance and were considered cumulatively to produce a final score for each area. The EBSAs for the PBGB LOMA are listed in order of significance, with the rating score in parenthesis (see Templeman 2007). The EBSAs are indicated by number in Figure 14.

The Southeast Shoal and Tail of the Banks (25.5)
Placentia Bay Extension (24.25)
The Southwest Shelf Edge and Slope (20.25)
St. Pierre Bank (10)
Laurentian Channel and Slope (9.5)
Smith Sound (8)
Eastern Avalon (5)
Lilly Canyon-Carson Canyon (4)
Northeast Shelf and Slope (3.5)
Burgeo Bank (3.25)
Virgin Rocks (2.5)

Many of these EBSAs overlap with, or are near the identified principal vessel corridors for the dispersion modeling (Fig. 14). Using the current models in these regions the three highest ranking EBSAs are assessed for potential impact and are considered in the advice and recommendations. The other EBSAs were also considered but to a lesser degree as warranted by their lower ranking.

The first three EBSAs are of particular concern based the qualities or dimensions that are responsible for the higher score and ranking and will be discussed here.

The Southeast Shoal and Tail of the Banks

This EBSA ranks highest and has the highest score (25.5) of the areas identified. This region of the Grand Banks was evaluated as having 'high' significance with respect to several properties of uniqueness (rarity). This area is a unique spawning and breeding ground for offshore capelin and an isolated nursery and rearing ground for Yellowtail Flounder. Oceanographic processes in this area are also considered unique/rare, having the warmest bottom water temperatures in the LOMA due to the proximity of the Gulf Stream and the existence of a well-defined gyre on the Southeast Shoal. In addition, the Southeast Shoal is the only shallow sandy offshore shoal in the LOMA, and houses the highest benthic diversity on the Grand Bank. This EBSA was also evaluated as having 'high' significance with respect to several properties of aggregation (density and concentration), including being a spawning and breeding area for capelin, northern sand lance and several ground fish species (American Plaice, Yellowtail Flounder, and Atlantic Cod), and a nursery and rearing ground for Yellowtail Flounder. The area is also a feeding ground for numerous species of marine mammals and seabirds, resulting in high biodiversity. Also important is the fact that the densest concentration of Striped Wolfish (listed as 'special concern' by COSEWIC) is found here.

Special consideration was taken in the assessment of the ocean current model for the dispersion of ballast exchange on vessel corridors A2 and F2 that would result in movement of released material into this top ranked EBSA, the Southeast Shoal and Tail of the Banks.

Placentia Bay Extension

The second highest scoring EBSA is Placentia Bay Extension, (#2 in Fig. 14) with a score of 24.25. This region of the LOMA was evaluated as having 'high' significance with respect to several properties of uniqueness, including that for oceanography, biodiversity and spawning. Oceanographic processes demonstrate a unique counter-crosswise gyre which enters the bay east and exits west, there are areas of localized upwelling and the temperature and salinity are more stable compared to other embayments. The EBSA represents an area of high pelagic and demersal diversity and is also important to seabirds, cetaceans, harbour seals, and leatherback turtles. Placentia Bay also contains the largest spawning stock of Atlantic Cod in the Northwest Atlantic. The area was evaluated as having 'high' significance with respect to several properties of aggregation given its high primary and secondary productivity and high concentrations of ichthyoplankton. Similarly, the largest stock of spawning Atlantic Cod occurs here, it is an important nesting and feeding site for birds, an important feeding ground for cetaceans, turtles and seals, an historic area for harbour seal reproduction, and historic summer migratory path for cetaceans. The area was evaluated as having 'high' significance with respect to several properties of fitness consequences given its importance as a fish spawning, nursery and rearing area and its use by various marine mammals for feeding and breeding.

Introduced species from ballast water exchange could be devastating to this EBSA. The recent identification of the AIS - European green crab, *Carcinus maenas*, in the more northern regions of Placentia Bay has raised serious concerns for the future of the productivity of this region. Vessel corridors F1, F2 and IC as well as ships in port within Placentia Bay are of particular and immediate concern for this EBSA (Fig. 14).

The Southwest Shelf Edge and Slope

The third EBSA of particular interest is the Southwest Shelf Edge and Slope (score 20.25) indicated on Figure 14 as # 3. This area is unique in that it has the highest density of pelagic seabirds feeding within the LOMA, it has the northern-most population of haddock in the Northwest Atlantic, the greatest number (biodiversity) of groundfish species, and a high concentration and biodiversity of cold water corals. With respect to aggregation, the haddock in the region spawn primarily along the edge of the southwest slope in the spring. Atlantic Halibut in the region are found almost exclusively along the southwest slope during the same time and marine mammals and leatherback turtles aggregate to feed, particularly in the summer. With respect to fitness, the southwest slope of the Grand Bank is also an important spawning area for redfish and a migration route for cod. Although not included in the terms of reference for this study, the high volume of shipping originating from the northeastern coast of the United States and Canada (Maritimes) using vessel corridor A3 as well as some traffic using corridor F1 and F2 from Europe, pose a particular risk for this EBSA.

FISHERIES RESOURCES

It is evident, based on the information in the preceding EBSA evaluation, that fisheries resources play a vital role in Regional integrated ocean management plans. Therefore, the risk to these stocks must be minimized by careful consideration of the locations and seasonality of alternate ballast water exchange zones and how they would affect the sustainability of the resource.

The fishery resources in the Newfoundland and Labrador region include a large number of commercially-important fish and invertebrate species that range in location from inshore areas, to occupying relatively large areas on the Grand Banks and northeast Newfoundland Shelf, to Slope water areas (Kulka *et* al. 2003). American Plaice (*Hippoglossoides platessoides*) is an example of a fish species widely distributed throughout the southern and northern Grand Banks. On the other hand, redfish (*Sebastes* sp.) show a patchy and dynamic distribution covering areas on the northeast Newfoundland Shelf, the Flemish Cap and the Laurentian Channel Slope. The Roughhead Grenadier (*Macrourus berglax*) is an example of several demersal fish species that occupy deepwater along the northeast Newfoundland Shelf and further south along the Slope waters on the Grand Banks and Flemish Cap. Spawning times of fish and invertebrate stocks can vary throughout the seasonal cycle extending from February through to October (Ollerhead et al 2004), although peak timing for many demersal fish range from April through July, while invertebrates typically spawn later during the autumn.

AQUACULTURE RESOURCES

One of the EBSAs discussed previously, the Placentia Bay extension, overlaps with several areas of aquaculture development, another important and growing industry in Newfoundland. There has been rapid aquaculture development along the southern regions of Newfoundland in Placentia Bay–Coast of Bays area. According to the provincial gover nment less than ten percent of the province’s potential aquaculture space is currently being utilized and has some of the last remaining areas available for aquaculture development in eastern Canada. It is important, given the effect AIS has had on the aquaculture industry in the Maritimes, that the sustainability and future development of the Newfoundland industry be protected from risk of exposure to AIS. The Newfoundland and Labrador Department of Fisheries and Aquaculture AquaGIS website shows the locations of licenses for current and developmental operations in Newfoundland. According to the Newfoundland Aquaculture Industry Association (2007) the value of the Newfoundland Aquaculture industry went from $33.5 million in 2005 to $53.5 million in 2006 representing a 60% increase in one year and production rose from

8,164 metric tons in 2005 to 10,400 metric tons in 2006. Although much of the recent growth has occurred on the South Coast, there are also large and significant aquaculture operations along the northeast coast, particularly in Notre Dame Bay, where a majority of the shellfish aquaculture sites are centered. According to the dispersion modeling, many of these sites are at risk from ballast exchange occurring from ships traveling to Labrador and ships approaching the Gulf of St. Lawrence through the Strait of Belle Isle due to the high transport volumes via the Labrador Current. Both finfish and shellfish industries are poised to expand rapidly in the immediate future. Figure 14 indicates the areas of significant aquaculture concentration and development in Newfoundland in brown and labelled with an "A" and their relationship to the vessel corridors studied.

STATUS OF AQUATIC INVASIVE SPECIES IN THE NEWFOUNDLAND AND LABRADOR REGION

EUROPEAN GREEN CRAB

The recent confirmation of the presence of the AIS European green crab, *Carcinus maenas*, in the more northern regions of Placentia Bay has raised serious concerns for the future of the productivity of this region (McKenzie et al 2007). The green crabs are particularly abundant in eelgrass beds which are the habitat for fish nurseries. Genetic studies on the lineage of the green crab found in Placentia Bay indicate that they are most closely linked with the green crabs in the Gulf of Maine and the Maritimes (Roman pers. com. 2007).

The green crab preys on shellfish and crustaceans and burrows in the sand, affecting eelgrass habitat. Population studies in Placentia Bay are being conducted by Fisheries and Oceans Canada in collaboration with Memorial University and the Provincial Department of Fisheries and Aquaculture to determine the distribution of green crab and potential impact on the ecosystem and the economics of the region. The effect of the Newfoundland enviro nment on the reproduction, distribution and spread of the European green crab is also being investigated.

The green crab is a near shore species, rarely occurring at depths of greater than 6 meters, and often found under intertidal rocks. Green crabs have wide oxygen, temperature and salinity tolerances and are extremely successful invaders. Green crabs compete with native crabs for food, eating a wide variety of clams, mussels and other invertebrates. There is also evidence that they eat juvenile lobsters (Rossong et al. 2006). Following their initial discovery in Placentia Bay, NL (August 2007), DFO Science found green crab at 7 of 9 locations surveyed in the Bay. Additional rapid assessment surveys were conducted in October 2007 on Newfoundland's West, South and Northeast coasts focusing on high risk ports, processing plants, potential aquaculture sites and multi-user areas. No European Green Crabs were found in the areas surveyed outside of Placentia Bay, although secondary spread through vessel traffic is a concern.

HARMFUL ALGAE

The increase and spread of toxic phytoplankton species in Australian waters and the effect on, and closures of, aquaculture sites in an area of the world where no harmful algae had been found before led to the increased concern over what was being spread world-wide through ballast water. Viable cysts from Japan were found in the ballast sediment which led to major economic consequences (Hallegraeff and Bolch 1992a, b). The first case of Paralytic Shellfish Poisoning (PSP) in Newfoundland was reported in Harbour Grace, Conception Bay in 1982 (White and White 1985). Since that time PSP and the dinoflagellate phytoplankton (*Alexandrium fundyense*) that produces the toxin has been found in blooms and as cysts in sediments (Schwinghammer et al 1994; McKenzie et al. 2002) throughout the province leading to site closures and husbandry strategies to deal with the toxin and human health (McKenzie et al. 1998, 2003). Diarrhetic shellfish poisoning (DSP) was found in 1993 along with a bloom of *Dinophysis norvegica* in Bonavista Bay (McKenzie et al 1994) and in 2001 associated with *Prorocentrum lima* living epiphytically on mussel lines (McKenzie and Mouland 2006). In recent years other algal toxins have been identified from aquaculture locations in southern and eastern Newfoundland. These toxins include yessotoxin, produced by *Protoceratium reticulatum*, pectenotoxin and spirolides (M. Quilliam, NRC Halifax, pers. com.). Phytoplankton that are not toxic but have been found to be harmful to fish and cause fish kills in British Columbia are the diatoms *Chaetoceros concavicornis* and *Chaetoceros convolutus*, both of these species are currently found on the south coast of Newfoundland. The sharp barbs and spines of their cells irritate fish gills causing mucus production and death.

