Development and Applications of Vessel Traffic Maps Based on Long Range Identification and Tracking (LRIT) Data in Atlantic Canada

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ABSTRACT

Long Range Identification and Tracking (LRIT) is a world-wide, satellite-based system that uses existing shipborne safety equipment to track vessel identification and positional information for passenger and cargo vessels of over 300 gross tonnage on international voyages. To date, tracking technologies such as LRIT have been used almost exclusively for real-time maritime domain awareness in support of maritime safety and security. This report describes geographic information system (GIS) techniques used for a retrospective vessel traffic analysis using LRIT data to produce 13 monthly maps and one 12-month composite map of shipping activity in Atlantic Canada. The application and limitations of LRIT data for marine conservation, environmental protection and response, and integrated coastal and oceans management are also discussed.

RÉSUMÉ

Le Système d'identification et de suivi des navires à grande distance (LRIT) est un système satellitaire à l'échelle mondiale qui fait usage de l'équipement de sécurité existant relatif à la navigation pour formuler des données de localisation et d'identification sur des navires à passagers et des navires de charge d'une jauge brute de plus de 300 tonneaux qui effectuent des voyages à l'échelle internationale. À ce jour, les technologies de suivi comme le LRIT ont été utilisées presque exclusivement aux fins de connaissance du domaine maritime en temps réel à l'appui de la sécurité et de la sûreté maritimes. Le présent rapport décrit les techniques du système d'information géographique (SIG) qui permettent d'effectuer une analyse rétrospective du trafic des navires à l'aide des données du LRIT en vue de produire treize (13) cartes mensuelles et une carte combinée s'étendant sur douze (12) mois qui présentent les activités de transport maritime au Canada atlantique. Le rapport traite également de l'application et des limites des données du LRIT aux fins de conservation marine, de protection et d'interventions environnementales ainsi que de gestion intégrée des côtes et des océans.

INTRODUCTION

The Maritimes Region's Oceans and Coastal Management Division (OCMD) of Fisheries and Oceans Canada (DFO) has developed spatial assessment and decision support tools, including human use maps (Breeze and Horsman, 2005), to facilitate marine conservation, sustainable development, and to identify and manage conflicting and compatible uses of ocean resources in support of integrated coastal and oceans management. Past decisions involving commercial shipping information have included environmental assessments (e.g., vessel traffic patterns in relation to proposed marine terminals), marine protected area and species at risk management measures (e.g., endangered North Atlantic right whale critical habitat areas), and the provision of DFO advice to Transport Canada for ballast water exchange zones. In our experience, ship movements in coastal areas and within vessel traffic separation schemes (TSS) are reasonably well known and readily captured by existing data collection streams (e.g., Automatic Identification Systems (AIS); Vessel Traffic Services (VTS) tracking systems). However, our access to remote monitoring systems to track offshore vessel traffic has been more limited, so less is known about the spatial and temporal patterns of commercial shipping beyond the coastal zone.

Earlier efforts to map commercial shipping activity in the Atlantic Canadian region utilized year 2000 inbound vessel traffic data from the Canadian Coast Guard's Eastern Canada Vessel Traffic Services Zone (ECAREG) system, which contained positional reports for commercial vessels of over 500 gross tonnage transiting within Canada's territorial sea (Breeze and Horsman, 2005; Figure 1). That mapping exercise revealed major spatial and temporal limitations in ECAREG data resolution, as well as substantial data gaps (e.g., vessels transiting Canadian waters without Canadian ports of call were not represented in the dataset). During the last decade, considerable gaps remained in our understanding of offshore commercial shipping patterns and intensity in Canada's exclusive economic zone, and by extension, our understanding of the risks posed to offshore ecosystems and other ocean sectors.

A number of distant-water vessel monitoring technologies have recently been made available to coastal states for the maintenance of security through maritime domain awareness (Cairns (2005), Lamprecht (2006), Hoye et al., (2008), Brooke et al., (2010) and Best (2011)). Long Range Identification and Tracking (LRIT) technology sits amongst the promising new class of satellite-enabled tracking options. This technical report describes geographic information system (GIS) techniques used for the development of preliminary LRIT data products covering Atlantic Canadian waters. The potential uses of LRIT-based vessel traffic maps for marine spatial planning in support of safety, security, and environmental protection and response are also discussed. The work presented here demonstrates the value of the LRIT system as a tool for integrated management of offshore ocean areas.

Long Range Identification and Tracking (LRIT) Data System

In 2006, the International Maritime Organization (IMO) adopted a resolution to promote the establishment of the LRIT system to provide global vessel identification and tracking for the enhancement of maritime safety and security (IMO, 2006). LRIT is a satellite-based system that detects information transmitted from mandatory shipboard equipment, the Global Maritime Distress Safety System.[1] Commercial vessels subject to the Safety of Life at Sea (SOLAS) Convention (i.e., mobile offshore drilling rigs, passenger ships, and cargo ships of over 300 gross tonnage on international voyages; Convention for the Safety of Life at Sea SOLAS, 1974) are required to transmit their location along with IMO and Maritime Mobile Service Identity (MMSI) numbers every 6 hours (Maritime Safety Committee, 2008). These automatic position reports may be transmitted as frequently as every 15 minutes when requested or remotely "polled" by entitled governments. By accessing SOLAS vessel identity and positional information in a timely manner, a coastal state may evaluate security risks posed by a ship off its coast and respond as required. Further, LRIT provides support for maritime search and rescue as well as environmental protection and response.

The Canadian LRIT program began in 2009 with the development of the LRIT Regulations[2] under the *Canada Shipping Act, 2001* and the establishment of the Canadian Coast Guard's LRIT National Data Centre (NDC). The NDC is responsible for collecting, managing and disseminating all LRIT data submitted by Canadian SOLAS-classed vessels wherever they are in the world. The NDC also has the authority to track foreign vessels that have submitted a Notice of Arrival indicating they are bound for Canadian ports (i.e., this is typically 96 hours prior to arrival and up to 2,000 nautical miles (NM) of a Canadian coast) and all vessels transiting within 1,000 NM of a Canadian coast.

By February 2010, flag ships from 84 countries were known to be reporting through the LRIT system, accounting for approximately 95 percent of all SOLAS class vessels world-wide. With this high-level of coverage, the LRIT system and associated data archives presented an unprecedented opportunity to fill the gap in our knowledge of commercial vessel traffic in Canada's offshore waters and to test the utility of LRIT data for tracking vessels in two sensitive marine areas: the Gully Marine Protected Area (MPA) and the Roseway Basin Area to be Avoided (ATBA).

METHODS

A tabular LRIT dataset acquired from the Maritime Security Branch of the Canadian Coast Guard was used to analyze commercial vessel activity off the Atlantic Canadian coast. The dataset comprised a continuous data stream of geographical positions reported at 6-hourly intervals for each vessel archived by the NDC over a 13-month period (February 2010–February 2011). The data included variables for latitude and longitude in decimal degrees, a date/time stamp, a unique vessel identifier code (vessel ID), vessel type (e.g., cargo, tanker, cruise ship) and country of registration. The LRIT system does not record direction of travel or vessel speed, and the acquired dataset did not include information related to port of origin or destination, vessel names, and IMO or MMSI numbers. Information related to vessel-specific identification was removed from the dataset for reasons of privacy and security. As such, the analysis

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[1] For additional IMO Guidance and Resolutions on the LRIT system, see online: <http://www.imo.org/OurWork/Safety/Navigation/Pages/LRIT.aspx>.

[2] Long-Range Identification and Tracking of Vessels Regulations. 2010. SOR/2010-227. Available online: <http://laws-lois.justice.gc.ca/eng/regulations/SOR-2010-227/>.

described here was limited to the determination of overall traffic patterns, dominant offshore corridors and monthly variations.

The 13-month LRIT dataset contained approximately 930,000 records covering the entire globe (i.e., these data include positional reports for Canadian-flagged vessels located world-wide, all vessels traveling within 1000 NM of a Canadian coast, and foreign vessels bound for a Canadian port). Figure 2 shows the global extent of the Canadian LRIT data reception range, including approximately 900 unique vessels reporting per day within 1,000 NM of the Canadian coast. In order to limit the geographic scope and the time required for data processing, an extraction window was used to select data pertinent to Atlantic Canada. This ~12-million km^2 study area, which is equivalent to approximately two percent of the Earth's surface area, was defined by the following coordinates: (62°00'30" N, 78°30'30" W) in the northeast corner and (27°59'30" N, 37°30'30" W) in the southwest corner (see Figure 2). The dataset extracted from the Atlantic window consisted of 504,000 records, more than 50 percent of the NDC-accessible data collected during the 13-month study period.

Vessel Track Lines

The data for the study area were first separated into calendar months in a geographic information system (ArcGIS 9.3) and the location of each report was plotted as a point object (Figure 3). Vessel-specific track lines were created by connecting points associated with each vessel ID in the correct temporal sequence using the date/time stamp associated with each position (Figure 4). Because the track lines generated by this process connect known vessel positions reported at 6-hourly intervals, track lines indicate the inferred path of the vessel rather than the true vessel track.

For each month of data, a small number of anomalous track lines were created as part of the point-to-track line conversion. Track lines that appear to cross short stretches of coastal lands are artifacts of the reporting interval; subtle adjustments to vessel trajectory (e.g., such as those performed for coastal navigation) will not be represented in a dataset of vessel positions reported at 6-hourly intervals (Figure 4A). This artifact can be hidden using masking (e.g., the land mass layer can be superimposed over anomalous track lines; Figure 4B). Additional anomalies, most easily visible as long line segments that cross large stretches of land and long vertical or horizontal line segments located near the edges of the data window (Figure 5A), were created by large temporal gaps in the dataset between consecutive vessel reports. In certain rare cases, this may have resulted from disruptions in signal transmission or detection; if several consecutive reports were not received by the NDC during a vessel transit, the vessel may appear to have travelled long distances across land (for example, see Figure 5A, box 1). Alternatively, this artifact might be created when a vessel traveled outside the data window (e.g., vessels en route to European ports) and then re-entered the area within the same month. In this case, consecutive points in the dataset would be joined by long vertical or horizontal line segments, depending on the location of the vessel prior to departure and after re-entry into the data window (for example, see Figure 5A, box 2). To correct for this type of anomaly, Microsoft Excel was used to clean and reprocess the data. Briefly, a query was developed to calculate the time gap between consecutive records for each vessel ID. For instances where the time gap was greater than 35 hours, a new track line was assigned to the remaining vessel-specific records in order to eliminate the anomalous segment (Figure 5B). A 35-hour time gap was used to identify breaking points for track lines because this was the shortest increment observed to create anomalous line segments.

Vessel Track Counts

A 2 x 2-arc minute polygon grid comprising 1,254,600 cells was created and aligned with latitude and longitude grid lines using a half-minute offset in both dimensions. The half-minute offset was used so that grid cell boundaries would align with other geospatial data[3] used by OCMD. A spatial join was performed between the grid cells and track lines to produce a count of vessel tracks within each 2 x 2-arc minute cell, which consumed 100 to 150 hours of processing time per month of data. This was completed for each of the 13 months of data (for example, see Figure 6). The vector polygon grid for each month was converted into a raster grid to allow for data compression and efficient visual display. A 12-month composite (March 2010–February 2011) was also produced by summing the raster grid counts for each month.

