Vessel Density Mapping of 2019 Automatic Identification System (AIS) Data in the Northwest Atlantic

Tyler Veinot, Adrian Nicoll, Kasia Rozalska and Scott Coffen-Smout

Marine Planning and Conservation
Aquatic Ecosystems Branch
Fisheries and Oceans Canada
Maritimes Region
Bedford Institute of Oceanography
PO Box 1006
Dartmouth, Nova Scotia, Canada B2Y 4A2

2023

Canadian Technical Report of Fisheries and Aquatic Sciences 3520

Fisheries and Oceans Canada   Pêches et Océans Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. II n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques.*

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Canadian Technical Report of
Fisheries and Aquatic Sciences 3520

2023

Vessel Density Mapping of 2019 Automatic Identification System (AIS) Data in the Northwest Atlantic

by

Tyler Veinot, Adrian Nicoll,[1] Kasia Rozalska and Scott Coffen-Smout

Marine Planning and Conservation
Aquatic Ecosystems Branch
Fisheries and Oceans Canada
Maritimes Region
Bedford Institute of Oceanography
PO Box 1006
Dartmouth, Nova Scotia, Canada
B2Y 4A2

[1] Transport Canada
330 Sparks Street
Ottawa, Ontario, Canada
K1A 0N5

Cat. No. Fs97-6/3520E-PDF ISBN 978-0-660-47205-8 ISSN 1488-5379

Correct citation for this publication:

Veinot, T., Nicoll, A., Rozalska, K. and Coffen-Smout, S. 2023. Vessel Density Mapping of 2019 Automatic Identification System (AIS) Data in the Northwest Atlantic. Can. Tech. Rep. Fish. Aquat. Sci. 3520: vi + 29 p.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Veinot, T., Nicoll, A., Rozalska, K. and Coffen-Smout, S. 2023. Vessel Density Mapping of 2019 Automatic Identification System (AIS) Data in the Northwest Atlantic. Can. Tech. Rep. Fish. Aquat. Sci. 3520: vi + 29 p.

The Automatic Identification System (AIS) is a global, satellite-based and terrestrial-based ship tracking system that uses shipborne equipment to remotely track vessel identification and positional information and is typically required on vessels of 300 gross tonnage or more on an international voyage, of 500 gross tonnage or more not on an international voyage, and passenger ships of all sizes. AIS tracking technologies are primarily used in support of real-time maritime domain awareness and for maritime security and safety of life at sea. This report describes a geographic information system (GIS) analysis of 2019 AIS data to produce yearly and monthly vessel density maps of all vessel classes combined and yearly density maps of each vessel class. The year 2019 was selected to portray shipping densities in a pre-COVID 19 pandemic depiction of the maritime transport sector in the Northwest Atlantic. Vessel density map applications include use in spatial analysis and decision support for marine spatial planning.

RÉSUMÉ

Veinot, T., Nicoll, A., Rozalska, K. and Coffen-Smout, S. 2023. Vessel Density Mapping of 2019 Automatic Identification System (AIS) Data in the Northwest Atlantic. Can. Tech. Rep. Fish. Aquat. Sci. 3520: vi + 29 p.

Le système d'identification automatique (SIA) est un système mondial de suivi des navires par moyen satellite et terrestre qui utilise de l'équipement embarqué pour suivre à distance l'identification des navires et les informations de position. Il est généralement requis sur des navires de plus de 300 tonnes lors d'un voyage international, ou un navire de 500 tonnes n'effectuant pas de voyage international, ainsi que les navires passagers de toutes tailles. Les technologies de suivi SIA sont principalement utilisées pour soutenir la connaissance du domaine maritime en temps réel et pour la sécurité maritime, ainsi que la sécurité de la vie en mer. Ce rapport décrit une analyse du système d'information géographique (SIG) des données SIA de 2019 pour produire des cartes de densité de navires annuelles et mensuelles pour toutes les classes de navires combinées et des cartes de densité annuelle pour chaque classe de navires. L'année 2019 a été choisie pour représenter les densités de navigation dans une représentation avant la pandémie COVID 19 du secteur de transport maritime dans l'Atlantique nord-ouest. Les applications cartographiques de densité des navires peuvent être utilisées dans l'analyse spatiale et à soutenir les décisions concernant la planification spatiale marine.

INTRODUCTION

The Marine Planning and Conservation (MPC) Program in the Maritimes Region of Fisheries and Oceans Canada (DFO) specializes in the development of decision-support tools and spatial analysis. This includes maps of ocean sector uses to manage spatial and temporal conflicts in support of marine spatial planning (MSP). MPC in Maritimes Region previously published vessel traffic maps based on Long Range Identification and Tracking (LRIT) data for Atlantic Canada (Koropatnick et al., 2012). Other commercial shipping density analyses in this region have included mapping coastal Automatic Identification System (AIS) data off the Eastern Shore Islands of Nova Scotia (Konrad, 2020) and coastal AIS data for Eastern Canada (Simard et al., 2014).

The purpose of this spatial analysis is to map commercial shipping densities of satellite and terrestrial AIS data by vessel class to illustrate 2019 shipping patterns in the Northwest Atlantic Ocean off Eastern Canada. The vessel mapping analysis was a collaboration of DFO Maritimes Region and Transport Canada. The year 2019 was selected to portray shipping densities in a pre-COVID 19 pandemic depiction of the maritime shipping sector. The produced map layers will be published as a data record on the Government of Canada's Open Data portal[1] and visualized online in DFO's MSP atlas application[2] for information sharing and decision support in marine spatial planning. Shipping intensity layers have broad applications in spatial planning for deconflicting ocean sector uses (e.g., shipping *vs*. fisheries, oil and gas, and coastal/offshore wind energy development), mitigating ecological sensitivities (e.g., shipping *vs*. marine mammal foraging areas and acoustic soundscape mapping), and for cumulative effects assessment of shipping and other ecosystem threats.