COLONIAL TUNICATES

The golden star tunicate, *Botryllus schlosseri,* was found in December 2006 on a small fishing vessel in Argentia, NL during an AIS harbour survey conducted by Fisheries and Oceans Canada and Memorial University (Callahan et al. 2007a and b). Argentia is a high traffic ferry terminal and port and is considered to be a high risk for aquatic invasions. The golden star tunicate is one of the four tunicate species of concern in the Maritime Provinces. It has spread to several areas of PEI and forms a carpet-like growth on objects in the water including buoys, mussel lines and wharves etc. The additional weight has an economic impact on the bivalve aquaculture operations. Following the initial finding in Argentia, the golden star was found in several other harbours in Placentia Bay growing on ship's hulls and wharves. Mitigation measures to prevent the spread of this tunicate to other bays through mussel movement were developed (brining) and put into place. The golden star tunicate has not been found at any Newfoundland aquaculture site to date.

The violet tunicate, *Botrylloides violaceus*, was found during a province-wide AIS rapid assessment survey conducted by Fisheries and Oceans Science Branch in collaboration with Oceans & Habitat Branch, Memorial University of Newfoundland and the Provincial Department of Fisheries and Aquaculture (Baines et al. 2007). In October 2007 survey personnel detected the violet tunicate for the first time in Newfoundland waters on boat hulls, wharves and natural rock in Belleoram, Fortune Bay. It is not known how or when the violet tunicate was introduced to Newfoundland. However, the recent increase in direct ship traffic from areas in the Maritimes which are known to have violet tunicates to Belleoram is highly suspect. Belleoram is the only area where this invasive tunicate has been detected. The violet tunicate is of serious concern in the Maritimes as it spreads rapidly and overgrows the floating structures and substrates that it colonizes. It has a significant impact on management and processing operations in the shellfish aquaculture industry and rapidly fouls finfish cages in affected areas. It also rapidly spreads and overgrows several habitat types. Spread of the violet tunicate is usually through movement via vessel hull fouling. Their potential for rapid growth allows them to exploit new enviro nments, potentially displacing native species and disrupting community dynamics. In particular, their tendency to colonize floating and benthic substrates and overgrow other organisms poses a threat to the viability of marine aquaculture and fishery operations. Fisheries and Oceans Canada, Memorial University and the Provincial Department of Fisheries and Aquaculture are working together to determine the most effective mitigation strategy.

Although currently not found in Newfoundland, of particular concern is the colonial tunicate *Didemnum vexillum*. It has been reported to be spreading and overgrowing bottom sessile species over large (> 230 km^2) cobble and sandy substrates on Georges Bank (Valentine 2007). This very aggressive species is raising particular concern over its impact on benthic habitats of commercially-important demersal groundfish and invertebrate stocks on Georges Bank and the possibility of spreading to other submarine banks further north. In coastal regions, this fast-growing invader may also pose a threat to commercial aquaculture operations by clogging pens and overgrowing suspended cultures. The colonial tunicate primarily colonizes many man-made hard substrates (ships hulls, dock structures and floats, wood and metal pilings, moorings and ropes, steel chain, automobile tires and polythene plastic) as well as natural rock outcrops and gravel seabeds composed of pebbles, cobbles, and boulders. These invaders have been shown to overgrow many epi-benthic and infaunal organisms. The current depth distribution for *D. vexillum* ranges from intertidal to depths of 65m. The reproduction of the colonial tunicate can arise from both sexual and asexual phases, and has the ability to remain in a dormant phase during unfavorable enviro nmental conditions (Daniel and Therriault 2006). The current distribution, growth and reproduction strategy of *D. vexillum* makes it a potential threat to the marine ecosystem in the Newfoundland and Labrador region.

Two other AIS have been found in Newfoundland waters. The most wide spread is the European crusting bryozoan, *Membranipora membranacea*. This bryozoan grows on kelp and was first discovered in Newfoundland in 2002 on the west coast (R. Hooper, pers. com.). It has since spread to other areas of the province including the northeast coast and particularly the south coast. The concern with this invasion is that as normally flexible kelp blades become encrusted with the bryozoan the blades eventually become rigid and break. In 2006 there was a particularly widespread occurrence of the European crusting bryozoan in kelp beds on the west coast and large areas of habitat were destroyed. The other invasive species identified during the AIS surveys of 2006 was the Japanese skeleton shrimp or *Caprella mutica.* The first confirmed occurrence was in Presque Harbour, Placentia Bay. These invasive species have since been found in several other locations in Placentia Bay, Connaigre Bay and Fortune Bay on the south coast. They are very similar in appearance to other Caprellid species commonly found in Newfoundland, *Caprella linearis and Caprella septentrionalis*. The impact of these organisms is yet to be determined.

REGULATORY GAPS AND RECOMMENDATIONS FOR RESEARCH

The goal of this assessment is to provide advice on the best alternative ballast exchange zones for international vessels traveling to Newfoundland and southern Labrador ports. During this assessment, particularly during the study of risk from ports of origin, it was determined that the more immediate and serious threat to Newfoundland waters was the arrival of ships from the Maritimes and Northeastern North America above the Massachusetts border. The current Transport Canada regulations do not require ballasting of Canadian vessels in Canadian waters and considers northwestern Atlantic waters north of Cape Cod, Massachusetts as a single water mass. Several of these regions have AIS that are not found in Newfoundland waters. The annual closures of shellfish harvest in the Maritimes and coastal US regions due to several harmful algae species and their toxins are another concern. The cysts and spores of harmful algae can easily be transported through ballast water.

The European green crab, recently detected in Placentia Bay, is found in the Northeastern United States as are several other AIS organisms that could be introduced into Newfoundland waters. The most serious of these is the colonial tunicate*, Didemnum vexillum*, which has been found to be spreading on Georges Bank and along the coastline of the Northeastern United States. This species is currently in Maine and is expected to spread into the Maritimes in a short period of time. *D. vexillum* is commonly referred to as "the blob" as it spreads along the benthos and man-made structures smothering everything in its path. *D. vexillum* has been introduced in New Zealand and has created serious economic hardship. Although the primary method of introduction is hull fouling, fragmentation of the colonies and their high survival rates are a potential concern in ballast water and more research is required to assess this risk.

The current Transport Canada testing procedure for ballast water exchange compliance uses salinity as the guideline. However in testing for compliance in marine to marine ports these guides are not adequate. Additional methods need to be considered for testing of ballast water exchange in marine transfers.

Therefore, based on these concerns additional research should include a detailed "port of origin risk assessment" as well as modified testing to determine the abundance and rate of introduction of AIS through ballast water. Research emphasis should be placed on Placentia Bay due to the high vessel traffic, milder climate, the multi-user nature of the bay and the concern expressed at the Arnold's Cove Minister's round table on AIS and other Placentia Bay issues.

DISCUSSION

The scientific advice on ABWEZs for the Newfoundland and Labrador region is based on oceanographic modeling (dispersion results), EBSAs within the PBGB LOMA and the sustainability of fisheries and aquaculture. Potential exchange zones are based on individual vessel routes approaching the Newfoundland and Labrador Region and other areas of the northwest Atlantic Ocean. The spatial distribution of the surface concentration and the temporal and spatial variation of the dispersion area are also taken into account. This study presents a first quantitative assessment of ballast water exchange off Newfoundland and Labrador based on verified model circulation patterns and extensive numerical drift experiments. Potential exchange zones are based on the monthly-mean circulation fields fixed at the 1-m depth. The sensitivity study has indicated some evident impacts of vertical turbulence, while the inclusion of the vertical current, the weather-band currents and the diel migration have limited effects on horizontal dispersion patterns. Potential exchange zones were divided into green, yellow and red zones for exchange along each vessel track (Fig. 15). Ballast exchange in the green zone would have minimal impact on the regions indicated, yellow zone was cautionary and should only be used in late fall and the red zones are strongly discouraged as they directly impact an area of concern (i.e., EBSAs or sustainable fisheries or aquaculture).

Existing regulations stating ballast exchange for transoceanic vessels is to take place before entering the 200 nautical mile (nm) EEZ at depths greater than 2000 m (Transport Canada 2007). This remains the preferred zone for ballast exchange for transoceanic vessels. However, under certain circumstances, and with the approval of the Minister of Transport, an alternate ballast water exchange zone may be utilized.

The Newfoundland potential exchange zones for Ballast Water Alternate Exchange Zones and rationale are as follows (Fig. 15):

Northeastern Newfoundland Shelf region:

Release off of the 1000 m isobath will generally drift into deep offshore areas, with some dispersion inside the 500 m isobath. After 15 days particles should still remain an estimated 150-200 nm offshore. According to dispersion models this seems to be consistent in both summer and winter conditions.

Release approximately 50 nm from shore (in waters deeper than 200 m) will generally drift south-westward, potentially reaching the portion of EBSA 9 which is listed as important to aggregation of the threatened Spotted Wolffish and Greenland Halibut. After 15 days particle dispersion would potentially be within 50 nm (and within 200-500 m depth) of Notre Dame Bay, an important area for shellfish aquaculture.

Release less than 50 nm from the shore at depths no greater than 200 m will drift in a southwestern direction potentially reaching the Northern portion of EBSA 9. After 15 days particles may have dispersed into the mouth of Notre Dame Bay (an estimated 25 nm from shore) in water no deeper than 200 m.

Given the above conditions exchange is to take place north of N50^{o}41’ and south of N54^{o}30’ from the 200 nm EEZ at depths greater than 2000 m to at least 50 nm from the Newfoundland coastline in waters deeper than 200 m. Areas east of Hamilton Bank, east of W53^{o}, should be avoided.

The Grand Banks region:

Release along the Western portion of EBSA 9 would drift southwest onto the Flemish Cap. After 15 days particles could reach EBSA 8 and the Eastern portion of EBSA 1.

Release on the Grand Banks region at depths less than 500 m would drift primarily southwest within an estimated 50 nm of the Southern Avalon Peninsula in summer months, and to the mouth of Placentia Bay during winter months. Particles may also drift southeast during summer months affecting EBSA 8.

Particles released south of Placentia Bay would concentrate along the south coast of Newfoundland, reaching the mouth of Placentia Bay in winter months and potentially affecting EBSAs 3, 4 and 5.

The potential exchange zone was modified during the National Peer Review process to ensure protection of identified EBSAs. Exchange is to take place outside the 200 nm EEZ in waters greater than 2000 m as described in the current regulations. No appropriate alternate zone has been identified inside the EEZ as waters are shallow in this area (≤ 200 m) and exchange inside the zone could potentially affect a number of Ecologically and Biologically Significant Areas (as described above). If vessel routes extend into the Laurentian Channel, this previously identified ABWEZ (Simard & Hardy 2005), may be used with approval from the Minister.

The Northeast coast, the Avalon and South coast regions:

Release off the Northeast coast less than 50 nm from shore would concentrate particles along the Northeast shore (Notre Dame Bay, Bonavista Bay, Trinity Bay and Conception Bay). Release on the Eastern Avalon would concentrate in the area of EBSA 7 and move in a southwestern direction just north of EBSA 3.