The track lines and the 2 x 2-arc minute polygon grid were constructed in a geographic coordinate system using the WGS84 datum. With the exception of Figure 6, all maps were plotted in a Mercator map projection, which is the projection used for navigational charts. The vessel track counts were thematically symbolized using five user-defined class breaks. To facilitate comparisons between months, the same class breaks were assigned to all 13 months so that only the upper limit of the top class varied between months. Class breaks for the 12-month composite were approximately ten times the values of the breaks used for the monthly maps.

RESULTS AND DISCUSSION

Thirteen monthly maps and a 12-month (March 2010–February 2011) composite of vessel track counts per 2 x 2-minute grid cell were produced. These maps serve to highlight commercial traffic patterns for vessels transiting within 1,000 NM from Canada's Atlantic coast (for examples, see Figures 7–11). The 12-month composite analysis shows the cumulative commercial vessel traffic for the entire study area (Figure 7). A closer view of the composite data for the Atlantic Region is also provided (Figure 8). When comparing the 12-month composite map generated from 2000 ECAREG data (see Figure 1) with the composite map based on 2010–2011 LRIT data (Figure 8), notable differences in shipping patterns appear alongside previously mapped routes. For example, a routing in the Bay of Fundy north of Grand Manan Island in southwest New Brunswick appears in the LRIT data that was not found using ECAREG data. A prominent route originating from Yarmouth on the southwest tip of Nova Scotia is not evident in the more current dataset, likely a result of the 2010 closure of the international ferry service between Nova Scotia and Maine, USA. The track lines of vessels transiting Canadian waters without a Canadian port of call are also apparent, such as those bound for Europe that have departed from ports along the eastern seaboard of the United States. Several predominant

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[3] For example, fisheries landings data, which are reported at a resolution of 1-arc minute, must be gridded using a half-minute offset to avoid falsely aggregating data into neighboring cells or double counting due to overlapping cells.

offshore routes to Europe are apparent in the LRIT-based composite (Figure 8), including one along the continental shelf break that appears to transect the Gully MPA. There is also a USA-Northern Europe route that passes mid-shelf north of Sable Island, a route not apparent in earlier data sources and thus previously unknown by the authors.

Overall, track line counts for the study area were highest in August 2010, and lowest in February 2010 (Figure 9; Table 1). The low number of vessels in February 2010 may be due in part to the level of LRIT coverage for that month. Flag state compliance with LRIT reporting improved over the timeframe of our investigation such that the study area had 665 more track lines in February 2011 than in February 2010 (Table 1). Notwithstanding the increase in reports, more northerly traffic routes, such as the predominant tracks that pass between Labrador and Newfoundland through the Strait of Belle Isle into the Gulf of St. Lawrence, are greatly reduced in the winter months, as navigation can be affected by the presence of pack ice and icebergs.

Roseway Basin is a seasonal Area to be Avoided (ATBA) that was proposed by Canada and adopted by IMO (IMO, 2007). Vessels of ≥ 300 gross tonnage are asked to avoid transiting this area from June 1st to December 31st to reduce the risk of vessel strikes for the endangered North Atlantic right whale. While the pattern of LRIT-derived track lines in and around Roseway Basin suggest that vessels are generally complying with IMO recommendations (for example, see Figure 10), over 480 tracks passed through the ATBA from February 2010 to February 2011. Counts within the ATBA remain comparatively high during the seasonal closure (25–48 per month), with September 2010 receiving the third highest number of transits in all 13 months of data (Table 1). While these numbers may indicate some level of non-compliance with IMO recommendations, such a conclusion would contradict the findings of another on-going program that monitors vessel traffic in the Roseway ATBA using terrestrial, VHF radio-based AIS, which collects vessel position information at very high frequencies (≥1-minute intervals, receiver range is 40–50 NM depending on factors such as weather and antenna height), and has documented a high degree of compliance with the ATBA restrictions (Vanderlaan and Taggart, 2009). Rather, it is more likely that many of the tracks that cross into the area are artifacts of the 6-hourly reporting interval. Small course corrections made to avoid the Roseway ATBA will not be captured in the LRIT dataset so tracks may appear to cross the ATBA even if vessels have navigated around it, not unlike the previously described routes that appear to cross coastal lands. As such, caution should be exercised when interpreting the path of vessel tracks at large map scales using this dataset.

The Gully Marine Protected Area (MPA) is a deep submarine canyon that is home to a variety of marine mammals, including endangered northern bottlenose and blue whales. The Gully MPA Regulations[4] prohibit any activity within or in the vicinity of the MPA that disturbs damages, destroys or removes any living marine organism or any part of its habitat. The Regulations permit the exercise of international navigational rights in the MPA year-round. However, vessels are asked to either reduce speed or avoid passage through the area to minimize acoustic disturbance and the risk of collisions with marine mammals (Canadian Coast Guard, 2011). Over 490 vessels appear to have passed through the Gully MPA from February 2010 to February 2011 (Table 1). Transits through the MPA were highest in August 2010, and lowest in February 2011

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[4] Gully Marine Protected Area Regulations. SOR/2004-112. Available online: <http://laws-lois.justice.gc.ca/eng/regulations/SOR-2004-112/index.html>.

(Figure 11). Overall, vessel transits each month were variable, and no obvious seasonal trends could be distinguished (Table 1). Further analysis is needed to determine whether a change in vessel speed can be detected over such a small geographic area using this LRIT dataset (vessel speed was not included in the dataset, but the average estimated speed between 6-hourly automatic position reports can be derived). Regardless, like the Roseway ATBA, caution should be taken when interpreting vessel tracks derived from 6-hourly LRIT reports at scales appropriate for compliance monitoring in the Gully MPA.

Ocean Management Applications of LRIT Data

In light of the above analysis, it is clear that the LRIT system helps to fill important gaps in our understanding of offshore commercial shipping patterns in Canada's exclusive economic zone and beyond. Interest in LRIT mapping products is anticipated from several quarters including federal and provincial regulators with oceans-related mandates, the shipping and ocean energy industries, and DFO-chaired multi-stakeholder planning groups (e.g., Gully Marine Protected Area Advisory Committee and the Right Whale Recovery Network). A wide variety of management applications can be envisioned for the LRIT data products. Below we discuss examples directly related to the work of the DFO Maritimes Region's Oceans and Coastal Management Division.

The traffic patterns emerging from this analysis will be most useful for decision-making at region-wide scales. For example, LRIT data-derived predominant traffic routes might be considered as part of an assessment of options for designating spatially defined "places of refuge,"[5] such as conveniently located ports or other sheltered coastal locations, that might be used for commercial ships in distress on the Scotian Shelf. Such an analysis would be timely, as the designation of "places of refuge" off Canada's Atlantic coast is an ongoing dialogue between the Company of Master Mariners of Canada, shipping industry associations, and maritime transport regulators, including Transport Canada.[6]

The Nova Scotia Energy Department, with a lead mandate for marine renewable energy development, has undertaken a strategic environmental assessment (SEA) for renewable energy in the Bay of Fundy and recently commissioned an SEA for Cape Breton Island, Nova Scotia (Nova Scotia Energy, 2009). LRIT data products can provide guidance for the operational siting of marine renewable energy infrastructure off the coast of Nova Scotia.

Canada's Atlantic coast has not had a major maritime oil spill for more than three decades, yet the risks of vessel-source pollution are clearly evident based on, among other potential sources, ongoing coastal oil trans-shipments. Assessing shipping accident risks posed to coastal and offshore ecosystems and related planning for vessel-source pollution preparedness can be enhanced though spatial and temporal knowledge of tanker transit routes and patterns via the LRIT system. Furthermore, Canada's oceans are also at risk from more chronic small-scale

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[5] For more information on Places of Refuge, see IMO's website: <http://www.imo.org/OurWork/Safety/Navigation/Pages/PlacesOfRefuge.aspx>.

[6] See conference proceedings "Shipping and Environmental Issues in 2011 – What more can be done?," Session 3, Places of Refuge for Ships in Need of Assistance, June 7–8, 2011, Company of Master Mariners, available online: <http://www.mastermariners.ca/cms/UserFiles/2011confproceed(1).htm>.

discharges of oily waste products from regular ship-based operations and illegal dumping (Serra-Sogas et al. 2008). The Oil in Canadian Waters Working Group, including Transport Canada, Environment Canada and the Canadian Coast Guard, is dedicated to deterring and investigating such activities using the LRIT system in combination with other remote vessel and pollution monitoring systems to determine trends in vessel traffic and identify patterns of illegal behaviour.

DFO is responsible for ensuring the protection and conservation of marine mammals and for protecting the designated Critical Habitat of any species listed as Endangered or Threatened under the *Species at Risk Act*. One anticipated application for LRIT data products was the ongoing monitoring of shipping activity in Critical Habitat areas for at-risk cetaceans, such as the Roseway ATBA and the Gully MPA, Critical Habitat for North Atlantic right whales (Brown et al., 2009) and endangered northern bottlenose whales (Department of Fisheries and Oceans, 2010), respectively. Vessel monitoring is needed to better characterize the potential threats posed by shipping, with results lending support to targeted outreach for conservation and safety purposes through specific port authorities, vessel agents and shipping associations. However, as we have illustrated, caution must be exercised when using this LRIT dataset for compliance monitoring at spatial scales appropriate for the Gully MPA or Roseway ATBA due to the low frequency reporting interval. The implementation of increased reporting rates for special management areas (e.g., hourly reports for vessels in the vicinity of the Gully MPA) is under investigation and would facilitate more detailed analyses of vessel activities, including area avoidance and changes in speed over relatively short distances. For near-shore management areas such as the Roseway ATBA, existing terrestrial AIS systems (e.g., Vanderlaan and Taggart, 2009) are a better choice for compliance monitoring with IMO-adopted avoidance recommendations.

Next Steps

At present, tracking technologies such as LRIT are used almost exclusively for near real-time maritime domain awareness. Here we have extended the application of LRIT data for a retrospective ocean use analysis in support of environmental protection and coastal and oceans management.

Future analyses of LRIT data could include a breakdown of vessel patterns by vessel type (e.g., cargo, tanker, and cruise ships), tonnage, length, draft and/or date of construction. The full dataset might also be processed to depict vessel traffic patterns in Canada's Pacific and Arctic Oceans in separate regional datasets, or as a cohesive single national dataset. The option to process and analyze a larger geographic and temporal dataset would also enable a better inference of origin/destination from the expanded vessel track lines. However, given the time-consuming nature of the GIS data processing to count vessel track lines within each of the 1,254,600 polygon grid cells, alternative software and data processing methods should be investigated.