The Automatic Identification System

The Automatic Identification System (AIS) is an automated vessel-tracking system used to enhance maritime safety by reducing the risk of collisions and by aiding search and rescue operations. The AIS system consists of very high frequency (VHF) transponder units that automatically transmit voyage data such as location, date, time, speed, and navigation status, in addition to static data such as vessel identity, type and dimensions. The data can be received by AIS receiver units onboard other vessels, shore-based facilities, or satellites. For vessels that are sailing, AIS messages are sent via the transponder units approximately every ten seconds or less for Class A transponders or every 30 seconds for Class B transponders. Anchored vessels transmit signals every 3 minutes for Class A and B transponders (MarineTraffic.com, n.d.).

Satellite messages are received via orbital satellites and have the benefit of covering areas of the ocean beyond the line of sight of land. However, due to orbit, time of day, and location variations in the number of available satellites, these datasets can have low temporal resolution (Carson-Jackson, 2012). Satellites also suffer from atmospheric conditions interfering with signal strength. Terrestrial data is received via a land-based network of AIS receiver stations. These stations have improved temporal resolution and are less affected by atmospheric conditions. Land-based receivers can receive the lower powered signals better than satellite orbital stations. However, land-based receivers can only receive signals from vessels within approximately 74 to 92 km (40 to 50 nautical miles) of the receiver location, and only if there is an unobstructed line of sight (Skauen et al., 2013; Proud et al., 2016; Skauen & Olsen, 2016; Smestad et al., 2017; Iacarella et al., 2020).

AIS was adopted by the International Maritime Organization (IMO) through the International Convention for the Safety of Life at Sea (SOLAS, 1974). The SOLAS Convention requires all vessels of 300 gross tonnage or more on an international voyage, cargo ships of 500 gross tonnage or more not on an international voyage, and passenger ships of all sizes to carry AIS transponders. In Canada, the Navigation

[1] See Open Data portal: <https://open.canada.ca/en/open-data>.
[2] See Canada Marine Planning Atlas - Atlantic: <https://gisp.dfo-mpo.gc.ca/apps/Atlantic-Atlas/?locale=en>.

Safety Regulations (2020) of the *Canada Shipping Act* (2001) require all vessels of 150 gross tonnage or more carrying more than 12 passengers on an international voyage; vessels, other than fishing vessels, of 300 gross tonnage or greater on an international voyage; and all vessels, other than fishing vessels, of 500 gross tonnage or greater on a domestic voyage to carry AIS. Other vessels may use AIS transponders on a voluntary basis for the purposes of safety of life at sea.

The Navigation Safety Regulations (2020) were amended in June 2019 requiring vessels not on a sheltered waters voyage that are certified to carry more than 12 passengers or are greater than eight metres in length carrying passengers, to carry either a Class A or a Class B AIS. Therefore, future analysis of AIS data will include additional data from smaller vessels.

For vessels in Canadian waters, section 118(1) of the Navigation Safety Regulations (2020) state that the following must be fitted with an AIS Class A transponder: (a) vessels that are 20 m or more in length, other than pleasure crafts; (b) vessels that carry more than 50 passengers; (c) vessels transporting substances, materials or articles to which the International Maritime Dangerous Goods Code, published by the IMO, applies; (d) vessels carrying pollutants, as defined in section 165 of the Act, in bulk; (e) dredges or floating plants that are located in any place where they constitute a collision hazard to other vessels; and (f) towboats that are 8 m or more in length. Section 118(2) states that every vessel, other than a vessel referred to in subsection (1), that is engaged on a voyage other than a sheltered waters voyage must be fitted with an AIS Class A or an AIS Class B transponder if (a) it is a passenger vessel; or (b) the vessel is 8 m or more in length and carries a passenger. Section 103(2) of the regulations applies AIS carriage exceptions for the following Canadian vessels: (a) fishing vessels; (b) cable ferries; (c) pleasure crafts; or (d) vessels operating exclusively in the waters of the Great Lakes, their connecting and tributary waters, and the waters of the St. Lawrence River as far seaward as a straight line drawn (i) from Cap-des-Rosiers to Pointe Ouest, Anticosti Island, and (ii) from Anticosti Island to the north shore of the St. Lawrence River along a meridian of longitude 63° W.

METHODS

AIS Data Sources

Terrestrial AIS data (raw NMEA format), captured by AIS receiver stations located along Canada's coastline, were provided by the Canadian Coast Guard (CCG). These stations vary in placement density with higher densities found between 42° and 60° latitude in Eastern Canada. The stations also differ in tower height above the water and their line-of-sight detection ranges. Processed satellite AIS data for 2019 (January 1 to December 31) were provided by Maerospace via Orbcomm under agreement with the Government of Canada. The dataset also included some terrestrial AIS data, however, duplicate AIS messages were removed in the data fusion process. The data were acquired to support multiple projects for Canadian government mandates where vessel traffic information is critical to making decisions or for planning purposes.

AIS messages are composed of dynamic and static message types. Dynamic messages include information that is highly variable such as speed, position, heading, and course. Static messages include information that is mostly consistent such as vessel name, origin, and destination. Broadcasting frequencies vary between message types with dynamic messages broadcasting every two to ten seconds and static messages approximately every six minutes. These messages can be joined using unique Maritime Mobile Service Identity (MMSI) numbers to create a dataset containing vessel-specific information alongside positional information.

AIS Data Processing

Raw terrestrial AIS messages, specifically Class A (1, 2 and 3) and Class B (18 and 19) positional (dynamic) messages were decoded into processed data (CSV format) using custom Python decoding scripts leveraging custom decoding functions. The resulting terrestrial AIS positional messages were fused with processed satellite AIS positional messages using custom Python scripts (Figure 1). The data fusion removes (1) duplicate positional messages, (2) erroneous latitude/longitude points, i.e., latitude and longitude not within the normal range (latitude >=90 or <=-90 and longitude >=180 or <=-180), (3) erroneous speed over ground (SOG) i.e., SOG >=102.3 (not available), and (4) erroneous course over ground (COG) to an extent, i.e., COG >=360.