Release in the region of Haddock Channel, just west of the Grand Banks, would move southwest affecting EBSA 3 before moving further offshore south of the Laurentian Channel.

The potential exchange zone was modified during the National Peer Review process to ensure protection of identified EBSAs and coastal regions. Exchange is to take place outside the 200 nm EEZ in waters greater than 2000 m as described in the current regulations. No appropriate alternate zone has been identified in this region inside the EEZ as waters are shallow in this area (typically ≤ 500 m) and exchange inside the zone could potentially affect a number of Ecologically and Biologically Significant Areas and important areas for aquaculture. If vessel routes extend into the Laurentian Channel, this previously identified ABWEZ (Simard & Hardy 2005), may be used with approval from the Minister.

Southwestern Newfoundland Shelf and West Coast region:

Exchange is to take place outside the 200 nm EEZ in waters greater than 2000 m. No appropriate zone exists inside the EEZ. If vessel routes extend into the Laurentian Channel, this previously identified ABWEZ (Simard and Hardy 2005), may be used with approval from the Minister.

CONCLUSIONS AND RECOMMENDATIONS

During the National Peer Review on Alternate Ballast Water Exchange Zones on January 14, 2009 a consensus was reached regarding the final recommendations for Newfoundland Alternate Ballast Water Exchange Zones (Fig. 16). The rationale regarding the selection of the recommended zone(s) is further described in the corresponding workshop proceedings and advisory documents.

It should be noted that these recommendations are for transoceanic vessels originating from International ports with a requirement to ballast before entering Canadian waters.

Based on the review of the current navigation conditions and the ecological sensitivities of the areas for potential ABWEZs on the east coast of Newfoundland and Labrador, no ABWEZs are recommended at this time.

For the northeastern coast of Newfoundland and Labrador region an ABWEZ could be located at least 50 nautical miles offshore and in water depths greater than 500 m (indicated in green Figure 16); but further research is needed before formal recommendations could be made.

For the southern and eastern coasts of Newfoundland and Labrador region, no ABWEZs are being recommended. If vessel routes extend into the Laurentian Channel, this previously identified ABWEZ (Simard and Hardy 2005), may be used with approval from the Minister.

The scientific review of marine traffic around Newfoundland and Labrador indicates that domestic and coastal commercial traffic would represent a much higher risk of aquatic invasive species introduction than international commercial traffic under the current ballast water regulations.

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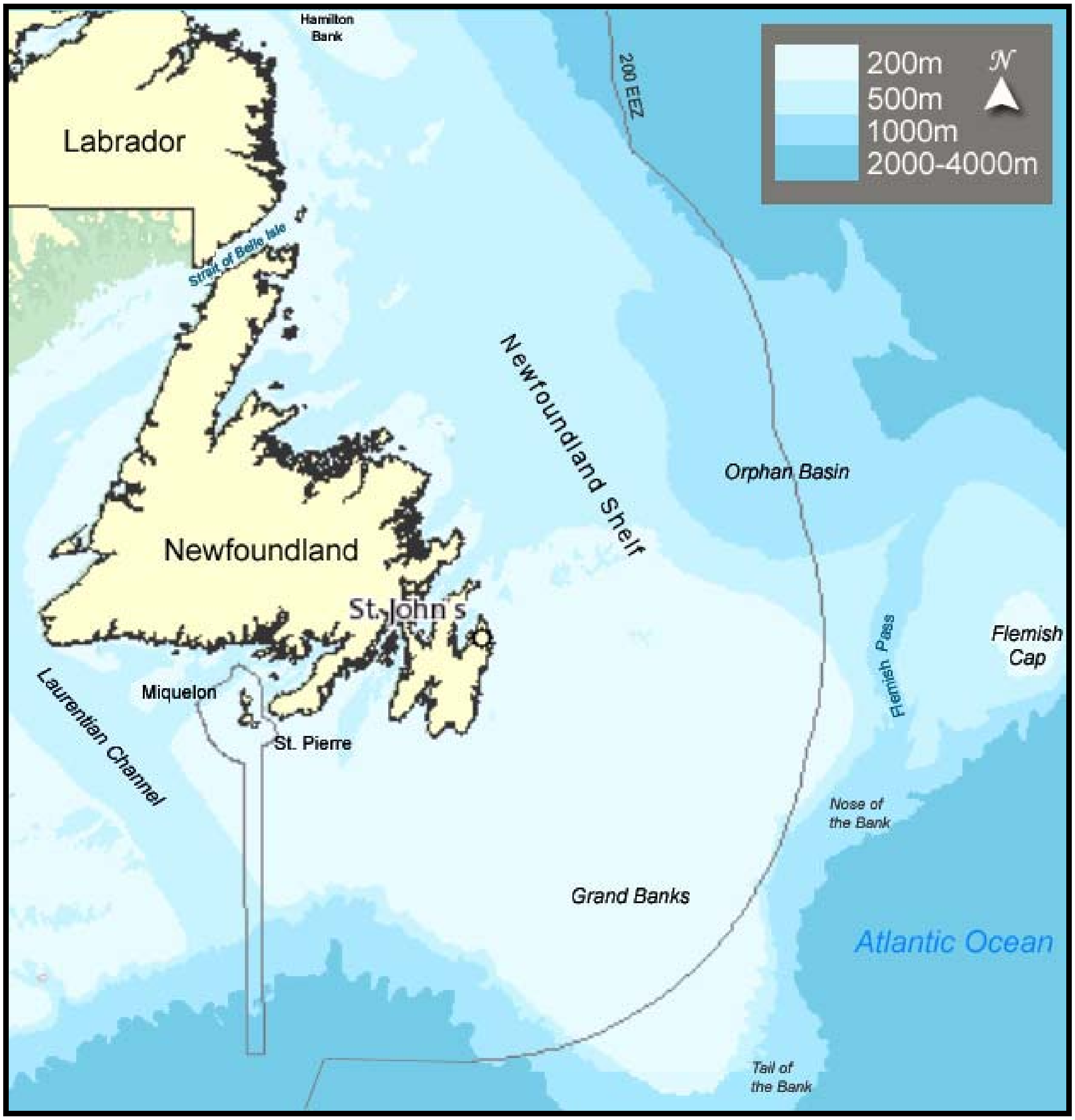


Figure 1. Map showing the Newfoundland and southern Labrador Shelf and adjacent Atlantic Ocean. The bathymetry and 200 nautical mile exclusive economic zone (EEZ) is provided for reference.

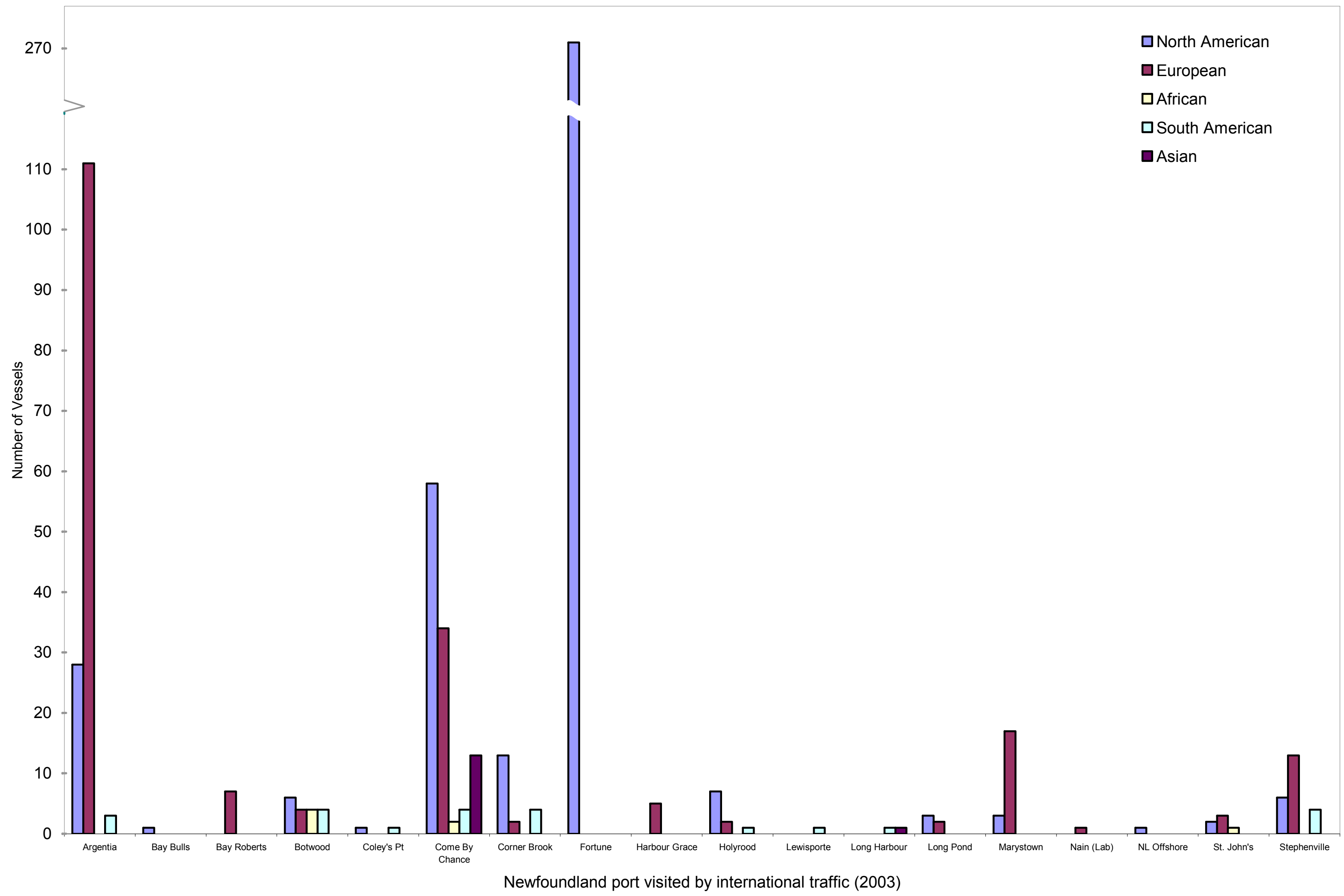


Figure 2. Number of international vessels entering Newfoundland ports throughout the 2003 shipping season.