As demonstrated above, the default 6-hourly reporting interval was not sufficient for reliable vessel route determination at the geographic scales appropriate for compliance monitoring in special management areas such as Roseway Basin ATBA and the Gully MPA. While vessel traffic in Roseway Basin can be tracked using other existing terrestrial AIS monitoring systems, for offshore areas such as the Gully MPA, LRIT is still our best option for commercial vessel tracking. Options for increasing LRIT reporting intervals for areas such as the Gully MPA are being explored. Meanwhile, the optimization of reporting intervals for different spatial scales could be investigated by resampling a higher report frequency (≥1 minute interval) AIS dataset at 15-minute, 30-minute, hourly, and/or multi-hour intervals to determine the effects on inferred vessel paths. Additional developments in this area might include the integration of archival LRIT data with data from terrestrial AIS systems, ballast water exchange reports, aerial pollution sightings data, and other human use data sources for multi-system data interrogation and improved compliance monitoring at multiple spatial scales.

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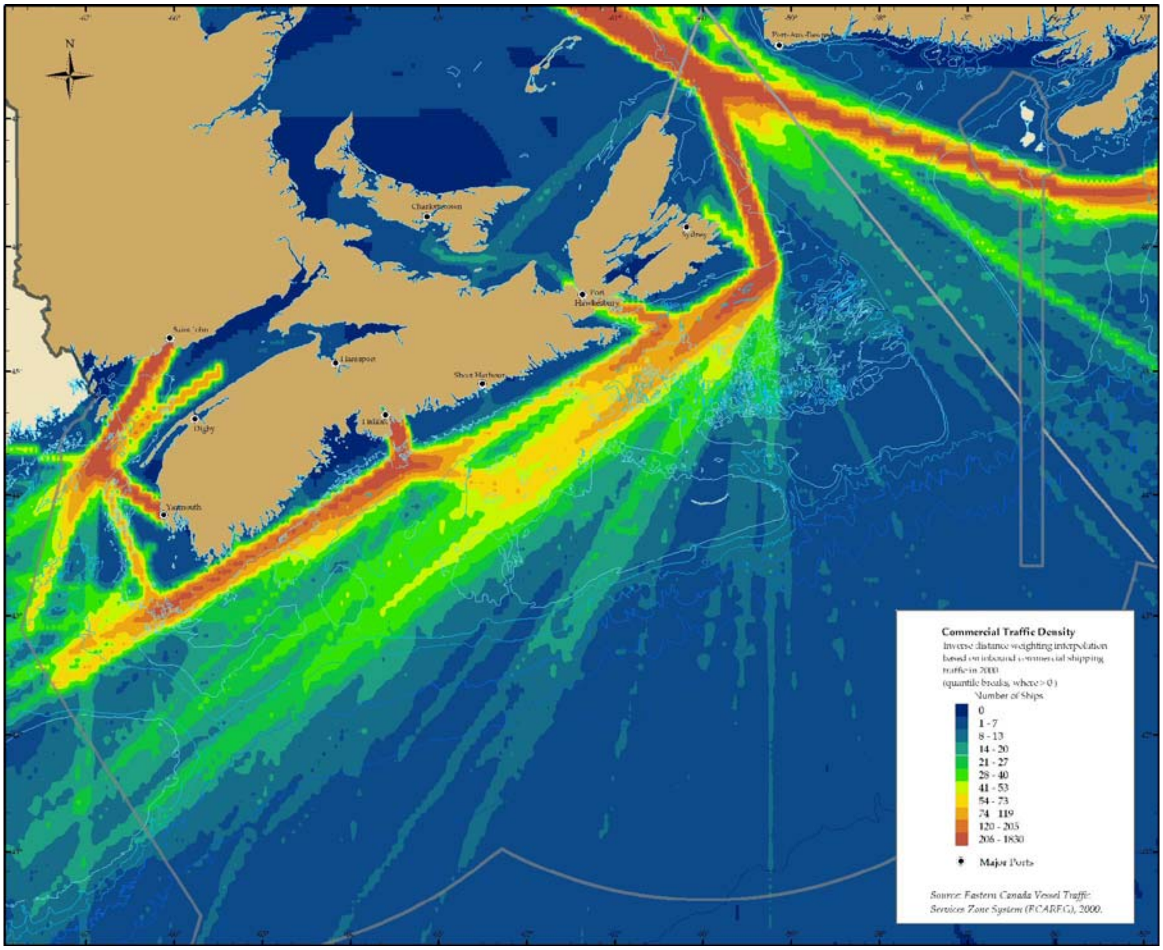
Figure 1. Commercial traffic counts derived from Eastern Canada Vessel Traffic Services Zone system data from 2000.



Source: H. Breeze and T. Horsman, eds., 2005. *The Scotian Shelf: An Atlas of Human Activities*. Oceans and Coastal Management Division, DFO Maritimes, Dartmouth, NS.

Figure 2. Global extent of the Long Range Identification and Tracking data collected by the Canadian National Data Centre from February 2010 to February 2011. Data include locations of Canadian-flagged vessels world-wide and foreign vessels bound for a Canadian port or transiting within 1,000 nautical miles of a Canadian coast. The 12-million km^2 data extraction window is shown in red.

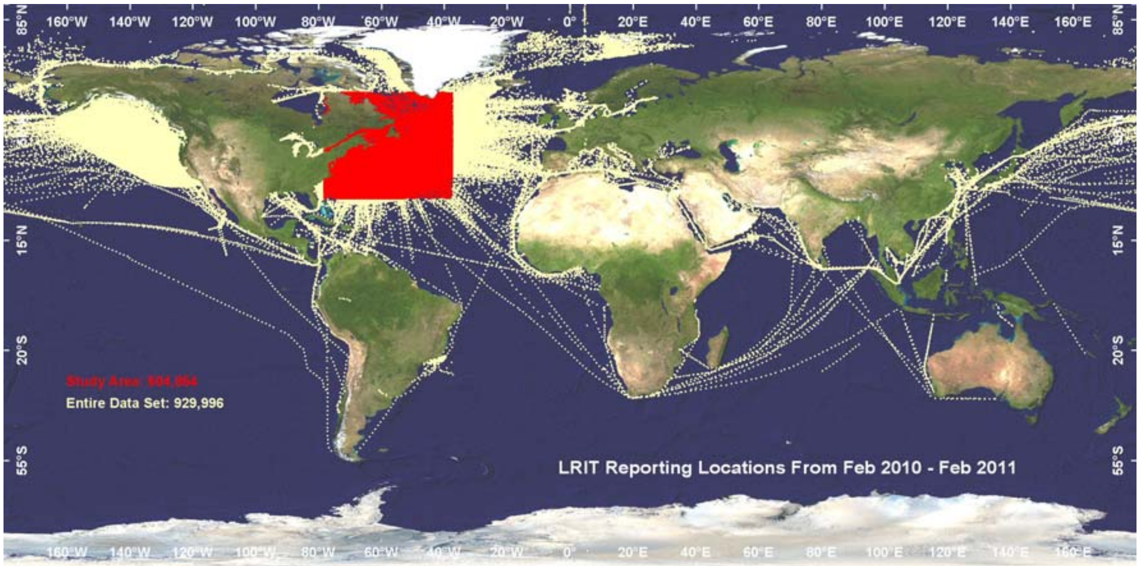


Figure 3. Vessel report locations from the February 2010 Long Range Identification and Tracking dataset within the study area. The Gully Marine Protected Area boundary (blue polygon) and Roseway Basin Area to be Avoided (orange polygon) are provided for geographic reference.

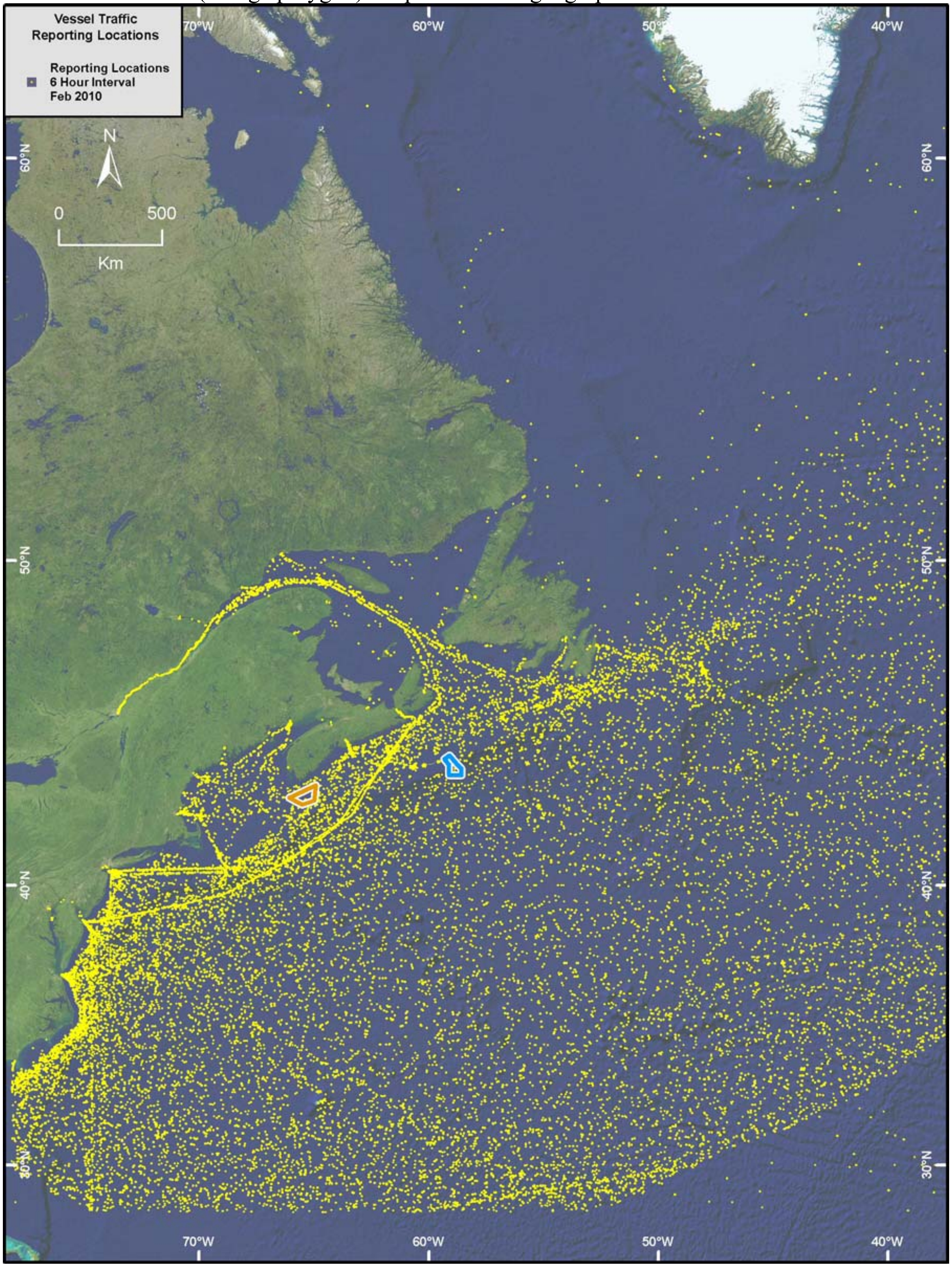


Figure 4. (A) Vessel report locations from the July 2010 Long Range Identification and Tracking dataset connected by vessel-specific track line segments. Several anomalous line segments cross over coastal lands when tracks are depicted without masking. Orange polygon: Roseway Basin Area to be Avoided.