Some of the AIS static data (e.g., vessel name, size, and type, etc.) were replaced with the information from a variety of online sources (MarineTraffic.com, MyShipTracking.com, and Industry Canada) to create a global derived AIS dataset.[3] These databases were used to classify vessel types/sizes because the information coming from AIS is manually inputted and can be incorrect (Harati-Mokhtari et al., 2007; Iphar et al., 2015). The information collected from these sources, specifically marine intelligence databases (e.g., MarineTraffic.com, MyShipTracking.com, and Lloyd's Register[4]) have been used in studies to classify vessels by type and size, rather than AIS data because they are more accurate (Svanberg et al., 2019).

Derived Tracklines

Tracklines (GIS polylines) were created from positional messages to represent vessel movement (MarineCadastre.gov AIS Track Builder, 2018). Vessel speeds of < 0.5 knots that are not indicative of a vessel in transit were removed prior to generating tracklines. A trackline was generated between consecutive positional AIS messages, as long as the next AIS message was within a given distance and time threshold for each unique vessel based on the vessel's unique MMSI number. If the next positional AIS message exceeded at least one of the thresholds (distance or time), then the trackline was terminated and a new trackline for the vessel was generated from the next point. The distance and time thresholds were 300 minutes and 80 km (50 miles). This was done to generate independent vessel movements over time, for each year/month of positional AIS data. The large time and distance thresholds are used because of spatial and temporal gaps that are present in some regions such as the Arctic that have inconsistent and variable revisit times for satellites (Winther et al., 2014). The disadvantage of using these thresholds is in instances where larger gaps between points leads to a trackline that is not as accurate, such as passing through land rather than going around landmasses.

The tracklines were queried to only include valid MMSI numbers (e.g., MMSI numbers with valid country codes were between 201000000 and 775999999) and were used to calculate statistics (e.g., number of tracks by month and vessel type) and to create maps of vessel traffic density (e.g., map the number of vessel transits by vessel types/sizes in given areas).

Study Area and Grid

The study area was defined as 79º W to 42º W and 38º N to 62º N in WGS84 (EPSG: 4326). The study area extent included marine areas from Hudson Strait and Ungava Bay in the north, south to Chesapeake Bay in

---

[3] MarineTraffic.com Vessels Database, available online: <https://www.marinetraffic.com/en/data/?asset_type=vessels&columns=flag,shipname,photo,recognized_next_port,reported_eta,reported_destination,current_port,imo,ship_type,show_on_live_map,time_of_latest_position,lat_of_latest_position,lon_of_latest_position,notes>; MyShipTracking.com Vessel Database, available online: <https://www.myshiptracking.com/vessels>; Industry Canada Ship Station Search, available online: <https://sd.ic.gc.ca/pls/engdoc_anon/mmsi_search.ship>.

[4] Lloyd's Register Ships in Class, available online: <https://www.lr.org/en/lrofships/>.

the Mid-Atlantic, and from the St. Lawrence River Estuary in the west to Flemish Cap beyond Canada's eastern exclusive economic zone (EEZ) limits. This study area was converted to Albers equal-area projection (ESRI:102001) from WGS84. To ensure proper coverage, the study area polygon was densified by every degree in order to create anchor vertices along the outer edge of the polygon defining this study area. This was done to allow the study area boundary to curve along the lines of latitude when transformed to Albers equal-area projection.

After the transformation, the study area was adjusted so that the upper and lower limits of the spatial extent met at rounded coordinate values in the Albers equal-area projection. The new extent was 1,210,000 m to 4,412,000 m on the X axis and 55,000 m to 3,504,000 m on the Y axis. From this extent a grid was created using 1 km by 1 km cells.

Finally, any grid cells that were completely within any land polygons based on a coastline dataset (NOAA, 2017; converted to NAD 1983 Albers Canada from EPSG:4326), or completely outside the study area, were removed from the dataset. This reduced the number of grid cells to be calculated from approximately 11 million to 4.3 million.

Producing Density Maps

The number of AIS tracks that passed through each grid cell was calculated. To convert the trackline count to an expression representing vessels per day, the trackline count in each grid cell was divided by the number of days in the timeframe (i.e., 365 for the yearly maps and number of days in any given month for the monthly maps). A Python script was created to run the processes to build the datasets using the following five steps:

Step 1: The AIS records were classified into the following categories: Cargo, Tanker, Fishing, Passenger and Other (see Table 1).

Step 2: A subset selection was created for each month and ship type to pass to a spatial join function. In order to create separate datasets for each month and type, a subset selection of the data was created using SQL queries for each month and vessel type.

Step 3: The subset selection was passed to the spatial join that joins the attributes from the intersecting tracks to each grid cell. This process also produced a count field showing how many tracks were joined to each cell.

Step 4: All vessels and yearly datasets were created by summing the grids created in the aforementioned steps. By summing the count fields for each month's vessel types an "All Vessels" grid was created for each month. Similarly, this process was repeated for each vessel type for all months to produce totals for 2019. In total, there were 78 vector grids created, but only 18 maps are included in this report.

Step 5: All the grids were converted to raster datasets representing the count values using the polygon-to-raster tool. To convert these raster datasets to show vessels per day the raster calculator was used to divide the cell values (count) by the number of days in each series. In total, there were 156 raster datasets produced as a final product showing vessel density in total counts and vessels per day, but as noted above, only 18 maps are included in this report.

Maps were created for each vessel type for 2019, as well as monthly composites for all vessel types combined. The colour ramp shows values from >0 to 10+. The vast majority of data are below 10 and only 0.012% of the grid cells had values >10, (i.e., 522 of 4,358,979 cells) from all vessels in 2019. Dataset statistics for the source tracks and the resulting grids are shown in Table 2.

RESULTS AND DISCUSSION

General Observations

The resultant 2019 vessel density maps for all vessel classes and total yearly and monthly densities are shown in Figures 2 to 19. Figure 2 depicts yearly density for all vessel classes per day per km^2. Figures 3 to 14 show monthly densities for all vessel classes per day per km^2. Figures 15 to 19 show yearly densities per day per km^2 for Cargo, Fishing, Other, Passenger, and Tanker vessels, respectively.