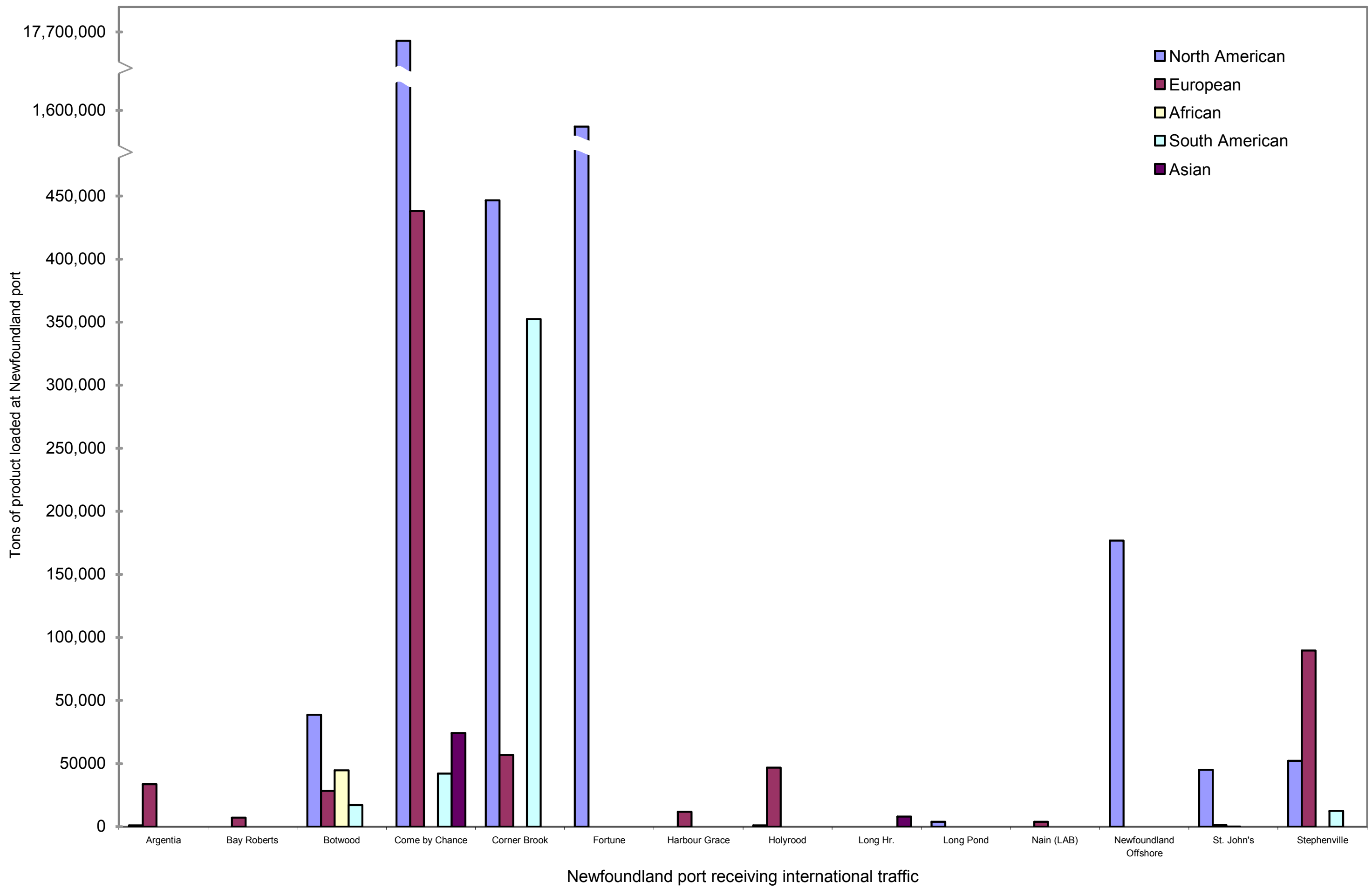


Figure 3. Tons of product loaded by international traffic at 14 Newfoundland ports during the 2003 shipping season.

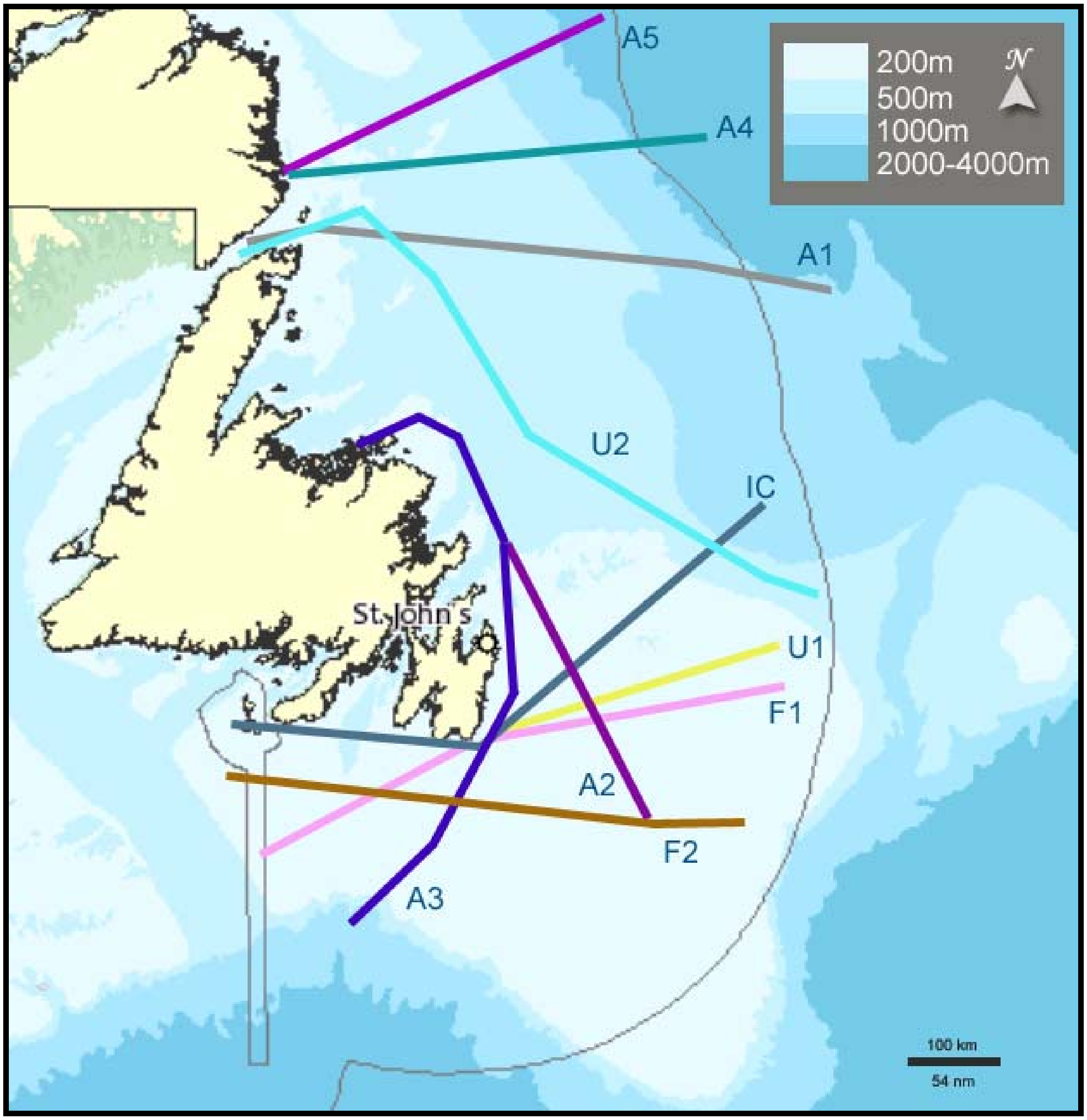


Figure 4. Selected principal vessel corridors over the Newfoundland Shelf based on the vessel transect density maps. Note the overlap of the IC and U1 corridor south of Newfoundland.

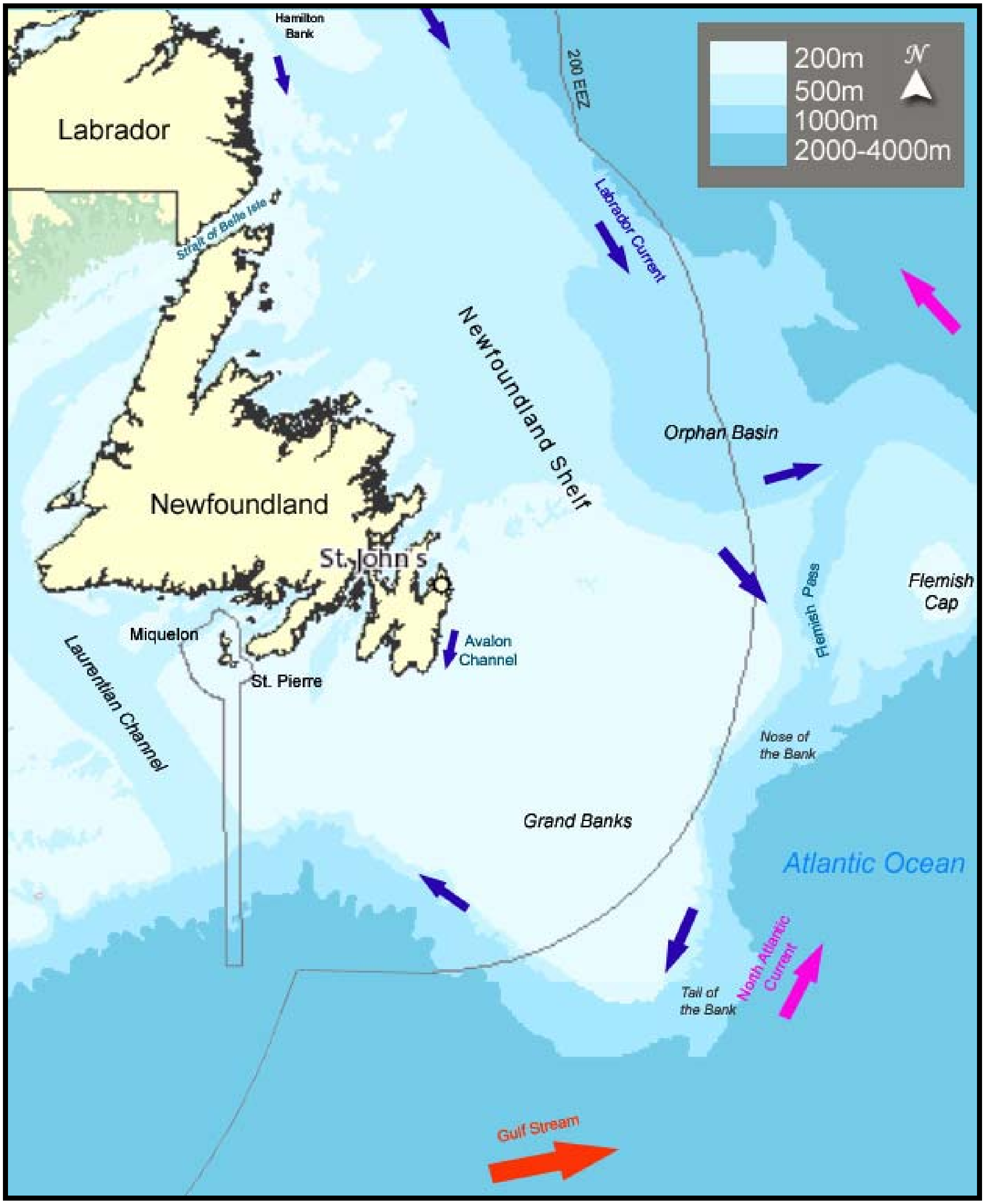


Figure 5. General circulation patterns and major currents of the Labrador and Newfoundland Shelf and adjacent northwest Atlantic Ocean.