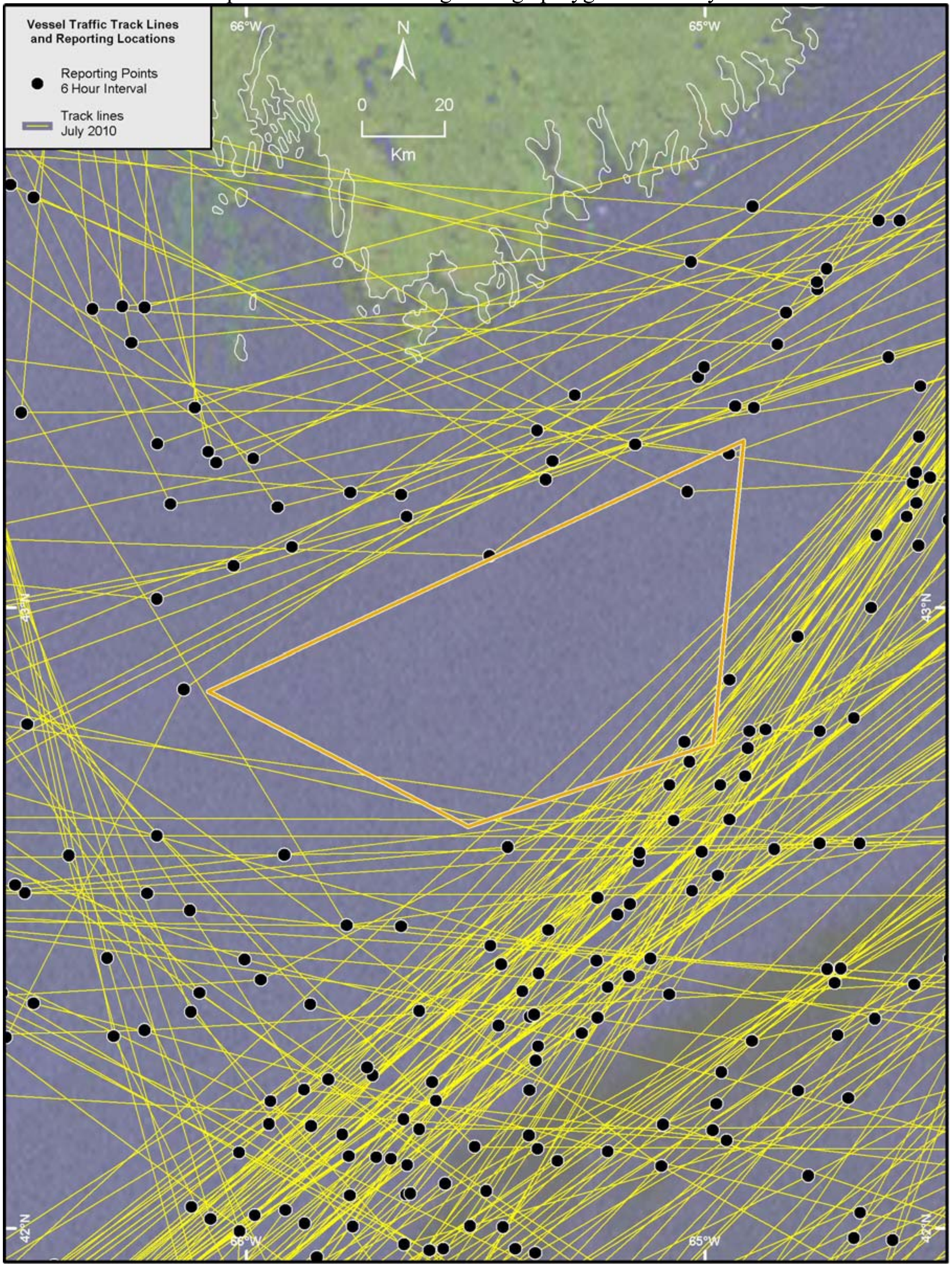


Figure 4. (B) Vessel report locations from the July 2010 Long Range Identification and Tracking dataset connected by vessel-specific track line segments. Anomalous line segments are masked by the land feature. Orange polygon: Roseway Basin Area to be Avoided.

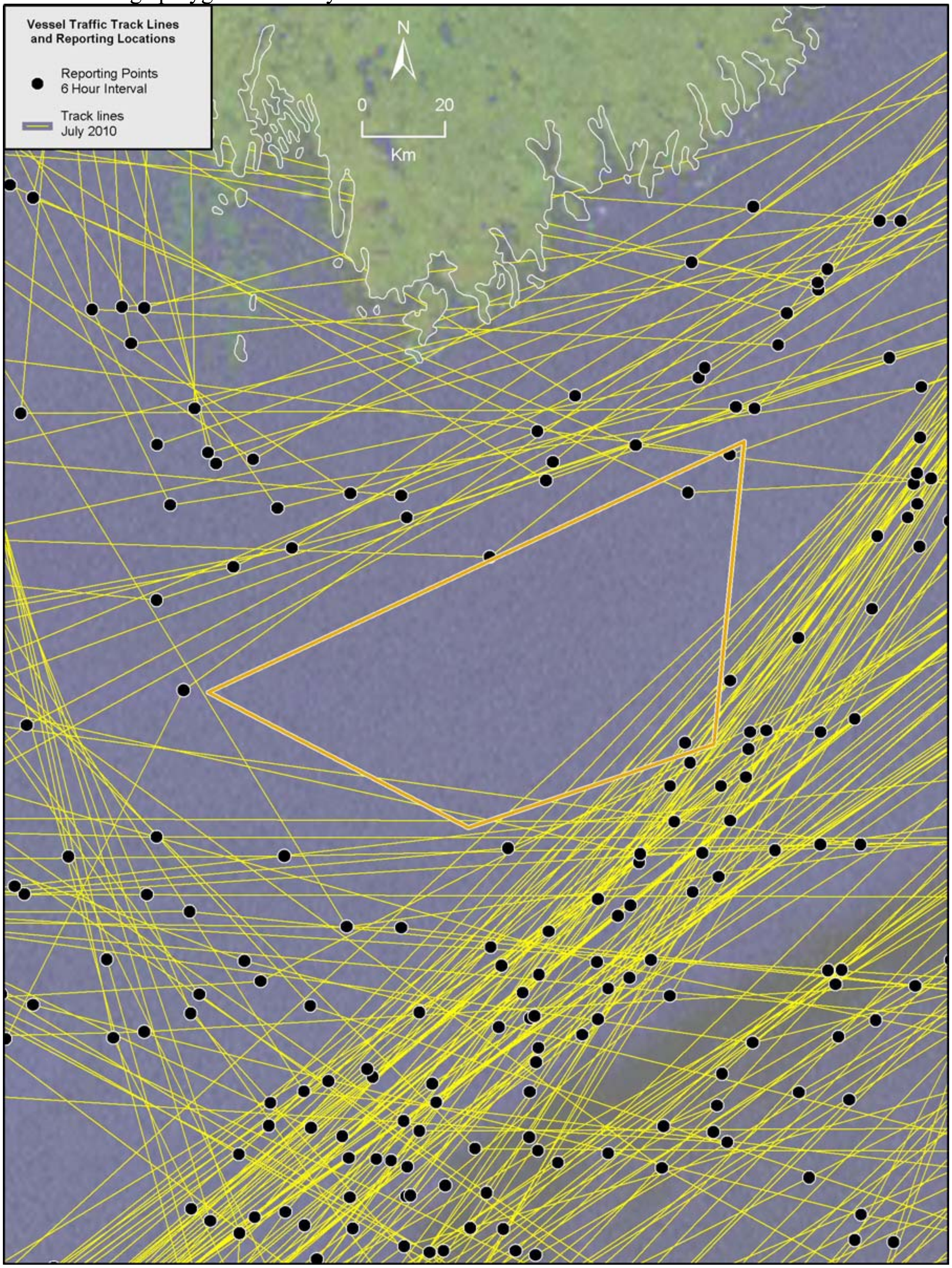


Figure 5. (A) Track lines generated from the original Long Range Identification and Tracking dataset for February 2010. Anomalous line segments cross land (polygon 1) and extend vertically along the edge of the data window (polygon 2). Blue polygon: Gully Marine Protected Area boundary; Orange polygon: Roseway Basin Area to be Avoided.