In general, the 2019 AIS density maps are a significant improvement in temporal resolution from previous LRIT mapping on a Northwest Atlantic scale (Koropatnick et al. 2012) and also provide improved spatial coverage compared to the terrestrial AIS maps of Canada's East Coast by Simard et al. (2014). Comparisons between these reports for observed changes in vessels per day per km^2 are limited by the fact that Simard et al. (2014) mapped daily ship-hours per km^2 for a smaller spatial extent using terrestrial AIS data only and Koropatnick et al. (2012) mapped track counts per 2 x 2-arc minute for LRIT data at a 6-hourly reporting frequency.

Highest vessel densities in Eastern Canada occurred at approaches to harbours (e.g., Saint John, NB, Halifax, NS, Port Hawkesbury, NS, Sydney, NS, Portland, ME, Boston, MA and New York, NY), in the Cabot Strait and the Gulf of St. Lawrence, along the Atlantic coast of Nova Scotia, off Newfoundland's southern coast, and in the Strait of Belle Isle. Ferry routes were distinctive visual features between Saint John, NB and Digby, NS, between Sydney, NS and Port aux Basques, NL, between Souris, PEI and Îles de la Madeleine, QC, and across the St. Lawrence River Estuary in Quebec.

The cargo vessel density map in Figure 15 shows vessel avoidance of Sable Island on the Scotian Shelf and general adherence to vessel Traffic Separation Schemes in Canadian and U.S. waters. Although AIS technology is exempt on Canadian fishing vessels under the Navigation Safety Regulations (2020),[5] the fishing vessel map in Figure 16 illustrates significant voluntary uptake of AIS technology by fishing vessels in Canadian waters, as well as AIS use by international fishing fleets operating beyond Canada's EEZ. The AIS fishing vessel map is not a comprehensive spatial footprint of fishing vessels operating in Canadian waters. Additional remotely sensed fisheries footprint intensity mapping can be visualized through DFO's vessel monitoring system (VMS) data. For example, VMS-based fisheries footprint maps have been produced and published for the pelagic longline fishery on the Scotian Shelf (Butler et al., 2019) and VMS data were merged with logbook data for all other fishing gear types in Eastern Canada and the Eastern Arctic (Koen-Alonso et al., 2018). These VMS-based fisheries footprint map layers are published on the Open Data portal.[6]

The other vessel density map in Figure 17 illustrates what appears to be two seismic program tracklines east of Labrador and north of Flemish Pass, as well as oil and gas supply vessels servicing offshore infrastructure on the Scotian Shelf off Nova Scotia and on Grand Bank east of Newfoundland. Ferry routes were depicted by the passenger vessel density in Figure 18. Tanker traffic appeared heaviest approaching Saint John, Halifax, Port Hawkesbury, Argentia, NL, and the St. Lawrence River Estuary (Figure 19).

Table 3 indicates the total number of active vessels by vessel class in the dataset, with 4,239 cargo vessels, 11,599 other vessels, 2,478 fishing vessels, 784 passenger vessels, and 2,164 tankers, totalling 21,264 vessels. The maximum number of trackline counts in any given grid cell was 34,620.

---

[5] Navigation Safety Regulations, 2020, SOR/2020-216, section 103(2).

[6] Maritimes Region Longline and Trap Gear Fisheries Footprint: <https://open.canada.ca/data/en/dataset/3d2e1a84-20f5-4a61-90e4-94760c80ebb9>; Fishing effort within Significant Benthic Areas in Canada's Atlantic and Eastern Arctic marine waters: <https://open.canada.ca/data/en/dataset/273df20a-47ae-42c0-bc58-01e451d4897a>.

Sources of Error

It is well-known that AIS data contains various sources of errors and omissions. Vessel information, such as identification, vessel type and dimensions, is entered manually and therefore subject to data entry errors, deliberate falsification of vessel position or identification, and turning off transponders (Harati-Mokhtari et al., 2007; McCauley et al., 2016). Voyage information such as position, time and speed is prone to transmission errors and can be deliberately interrupted or altered (Balduzzi et al., 2014; McCauley et al., 2016; and Mazzarella et al., 2017). Simard et al. (2014) noted spurious spatial coordinates, time errors, interruptions, and erroneous or missing vessel lengths. As mentioned in the Methods section, some static information was corrected using online databases.

Konrad (2020) also used publicly available databases to confirm reported vessel details such as vessel type and dimensions in an area along the Atlantic coast of Nova Scotia. Rates of agreement were calculated between reported and actual vessel types. In Konrad (2020), vessels reported as cargo or tanker types had the highest rates of agreement at 99 percent, whereas those reported as passenger vessels had an agreement of 79 percent, and those reported as fishing vessels only had an agreement of 32 percent.

Fishing vessels in Canada are not legally mandated to carry AIS under the Navigation Safety Regulations (2020). In the U.S., only fishing vessels greater than 65 feet in length require AIS (United States Coast Guard, 2019). Due to these regulations and the likelihood that fishing vessels have low accuracy in vessel type reporting as noted by Konrad (2020), the map of fishing vessel density in Figure 16 underrepresents the actual fishing footprint and should be supplemented with VMS data.

Ferry traffic is underrepresented in the passenger vessel density map due to multiple crossings that are represented by a single trackline. This occurs because the vessels do not stay in port long enough to reach the threshold for a new trackline to be created. In addition, it was observed that vessels operating in different areas reported the same MMSI number at the same time of operation. This error prevented tracks for that time period from being created as the distance between AIS points exceeded threshold limits. This observation was noted with ferries in the St. Lawrence River between Montreal and Rivière-du-Loup, Quebec in the January 2019 data. This resulted in an underestimate for ferry tracks in this area.

ACKNOWLEDGEMENTS

The authors acknowledge the constructive review comments by the peer reviewers Angelia Vanderlaan (DFO Science) and Jessica Wingfield (DFO Marine Planning and Conservation) and thank Diego Ibarra at Dalhousie University for supporting earlier AIS mapping efforts.

REFERENCES

Balduzzi, M., Pasta, A., and Wilhoit, K. 2014. A security evaluation of AIS automated identification system. ACSAC ‘14: (Proceedings of the 30th Annual Computer Security Applications Conference, December 2014): 436–445, https://doi.org/10.1145/2664243.2664257.