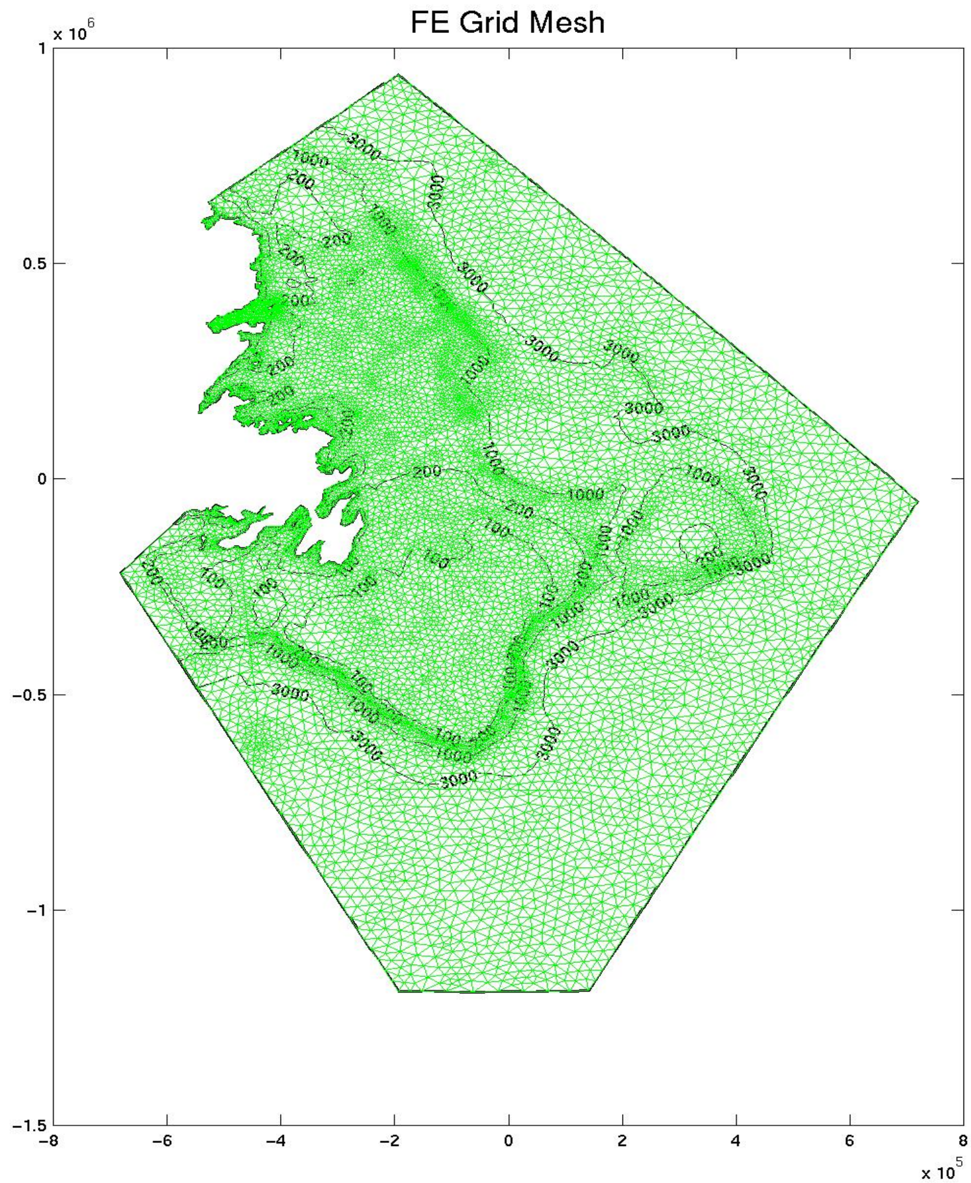


Figure 6. The horizontal finite-element grid is used in the numerical model. The depth contours and axes coordinates are in meters. The model origin is at 48.50ON 49.75OW.

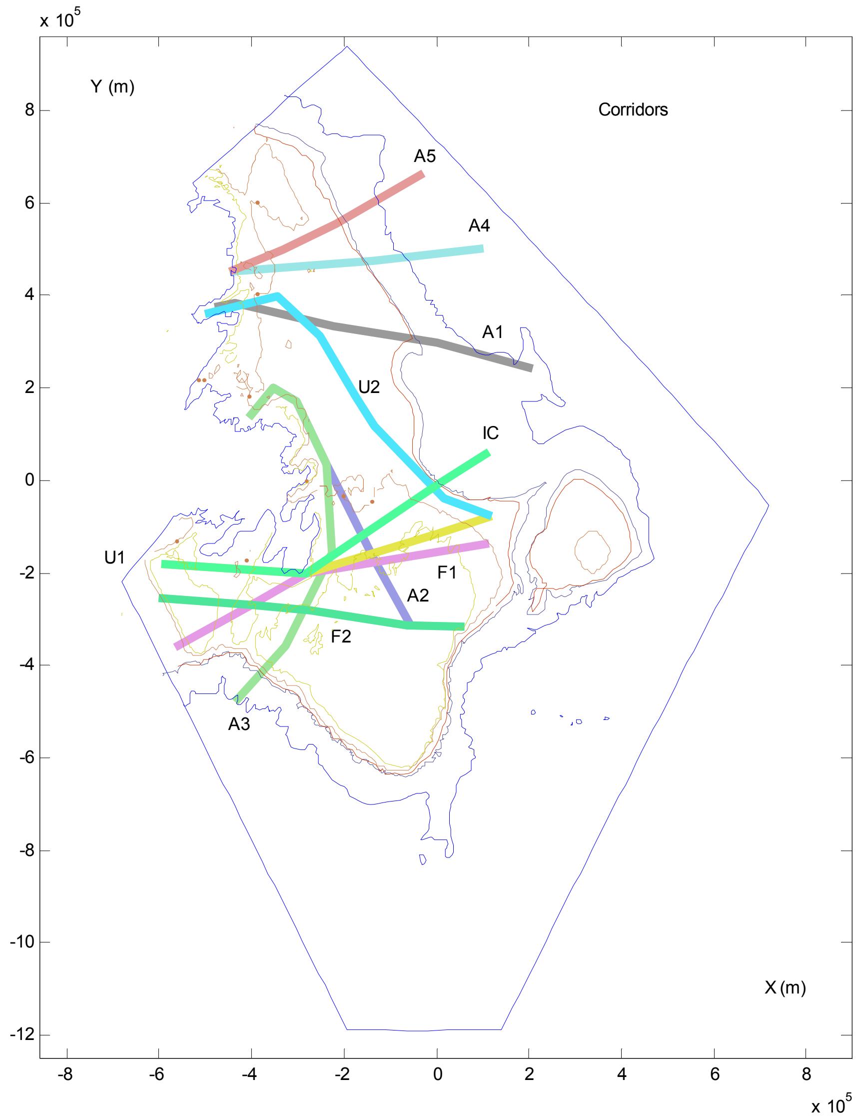


Figure 7. Selected principal vessel corridors over the Newfoundland Shelf based on the vessel transect density maps of Kelly (2002) within the model boundaries.

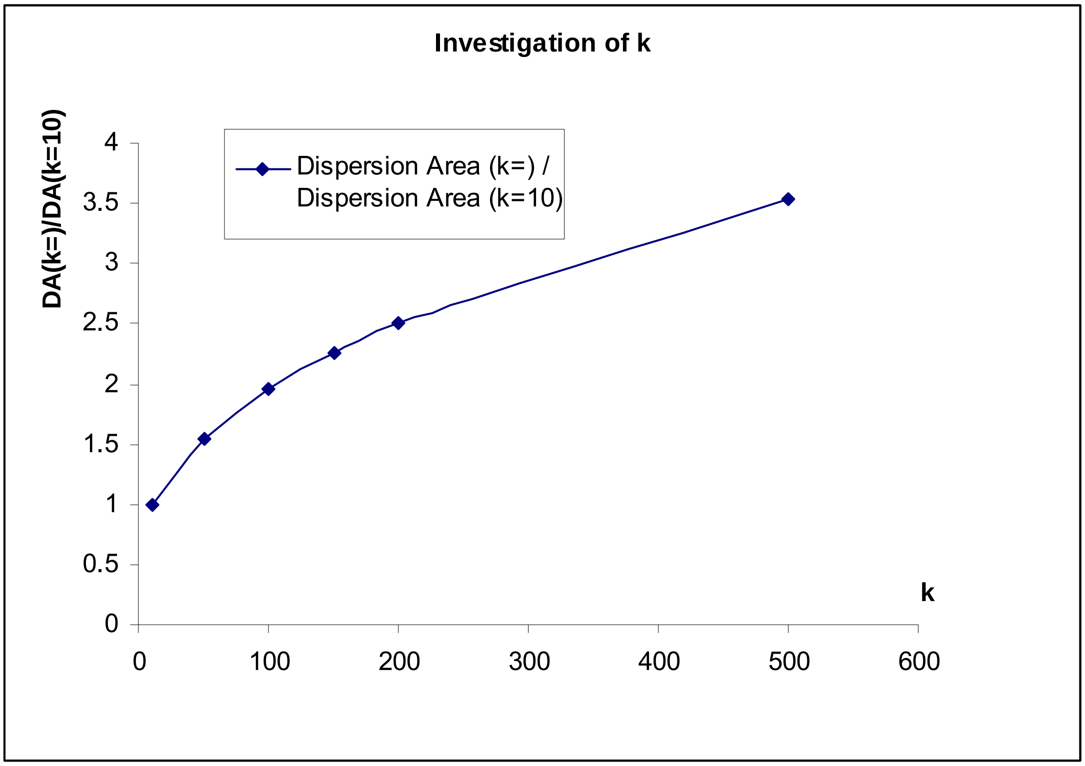


Figure 8. Variation of the model dispersion area with the horizontal diffusivity (k) along a segment of the IC corridor. Shown is the ratio relative to the dispersion area of $k=10\ m^2/s$.