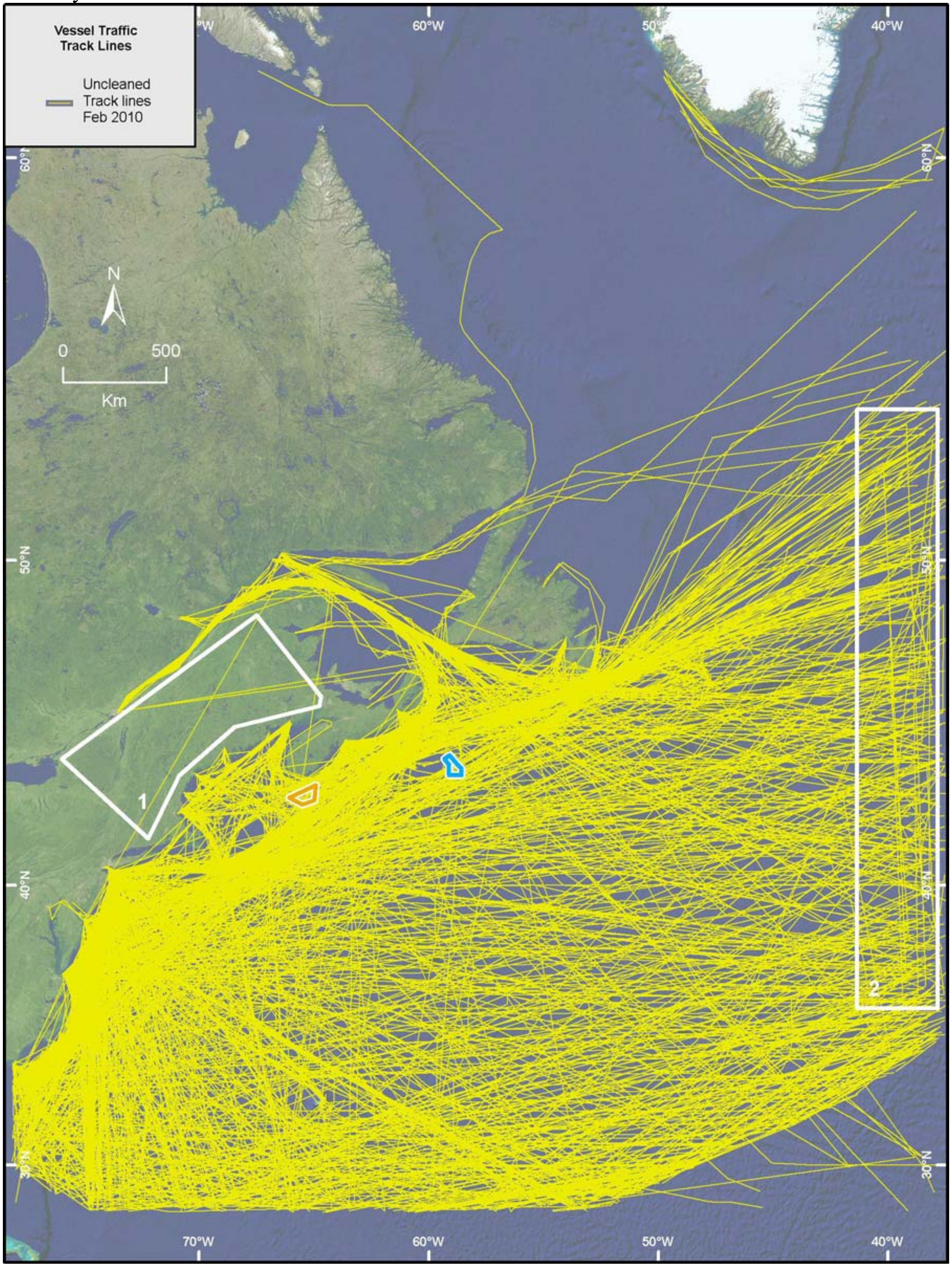


Figure 5. (B) Track lines generated from the original Long Range Identification and Tracking dataset for February 2010. Note that the anomalous line segments (formerly visible within polygon 1 and 2) have been removed. Blue polygon: Gully Marine Protected Area boundary; Orange polygon: Roseway Basin Area to be Avoided.

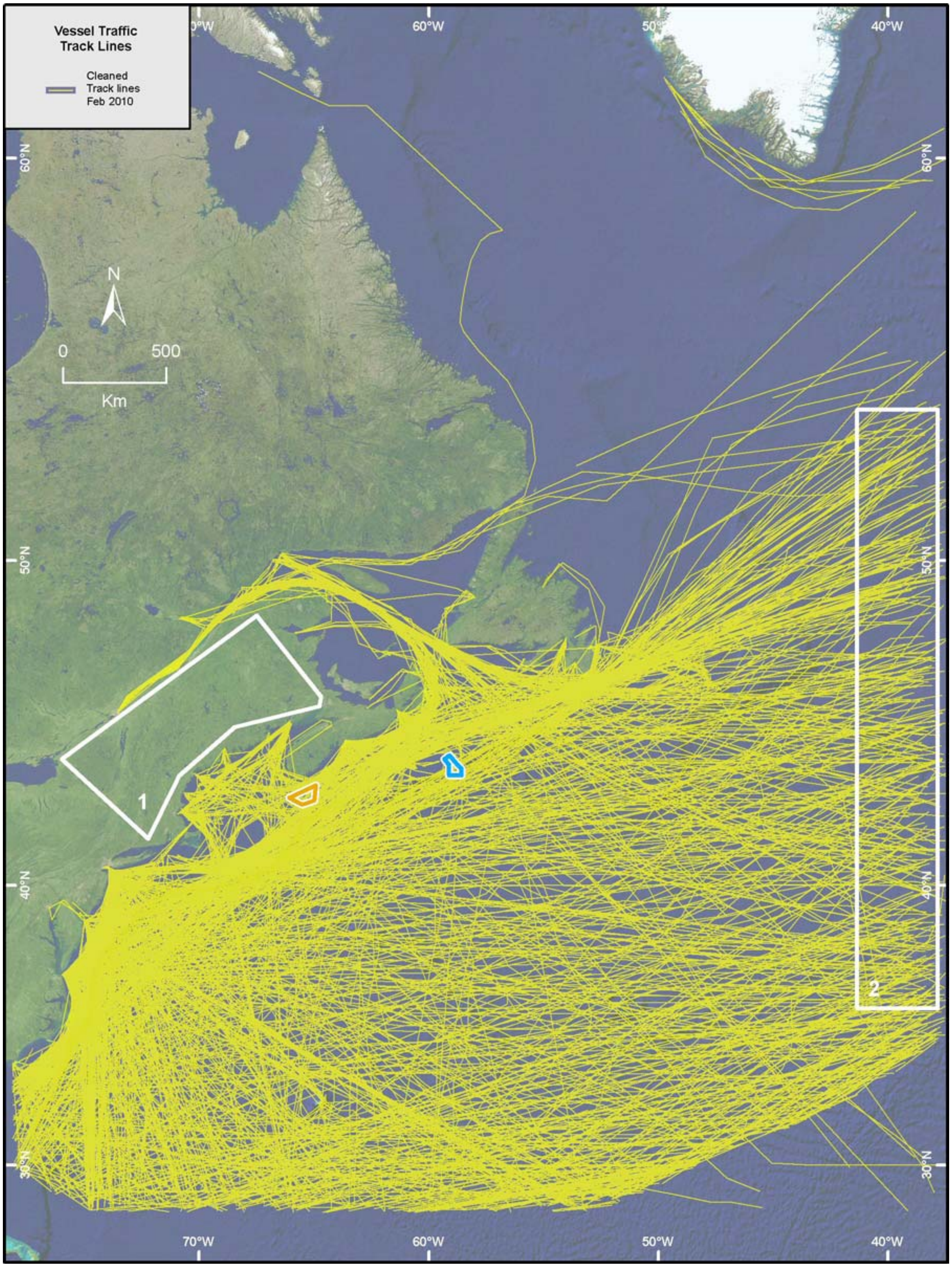


Figure 6. The generation of vessel track line counts. Vessel track lines were generated from the Long Range Identification and Tracking dataset for March 2010 and overlain by the 2 x 2-arc minute polygon grid. The number within each grid cell indicates the track line tally for each cell. This map displays the track lines and grids using a geographic coordinate system and the WGS84 datum. Orange polygon: Roseway Basin Area to be Avoided.

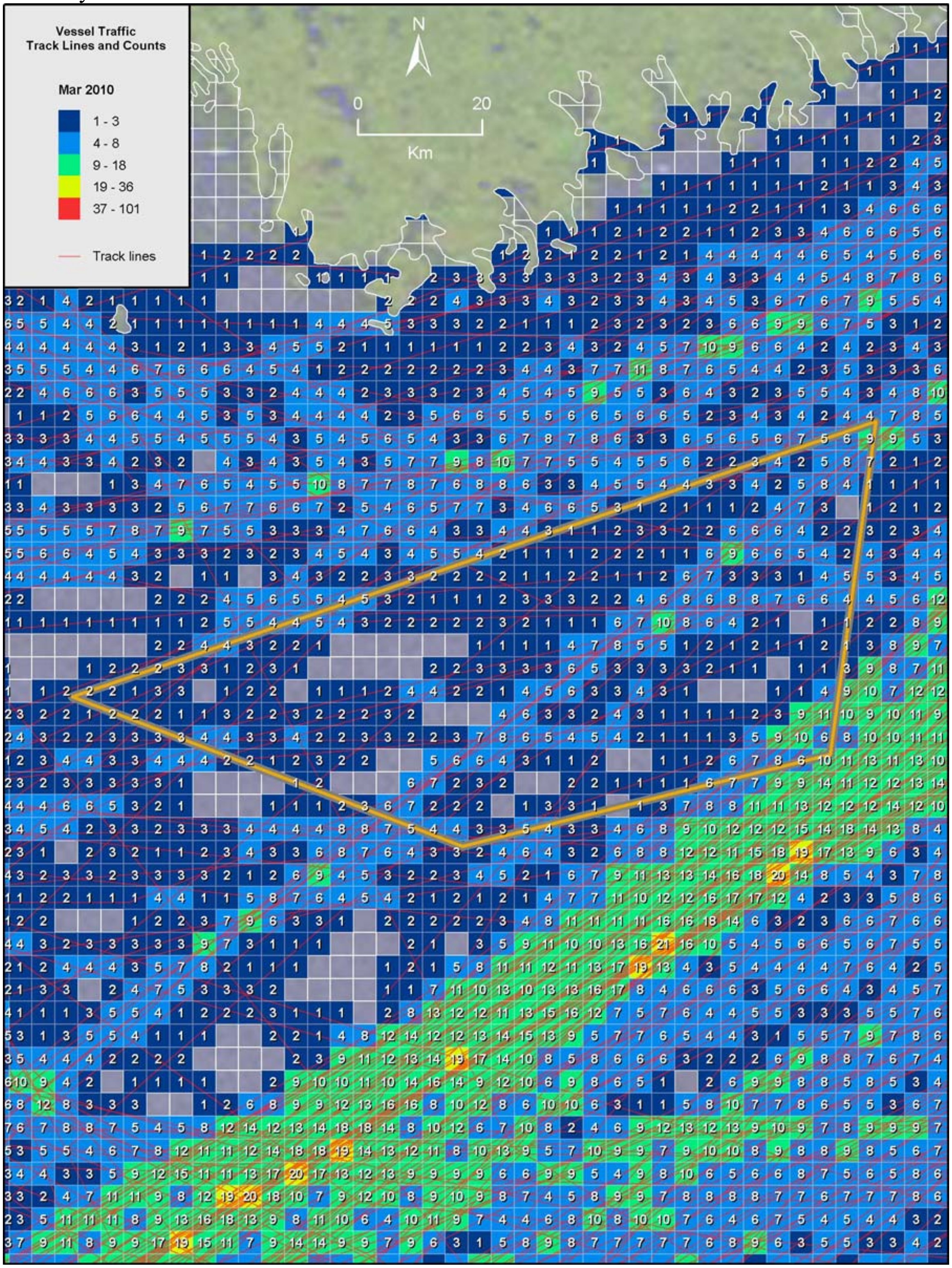


Figure 7. Composite raster of vessel track counts per 2 x 2-arc minute grid cell generated from the 12-month (March 2010–February 2011) Long Range Identification and Tracking dataset (study area view). Blue polygon: Gully Marine Protected Area boundary; Orange polygon: Roseway Basin Area to be Avoided.