Butler, S., Ibarra, D. and Coffen-Smout, S. 2019. Maritimes Region Longline and Trap Fisheries Footprint Mapping for Marine Spatial Planning and Risk Assessment. Can. Tech. Rep. Fish. Aquat. Sci. 3293: v + 30 p.

Carson-Jackson, J. 2012. Satellite AIS – Developing Technology or Existing Capability? *Journal of Navigation* 65(2) (2012): 303–321. https://doi.org/10.1017/S037346331100066X.

Harati-Mokhtari, A., Wall, A., Brooks, P. and Wang, J. 2007. Automatic identification system (AIS): Data reliability and human error implications. *Journal of Navigation* 60(3) (2007): 373–389.

Iacarella, J.C., Clyde, G., and Dunham, A. 2020. Vessel tracking datasets for monitoring conservation effectiveness. Canadian Technical Report of Fisheries and Aquatic Sciences. 3387. 31 p.

International Convention for the Safety of Life at Sea. 1974. Adopted 1 November 1974; Entry into force: 25 May 1980. https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx.

Iphar, C., Napoli, A., and Ray, C. 2015. Detection of false AIS messages for the improvement of Maritime Situational Awareness. OCEANS 2015 - MTS/IEEE Washington. doi:10.23919/oceans.2015.7401841.

Koen-Alonso, M., Favaro, C., Ollerhead, N., Benoît, H., Bourdages, H., Sainte-Marie, B., Treble, M., Hedges, K., Kenchington, E., Lirette, C., King, M., Coffen-Smout, S., and J. Murillo. 2018. Analysis of the overlap between fishing effort and Significant Benthic Areas in Canada’s Atlantic and Eastern Arctic marine waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/015. xvii + 270 p.

Konrad, C.M. 2020. Analysis of Automatic Identification System (AIS) Data for the Eastern Shore Islands, Nova Scotia, 2017-2018. Can. Manuscr. Rep. Fish. Aquat. Sci. 3172: vi + 39 p.

Koropatnick, T., Johnston, S.K., Coffen-Smout, S, Macnab, P., and Szeto, A. 2012. Development and Applications of Vessel Traffic Maps Based on Long Range Identification and Tracking (LRIT) data in Atlantic Canada. Can. Tech. Rep. Fish. Aquat. Sci. No. 2966. vi, + 27 p.

MarineCadastre.gov AIS Track Builder, 2018. The Marine Cadastre Project: A collaboration of NOAA Office for Coastal Management and the Bureau of Ocean Energy Management (BOEM). AIS Utilities 2018 Pro, July 2018 (v1.0) [Esri ArcGIS Pro]. BOEM.

MarineTraffic.com, n.d. How often do the positions of the vessels get updated on MarineTraffic?: https://help.marinetraffic.com/hc/en-us/articles/217631867-How-often-do-the-positions-of-the-vessels-get-updated-on-MarineTraffic-.

Mazzarella, F., Vespe, M., Alessandrini, A., Tarchi, D., Aulicino, G., and Vollero, A. 2017. A novel anomaly detection approach to identify intentional AIS on-off switching. *Expert Systems with Applications* 78 (15 July 2017): 110–123.

McCauley, D.J., Woods, P., Sullivan, B., Bergman, B., Jablonicky, C., Roan, A., Hirshfield, M., Boerder, K. and Worm, B. 2016. Ending hide and seek at sea. *Science* 351 (6278) (2016): 1148–1150.

NOAA (National Oceanic and Atmospheric Administration). 2017. Shoreline/Coastline Resources. National Centers for Environmental Information, https://www.ngdc.noaa.gov/mgg/shorelines/.

Proud, R., Browning, P., and Kocak, D.M. 2016. AIS-based mobile satellite service expands opportunities for affordable global ocean observing and monitoring. OCEANS 2016 MTS/IEEE Monterey. doi:10.1109/oceans.2016.7761069.

Simard, Y., Roy, N., Giard, S., and Yayla, M. 2014. Canadian Year-Round Shipping Traffic Atlas for 2013: Volume 1, East Coast Marine Waters. Can. Tech. Rep. Fish. Aquat. Sci. 3091 (Vol. 1) E: xviii + 327 pp. https://publications.gc.ca/collections/collection_2014/mpo-dfo/Fs97-6-3091-1-eng.pdf.

Skauen, A.N., Helleren, Ø., Olsen, Ø. and Olsen, R. 2013. Operator and User Perspective of Fractionated AIS Satellite Systems. Proceedings of the AIAA/USU Conference on Small Satellites, Around the Corner, SSC13-XI-5.

Skauen, A. N., and Olsen, Ø. 2016. Signal environment mapping of the automatic identification system frequencies from space. *Advances in Space Research*, 57(3) (2016): 725–741. doi:10.1016/j.asr.2015.12.002.

Smestad, B.B., Asbjørnslett, B.E., and Rødseth, Ø.J. 2017. Expanding the possibilities of AIS data with heuristics. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation* 11(2), (2017): 93–100. doi:10.12716/1001.11.02.10.

Svanberg, M., Santén, V., Hörteborn, A., Holm, H., and Finnsgård, C. 2019. AIS in maritime research. *Marine Policy* 106 (2019): 103520. doi:10.1016/j.marpol.2019.103520.

Transport Canada, Navigation Safety Regulations, 2020 (SOR/2020-216), https://laws-lois.justice.gc.ca/eng/regulations/SOR-2020-216/index.html.

United States Coast Guard, 2019. Part 164, Navigation Safety Regulations, 2019-07-01, https://www.govinfo.gov/content/pkg/CFR-2019-title33-vol2/xml/CFR-2019-title33-vol2-part164.xml.

Winther, M., Christensen, J.H., Plejdrup, M.S., Ravn, E.S., Eriksson, Ó.F., and Kristensen, H.O. 2014. Emission inventories for ships in the Arctic based on satellite sampled AIS data. *Atmospheric Environment* 91 (2014): 1–14. https://doi.org/10.1016/j.atmosenv.2014.03.006.