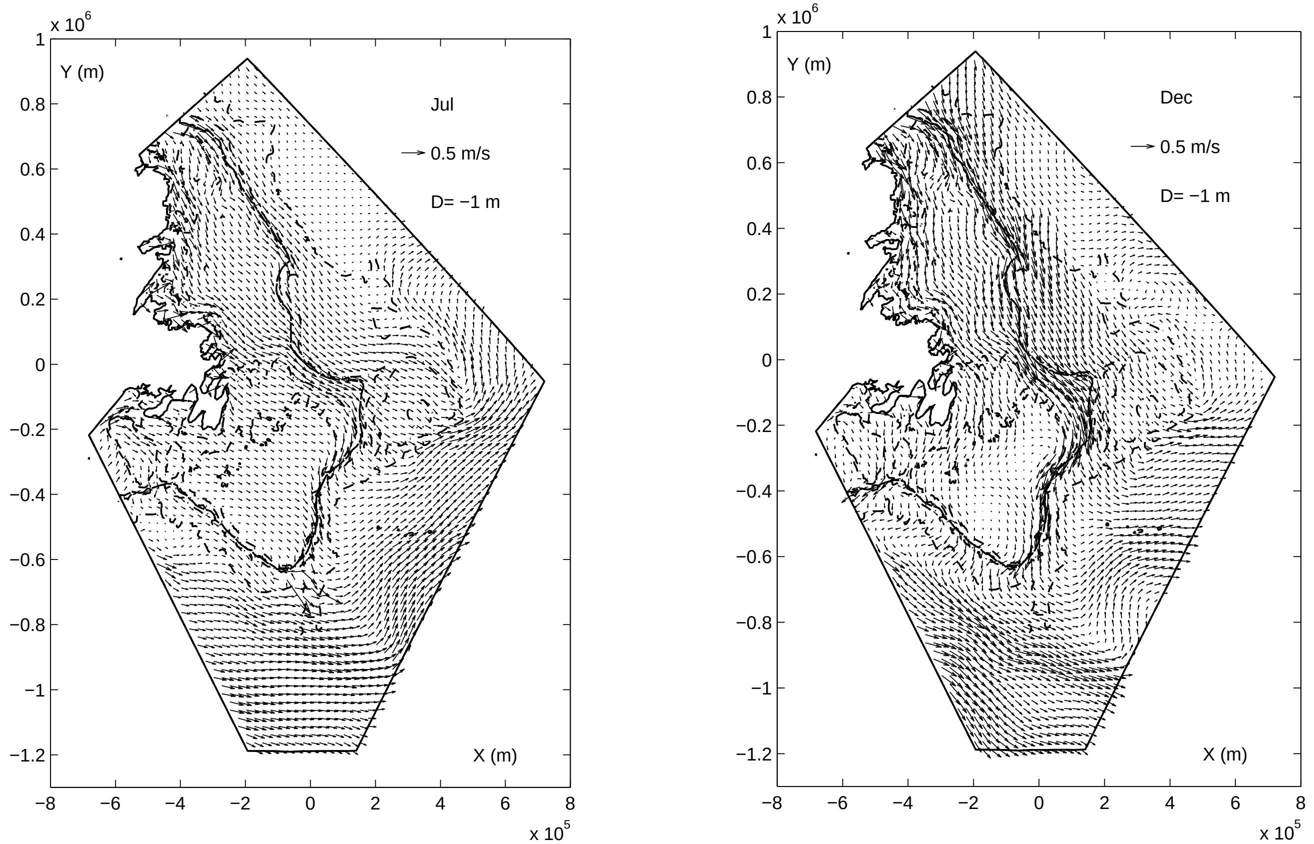


Figure 9. The model current fields at the 1-m depth in July and December. The 100-, 200-, 500-, 1000- and 3000-m isobaths are also shown.

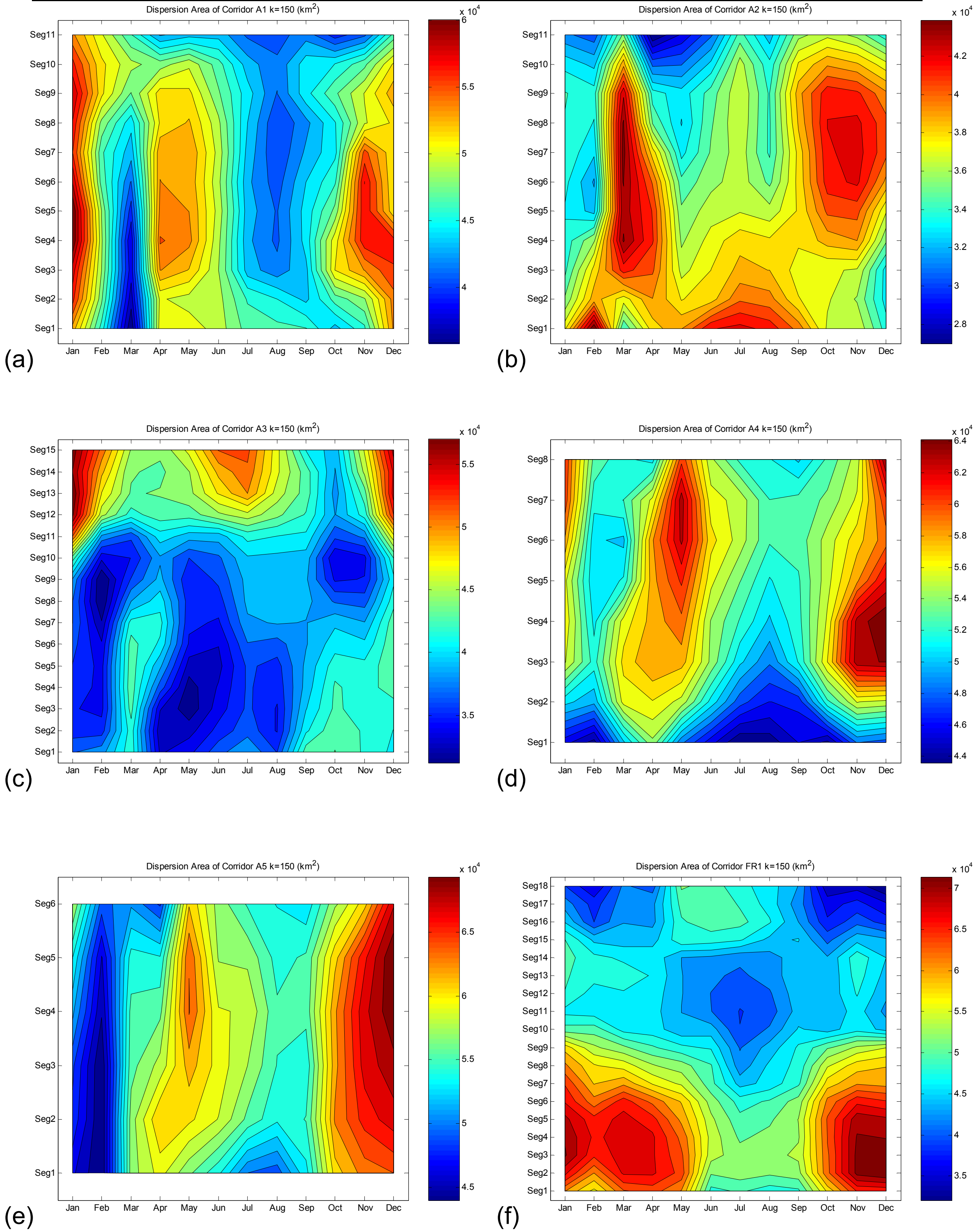
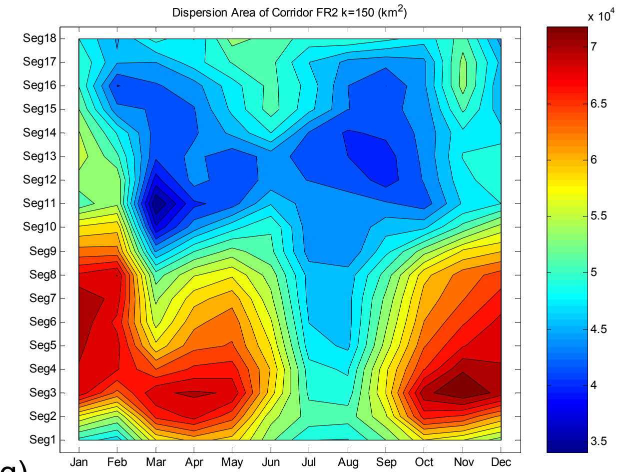
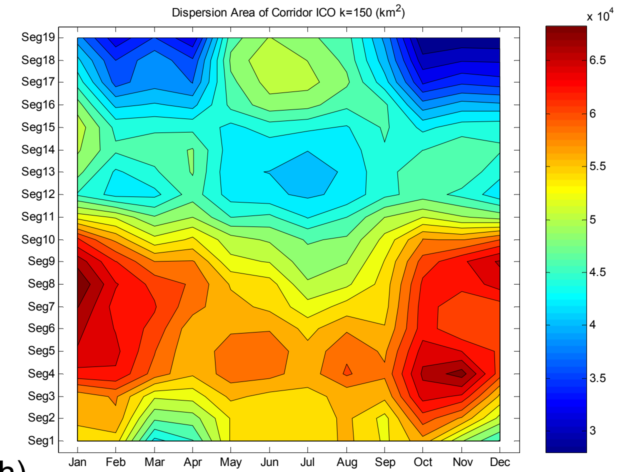


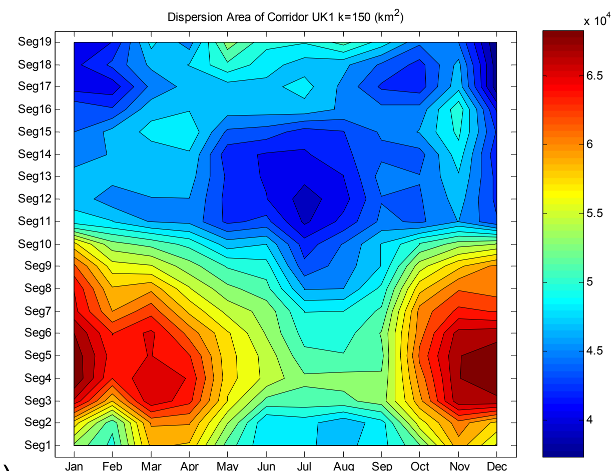
Figure 10. Variation of the dispersive area with segment and month for the 10 corridors. (a) A1, (b) A2, (c) A3, (d) A4, (e) A5, (f) F1, (g) F2, (h) IC (i) U1 and (j) U2. See Figure 7 for the corridor locations. The segment numbers from the west, except for A3 from the south (see Fig. 4).



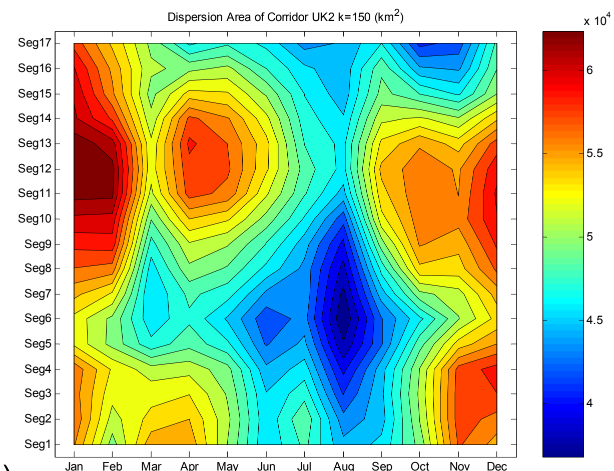
(g)



(h)



(i)



(j)

Figure 10. (Continued).