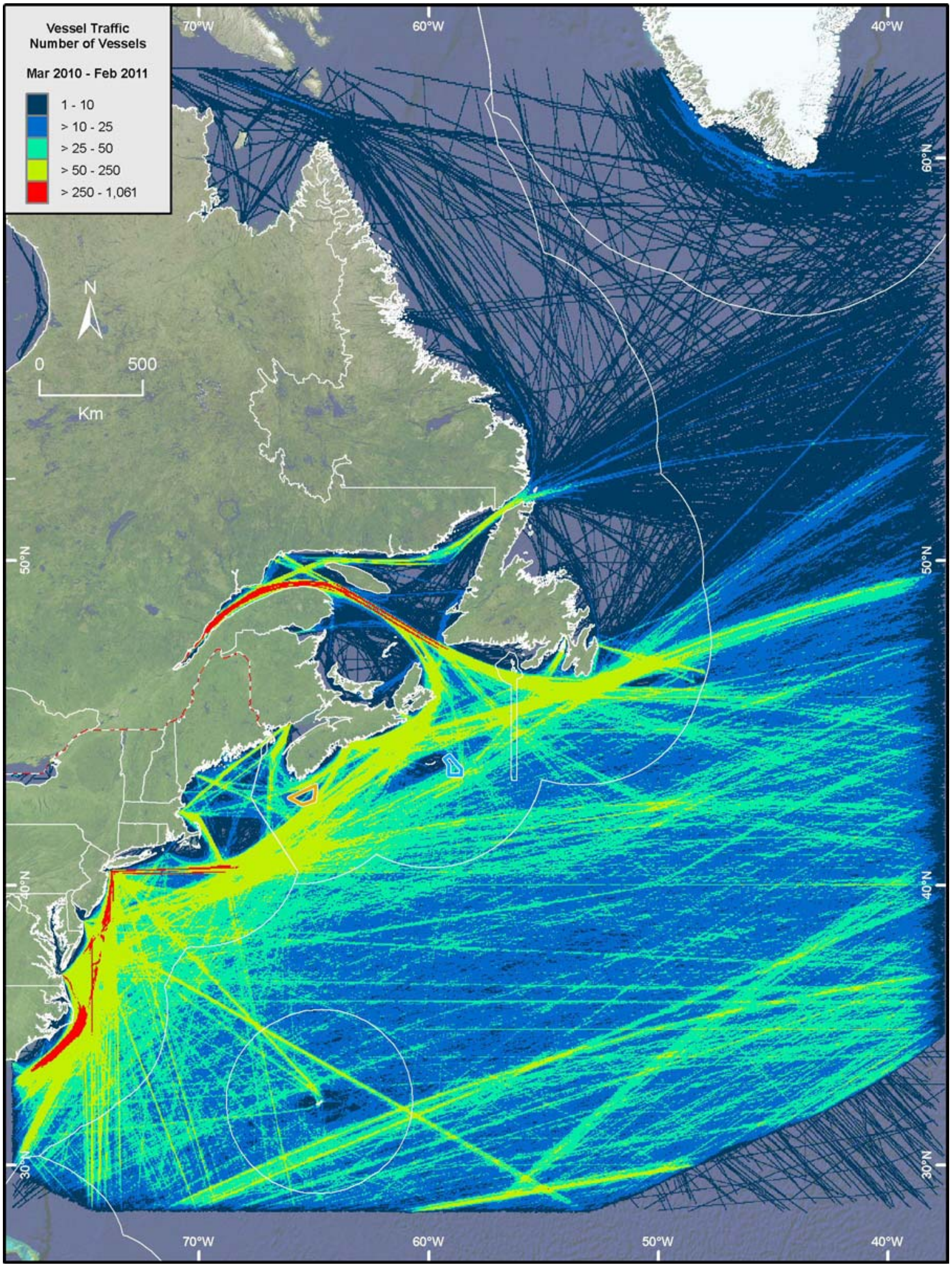


Figure 8. Composite raster of vessel track counts per 2 x 2-arc minute grid cell generated from the 12-month (March 2010–February 2011) Long Range Identification and Tracking dataset (Atlantic region view). Blue polygon: Gully Marine Protected Area boundary; Orange polygon: Roseway Basin Area to be Avoided.

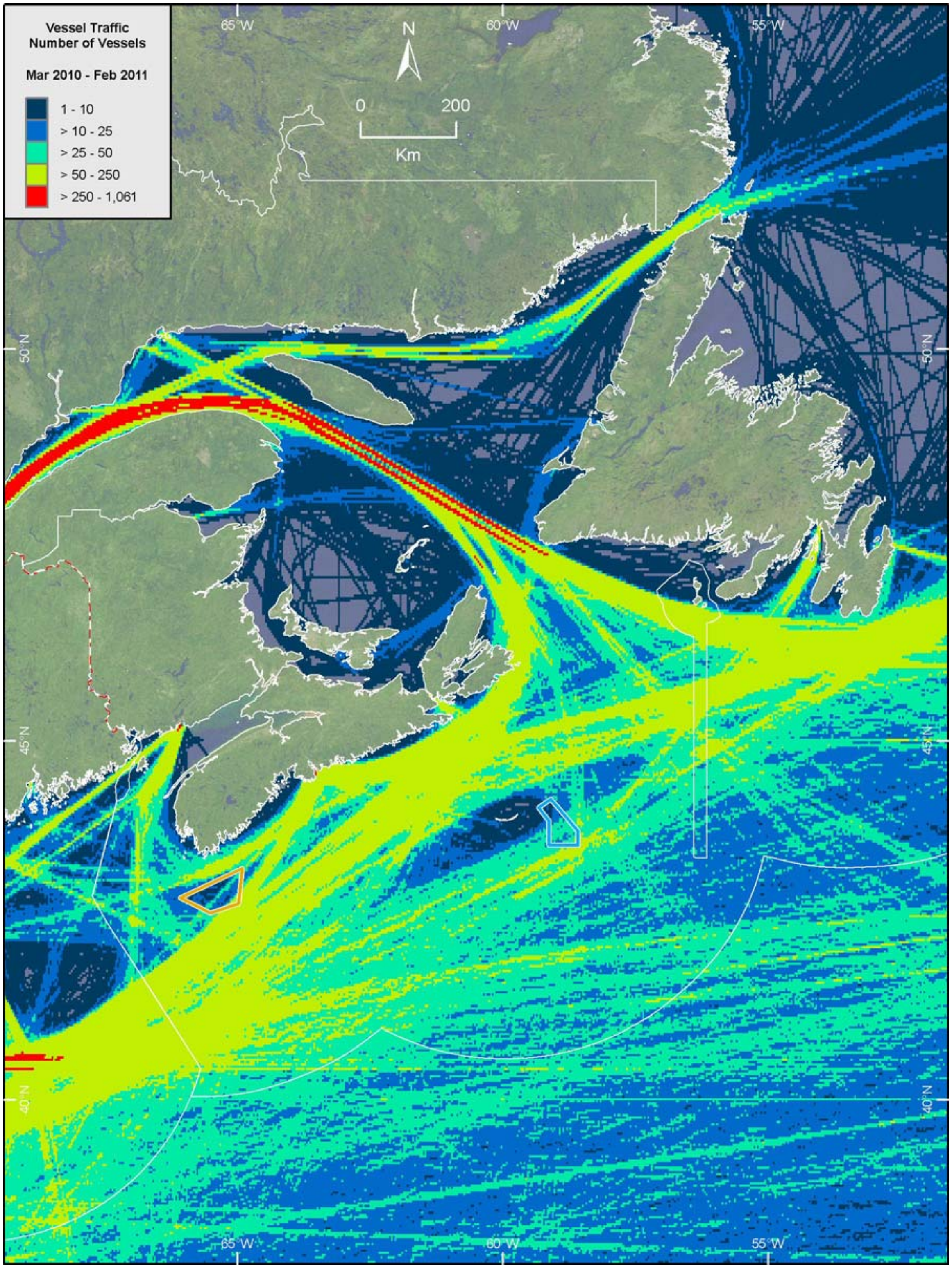


Figure 9. (A) Vessel track counts per 2 x 2-arc minute grid cell generated from the August 2010 Long Range Identification and Tracking dataset (Atlantic region). This month contained the highest number of tracks of all the months in the dataset. Blue polygon: Gully Marine Protected Area boundary; Orange polygon: Roseway Basin Area to be Avoided.

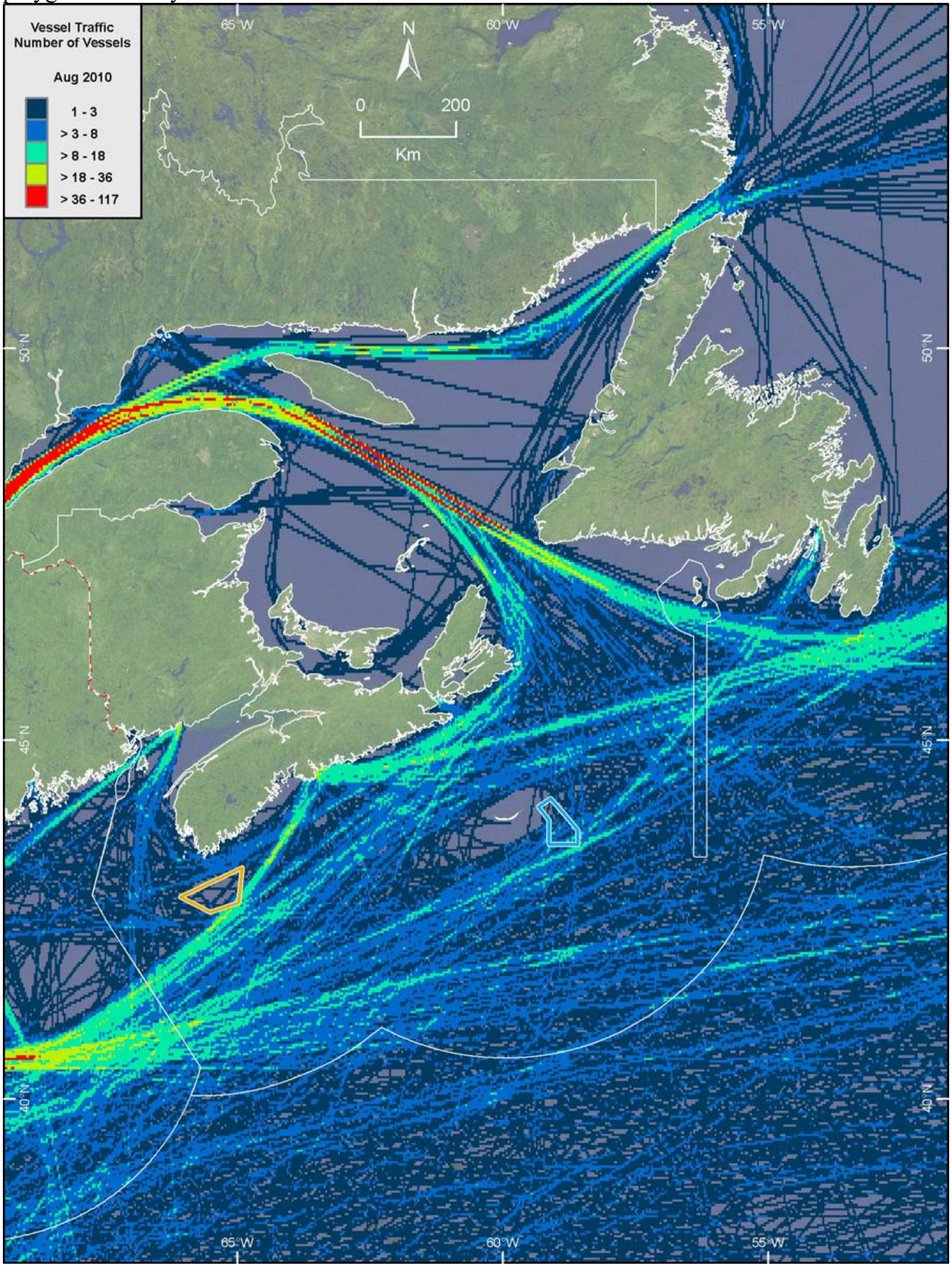


Figure 9. (B) Vessel track counts per 2 x 2-arc minute grid cell generated from the February 2010 Long Range Identification and Tracking dataset (Atlantic region). This month contained the lowest number of tracks of all the months in the dataset. Blue polygon: Gully Marine Protected Area boundary; Orange polygon: Roseway Basin Area to be Avoided.