FIGURES AND TABLES

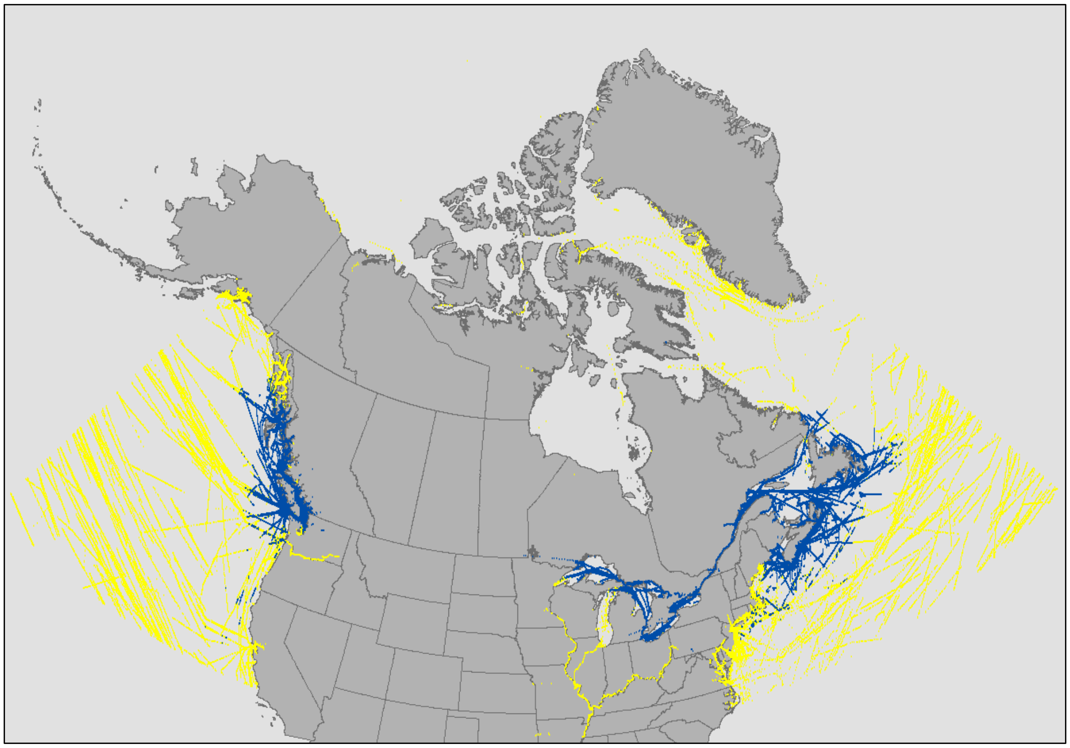

Figure 1. Spatial distribution of fused AIS positions for 1 day in August 2019. Yellow points represent AIS coming from the satellite AIS provider and blue points represent AIS coming from terrestrial receivers from the CCG.

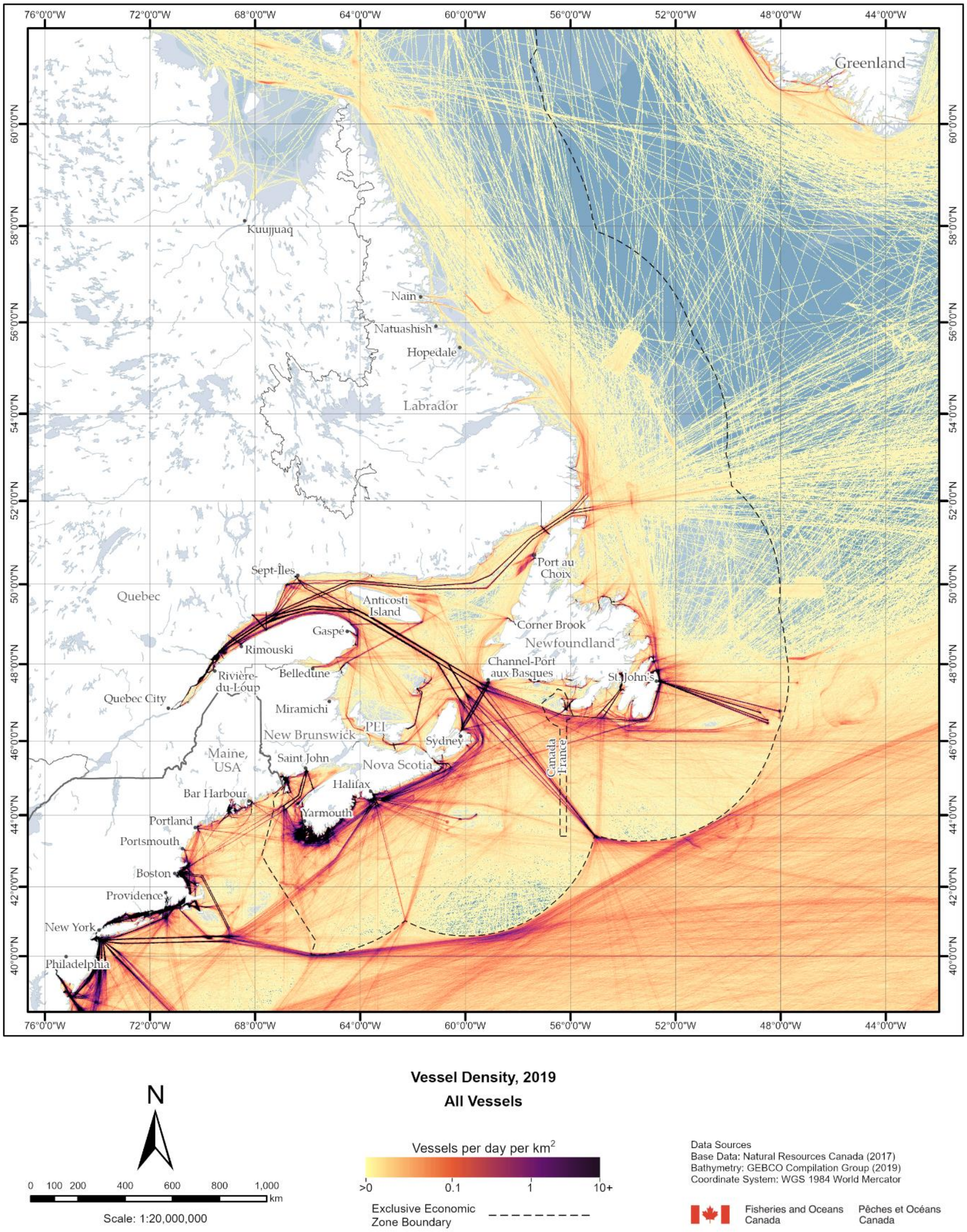

Figure 2. 2019 All Vessel Density (Vessels/day/km^2)