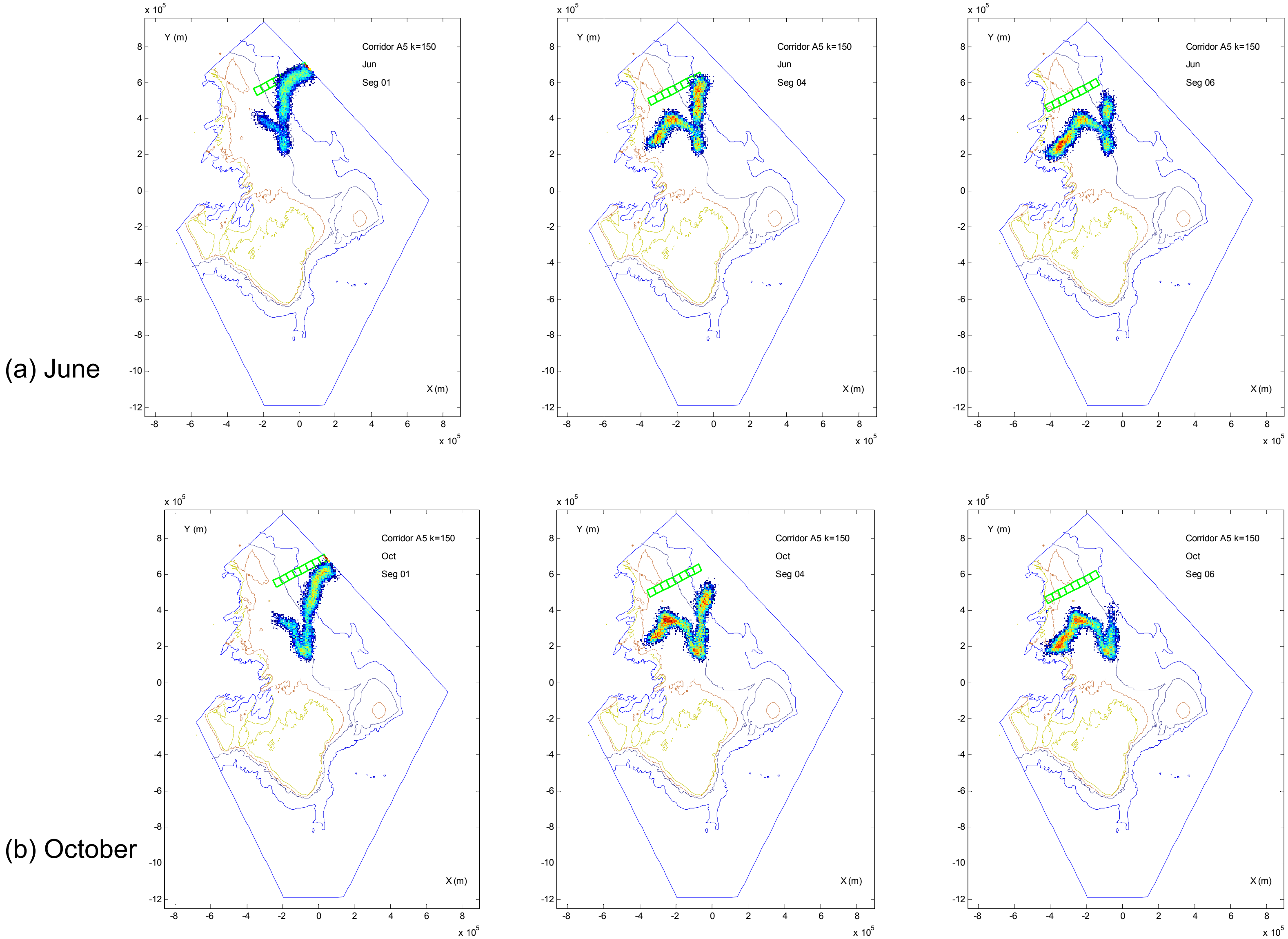


Figure 11. Concentration (in arbitrary units) distribution for Corridor A5 after 15d for the months of (a) June and (b) October. The 100-, 200-, 1000- and 3000-m isobaths are also shown.

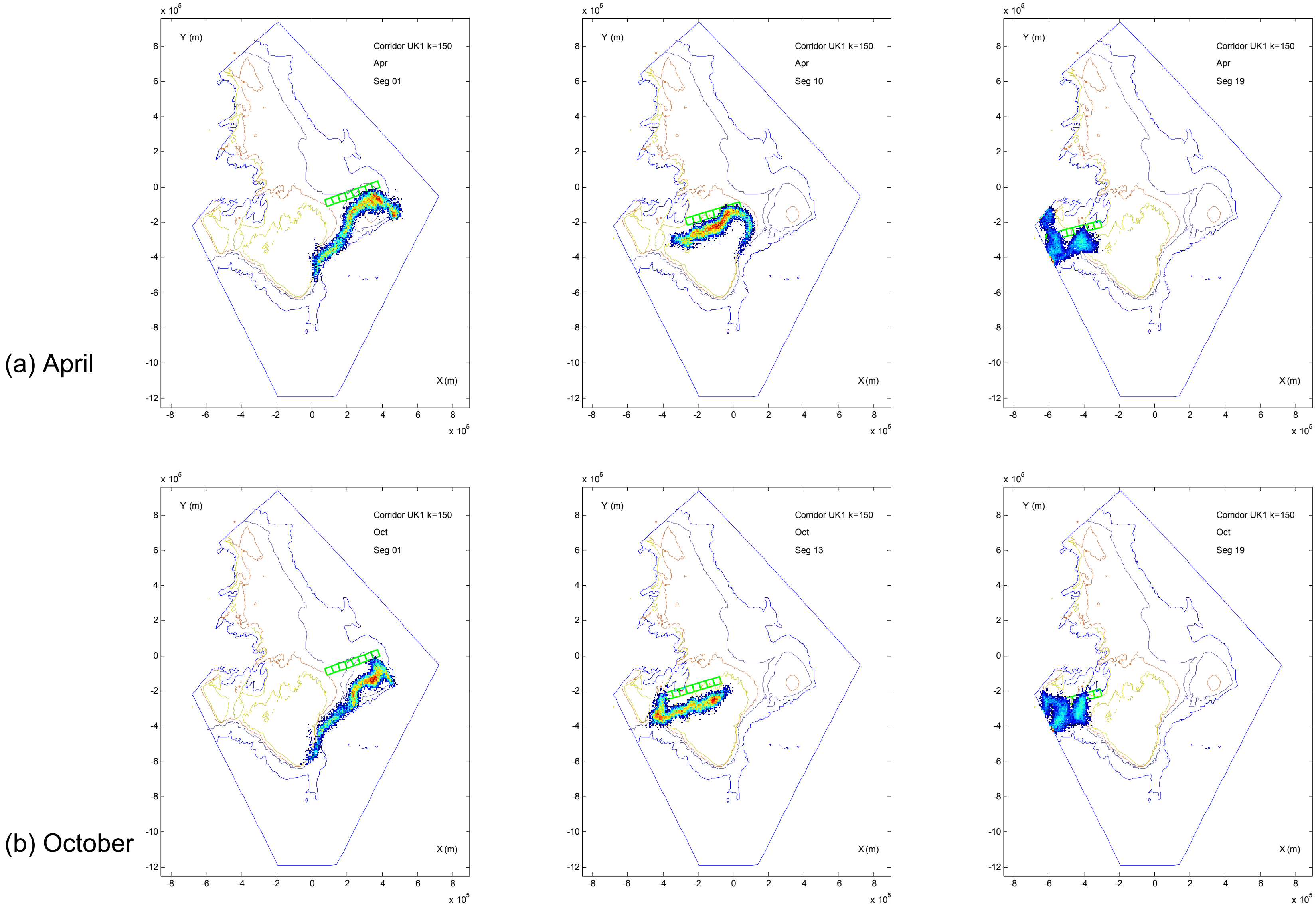


Figure 12. Concentration (in arbitrary units) distribution for Corridor UK1 after 15d for the months of (a) April and (b) October. The 100-, 200-, 1000- and 3000-m isobaths are also shown.

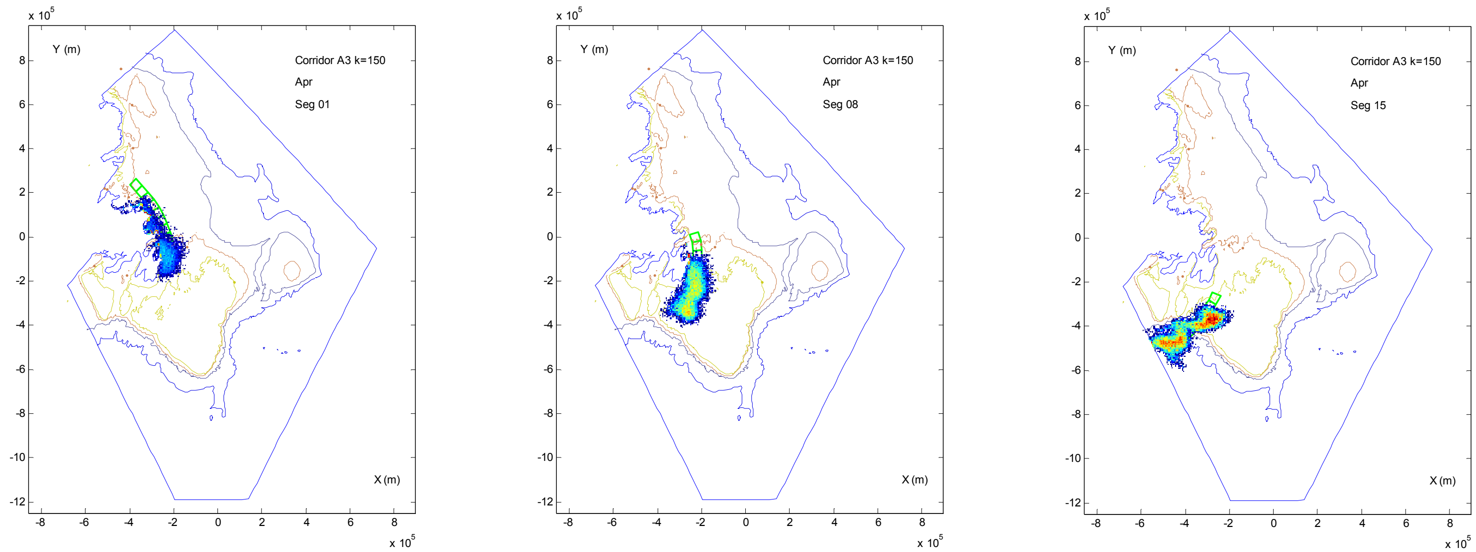


Figure 13. Concentration (in arbitrary units) distribution for Corridor A3 in April after 15d. The 100-, 200-, 1000- and 3000-m isobaths are also shown.