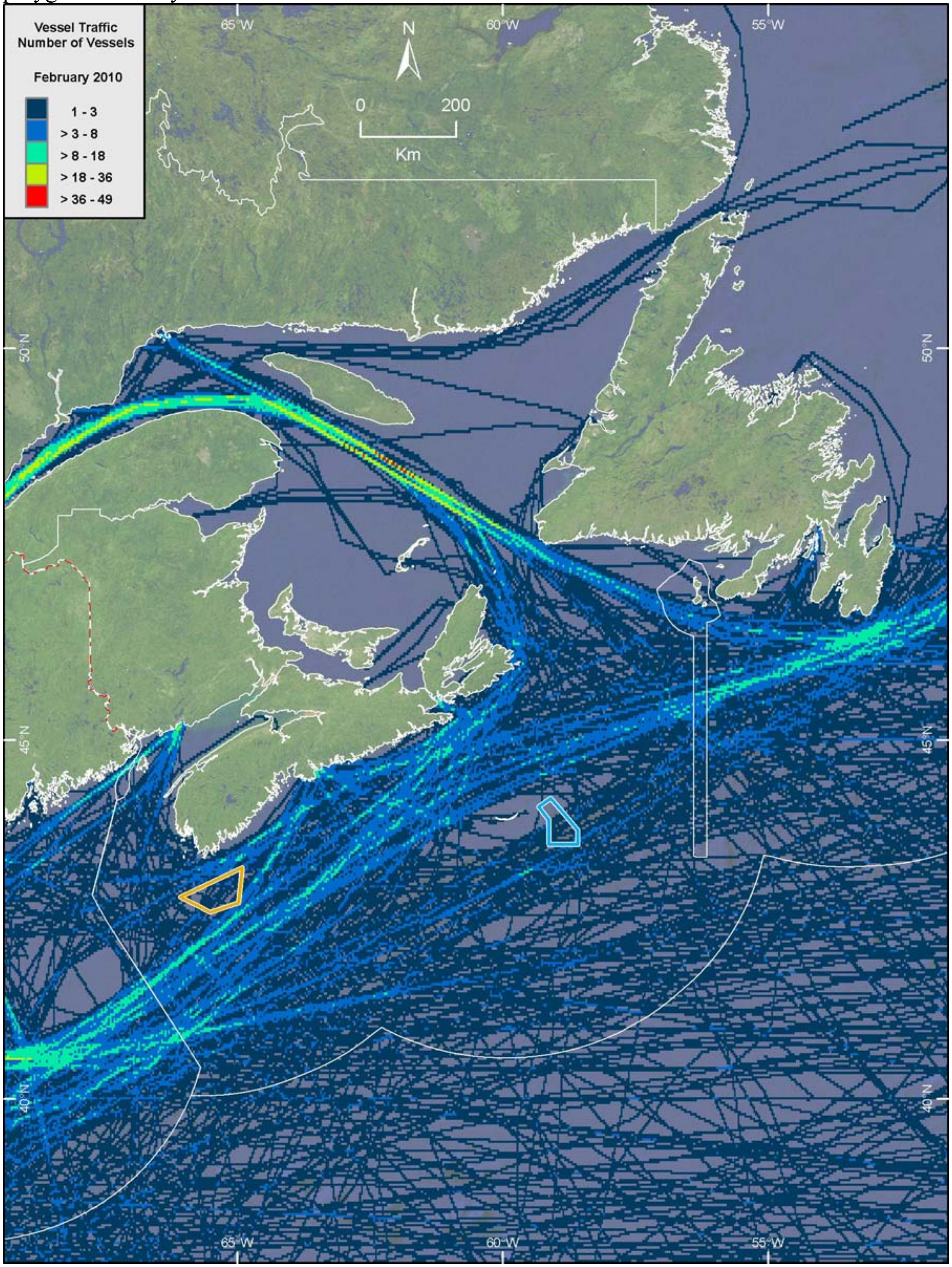


Figure 10. (A) Vessel track counts per 2 x 2-arc minute grid cell generated from the March 2010 Long Range Identification and Tracking dataset. Tracks crossing the Roseway Basin Area to be Avoided (orange polygon) were highest in this month. Grey lines: vessel tracks.

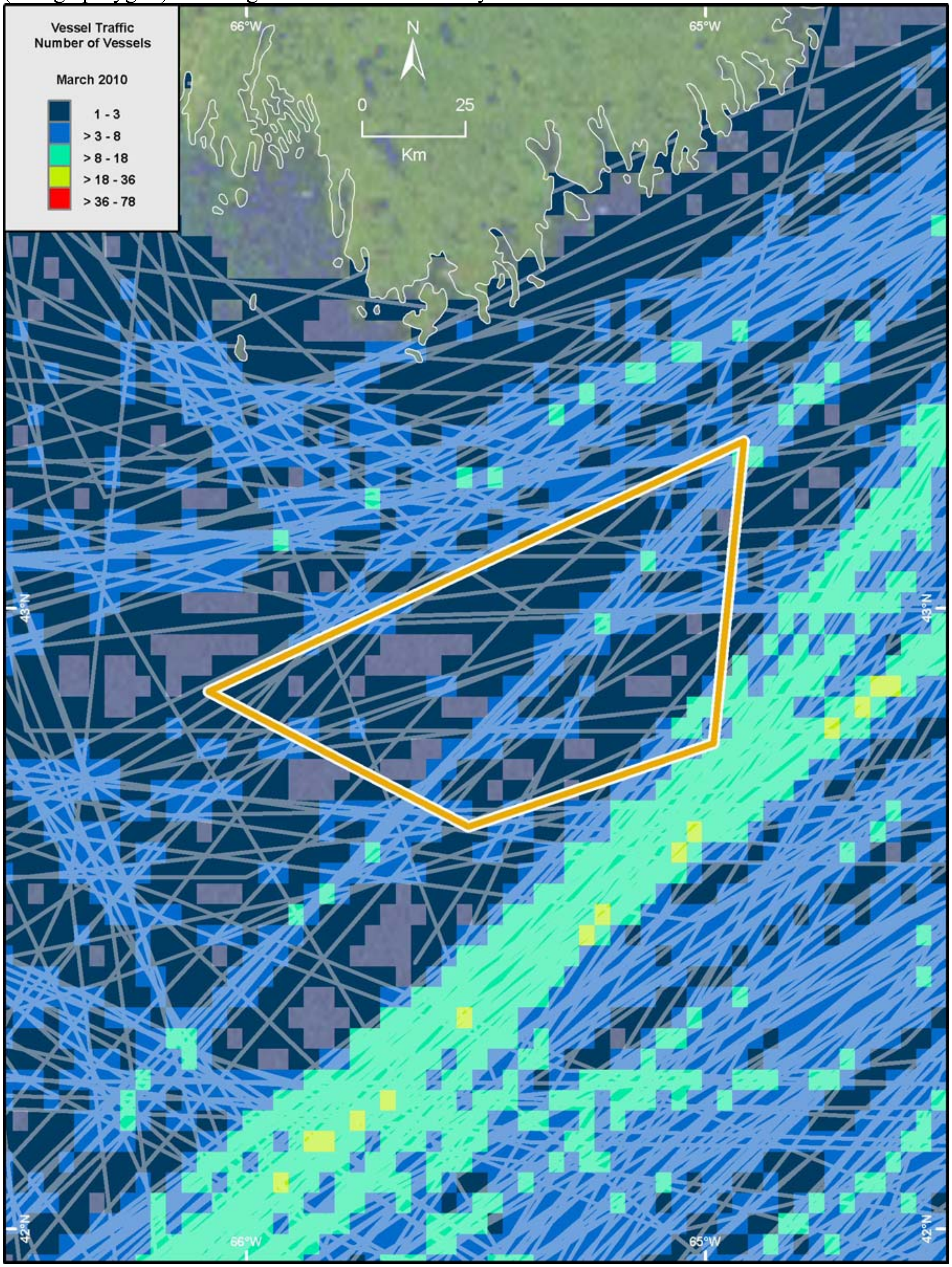


Figure 10. (B) Vessel track counts per 2 x 2-arc minute grid cell generated from the July 2010 Long Range Identification and Tracking dataset. Tracks crossing the Roseway Basin Area to be Avoided (orange polygon) were lowest in this month. Grey lines: vessel tracks.