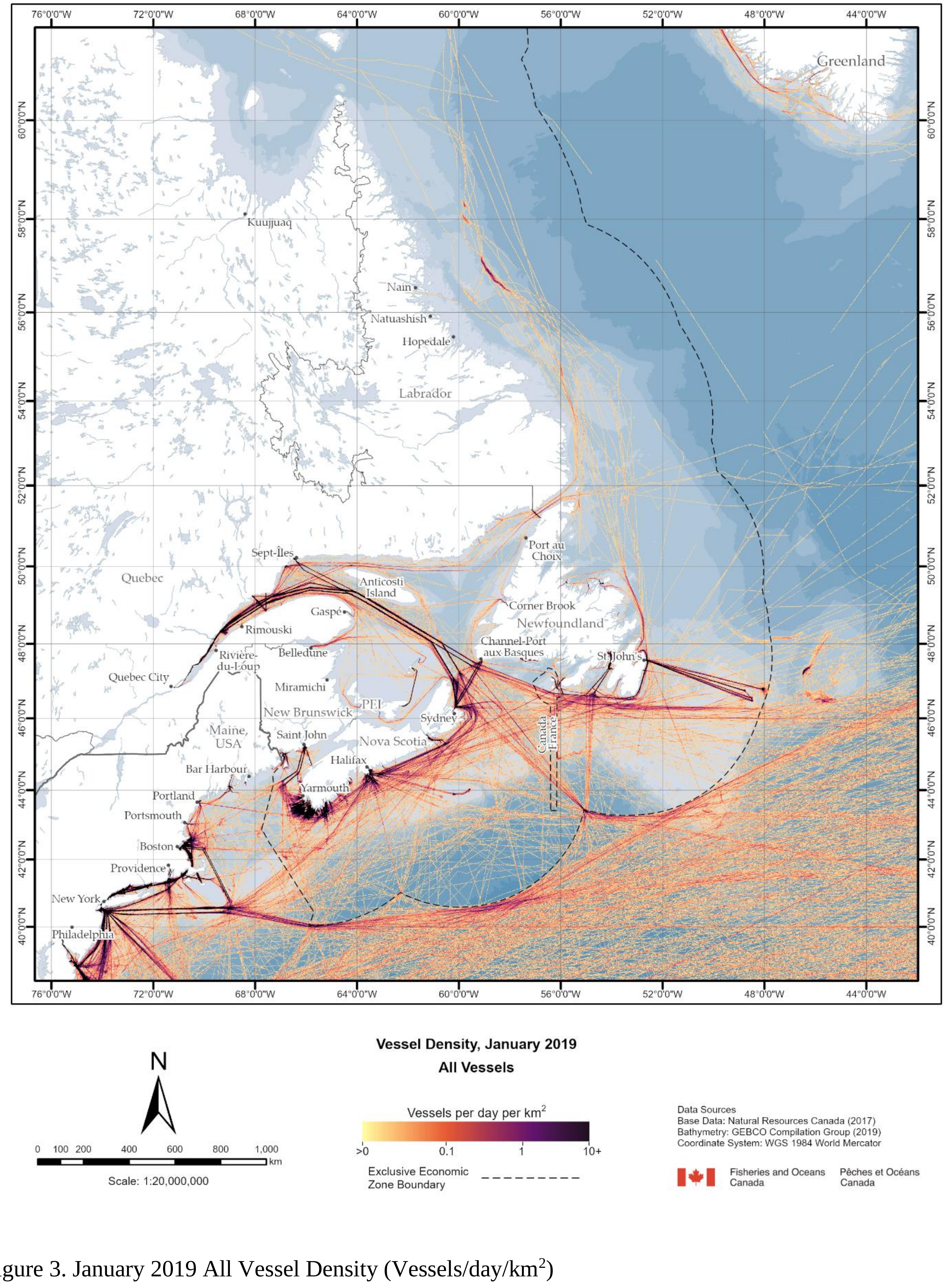

Figure 3. January 2019 All Vessel Density (Vessels/day/km^2)