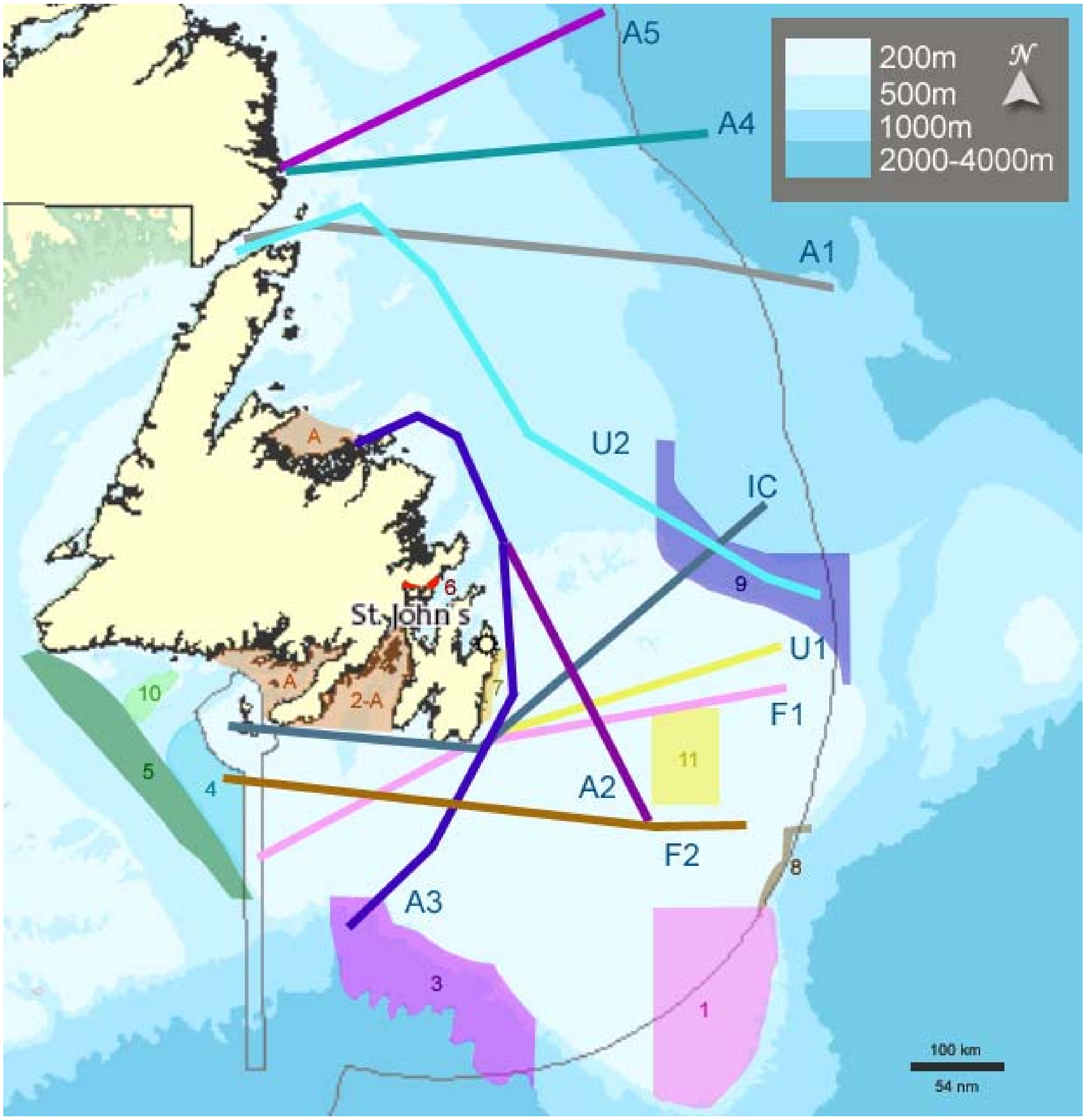


Figure 14. Compilation map with Placentia Bay Large Ocean Management Area (LOMA): Ecologically and Biologically Significant Areas (EBSA) and primary aquaculture areas (A) on south coast and northeast coast highlighted in brown demonstrating their proximity to vessel corridors.

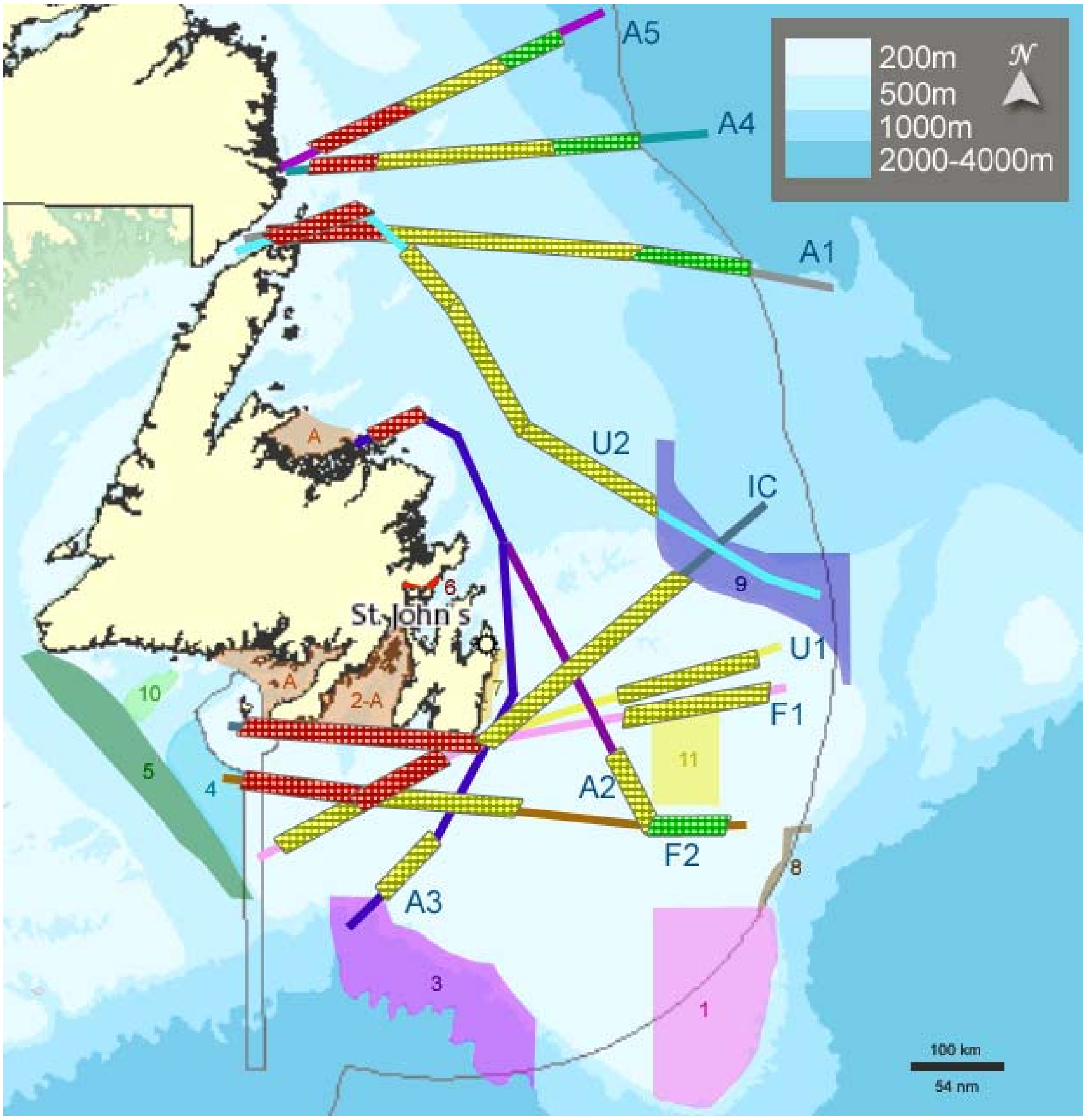


Figure 15. Potential exchange zone map with compilation of pertinent elements in alternate ballast water zone selection including water depth, primary vessel corridors, EBSAs, primary areas for Aquaculture zones using the oceanographic current model for particle dispersion. Green areas are potential areas for ABWZ in the Newfoundland and Labrador region, yellow areas are a seasonal or moderate concern and red areas strongly discouraged due to the probable impact on EBSAs and sustainable fisheries and aquaculture in the Region.

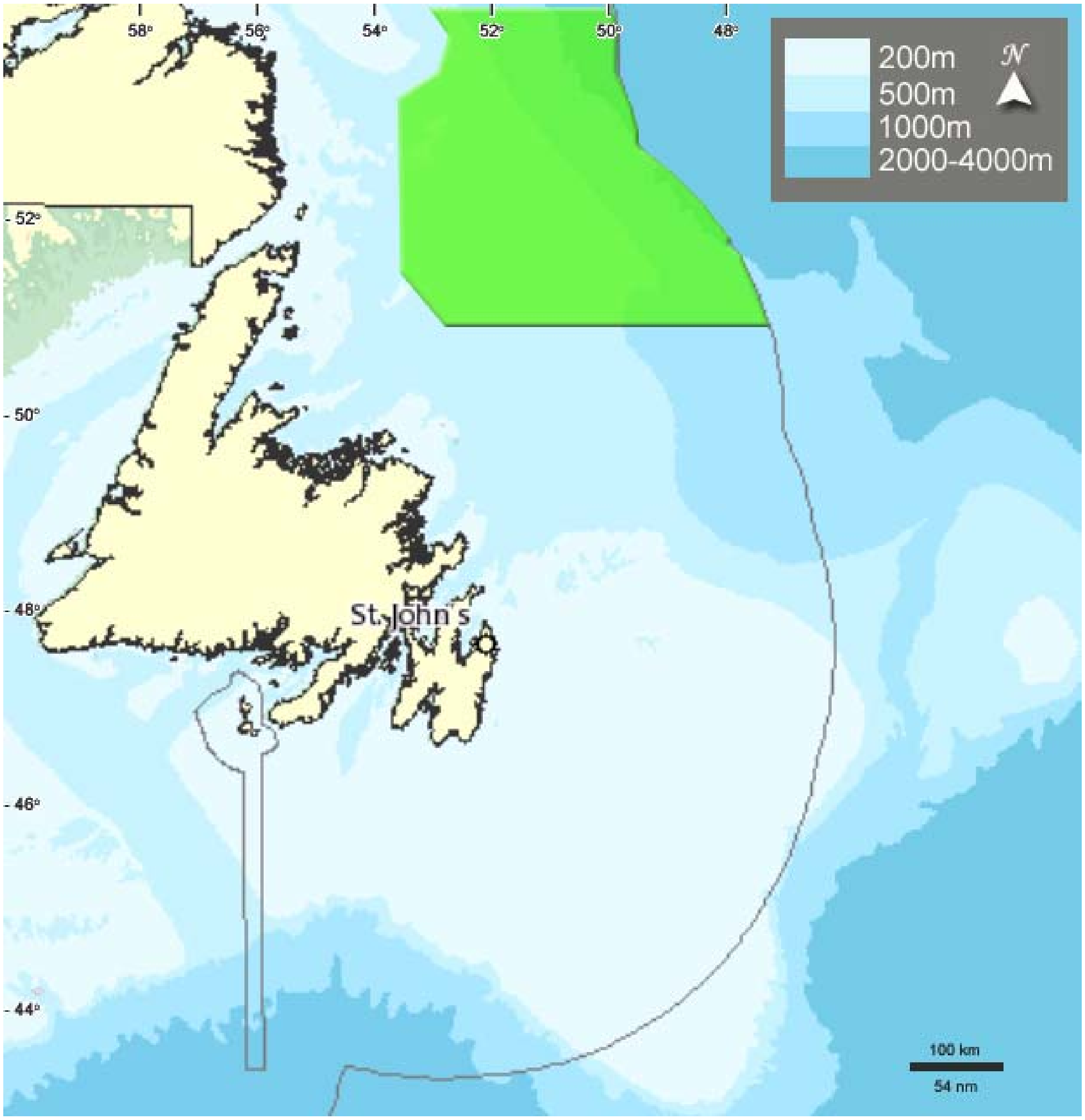


Figure 16. Final Alternate Ballast Water Exchange Zone recommendation map as reached though the National Peer review on Alternate Ballast Water Exchange Zones for vessel traffic to Newfoundland.