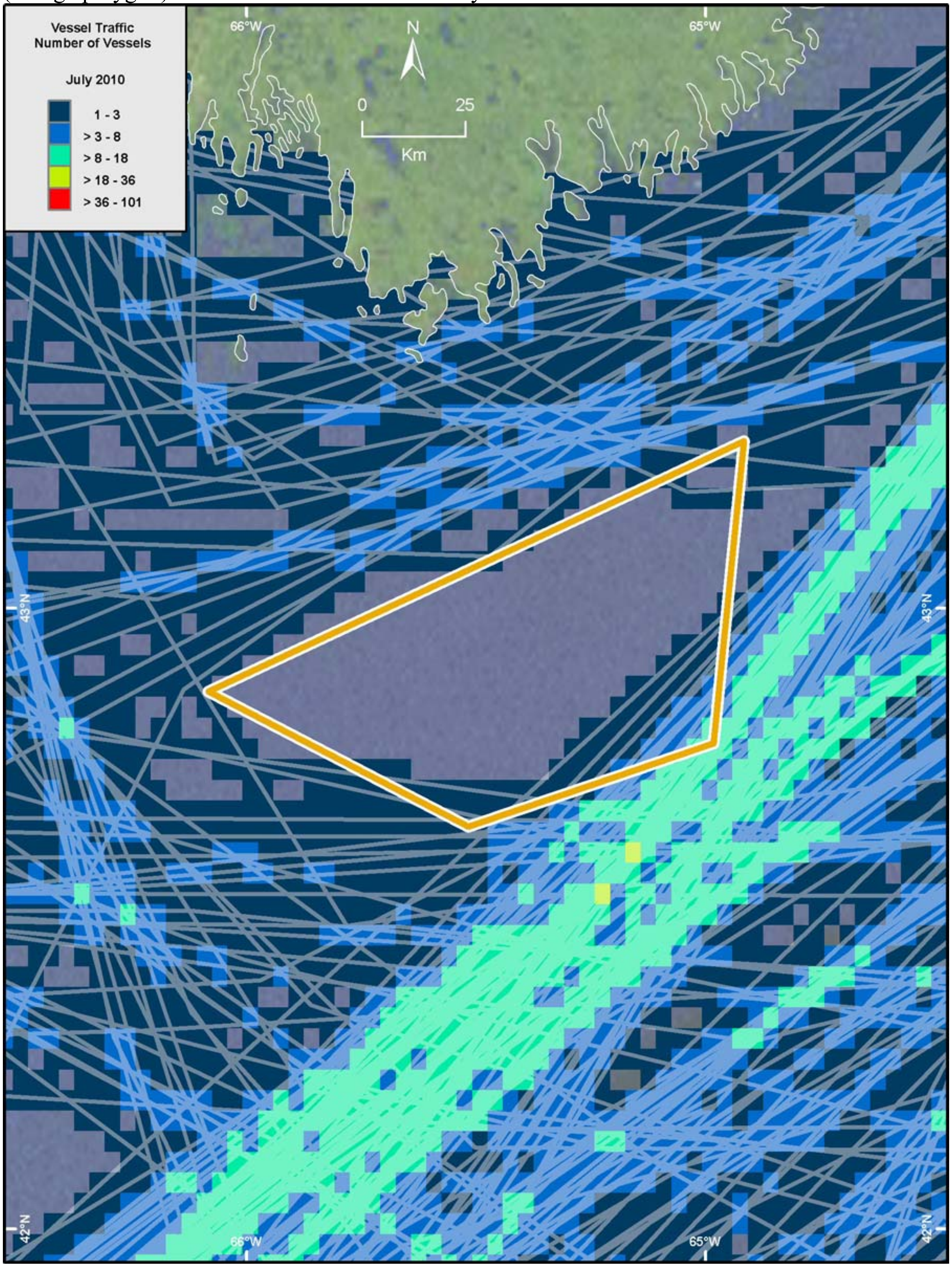


Figure 11. (A) Vessel track counts per 2 x 2-arc minute grid cell generated from the August 2010 Long Range Identification and Tracking dataset. Tracks crossing the Gully Marine Protected Area (blue polygon) were highest in this month. Grey lines: vessel tracks.

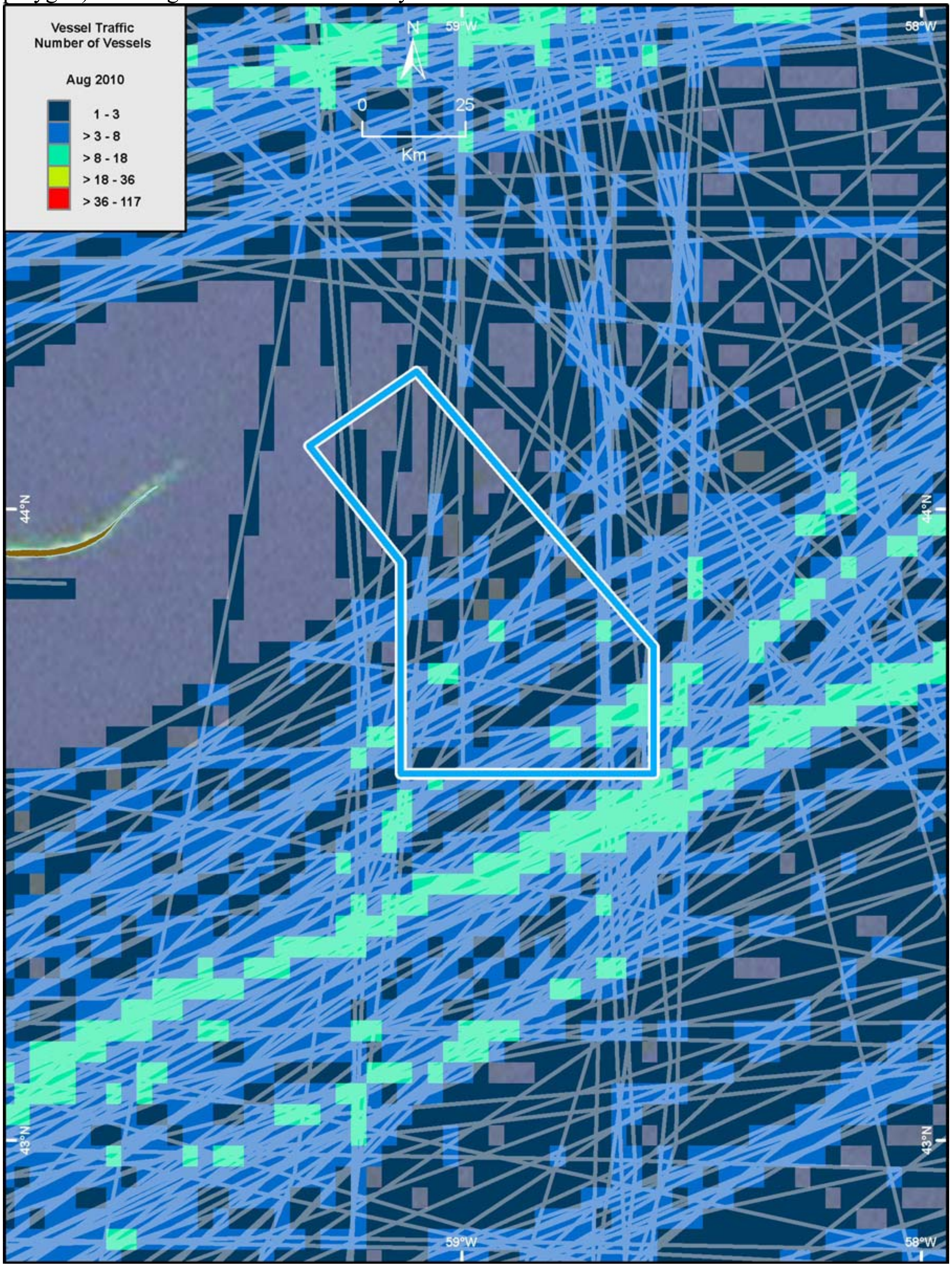


Figure 11. (B) Vessel track counts per 2 x 2-arc minute grid cell generated from the February 2010 Long Range Identification and Tracking dataset. Tracks crossing the Gully Marine Protected Area (blue polygon) were lowest in this month. Grey lines: vessel tracks.

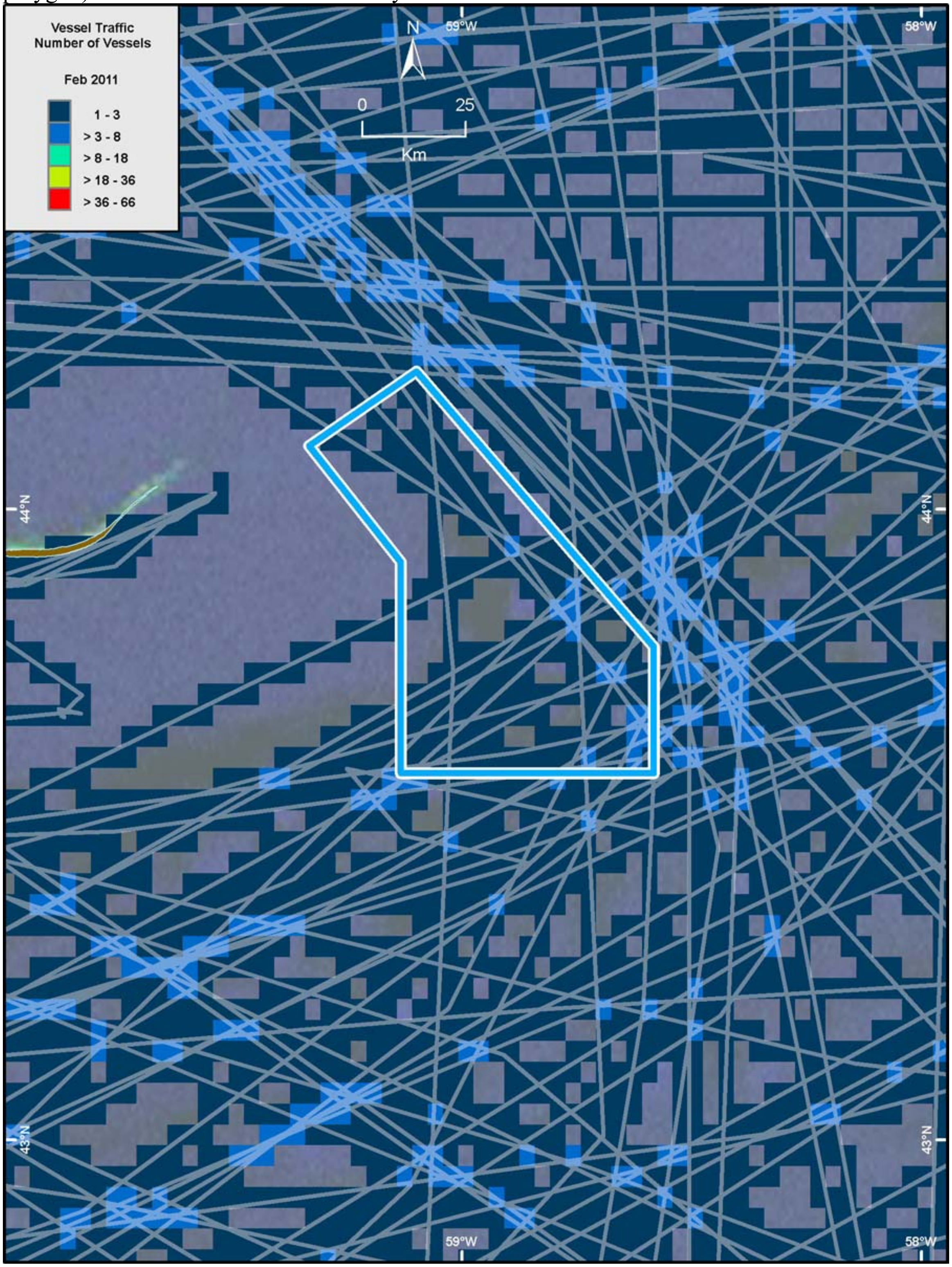


Table 1. Vessel track counts generated from 13 months of Long Range Identification and Tracking data from the Canadian National Data Centre.

	Number of Track Lines		
	Study Area	Roseway Basin ATBA*	Gully MPA
February, 2010	1508	29	24
March, 2010	2155	50	34
April, 2010	2371	40	44
May, 2010	2508	37	42
June, 2010	2550	36	42
July, 2010	2445	25	28
August, 2010	2765	38	61
September, 2010	2666	43	41
October, 2010	2599	30	32
November, 2010	2575	38	41
December, 2010	2521	37	52
January , 2011	2433	47	36
February, 2011	2173	36	20
13-Month Total	31269	486	497

* Shaded cells indicate months when the ATBA closure is in effect.