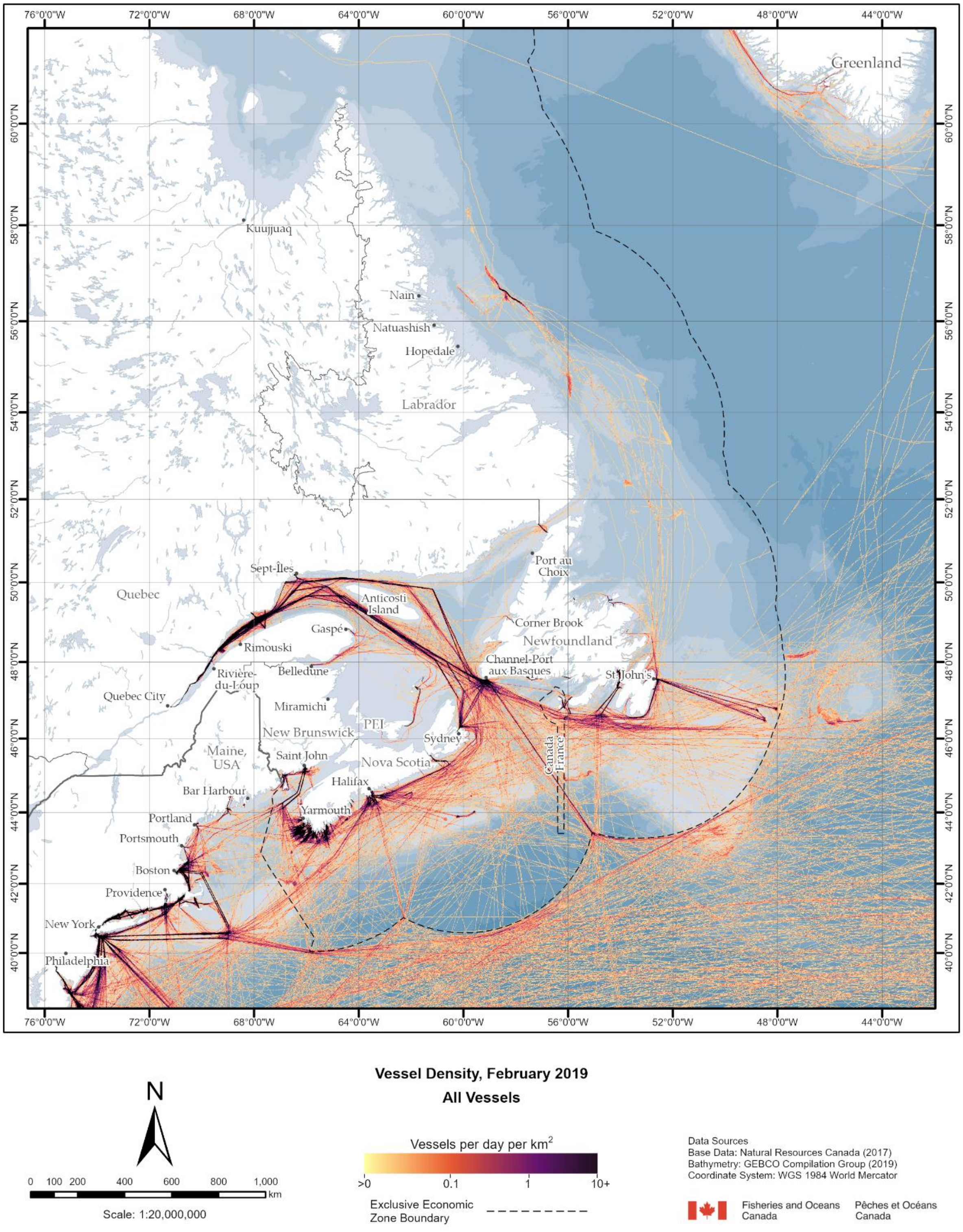

Figure 4. February 2019 All Vessel Density (Vessels/day/km^2)

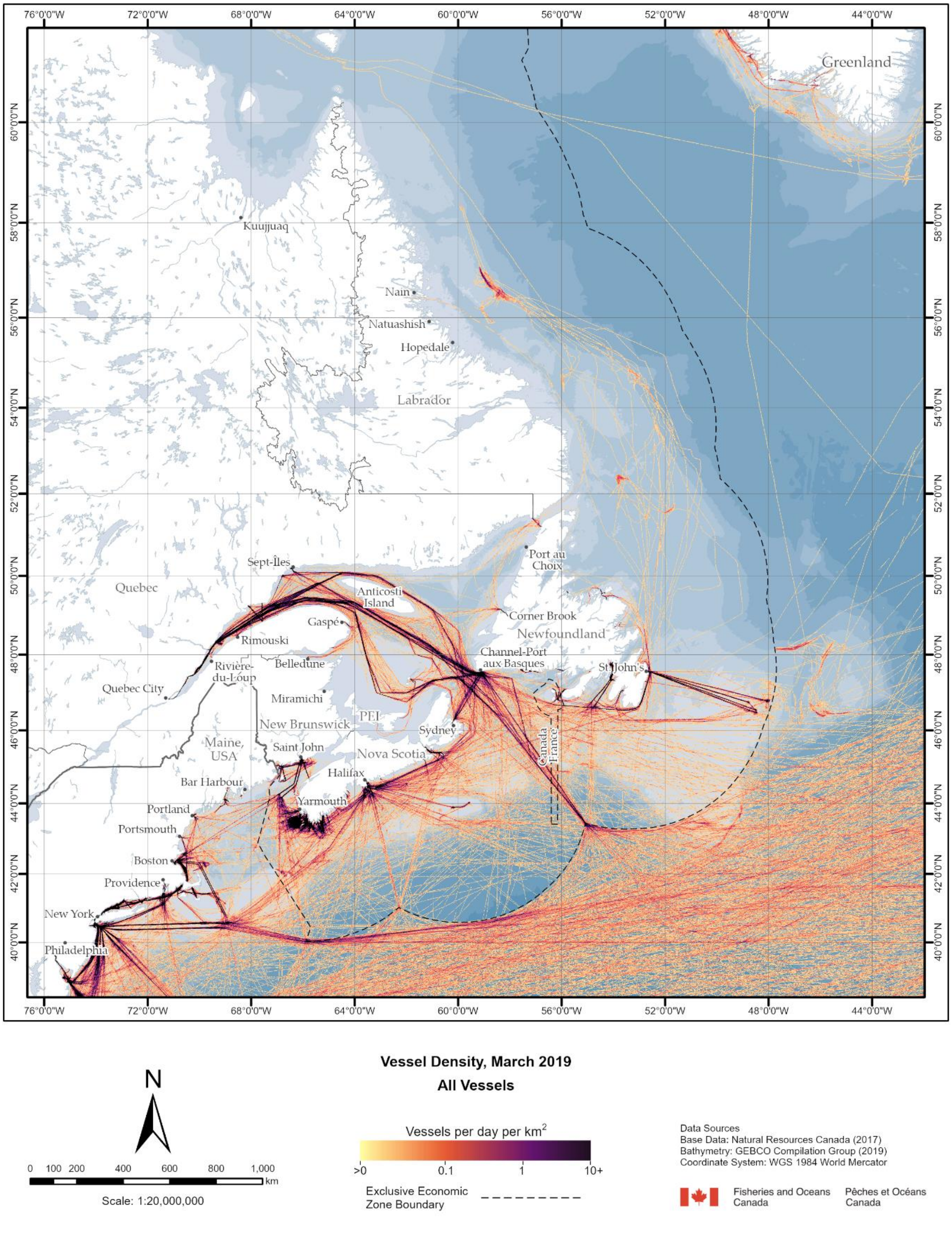

Figure 5. March 2019 All Vessel Density (Vessels/day/km^2)

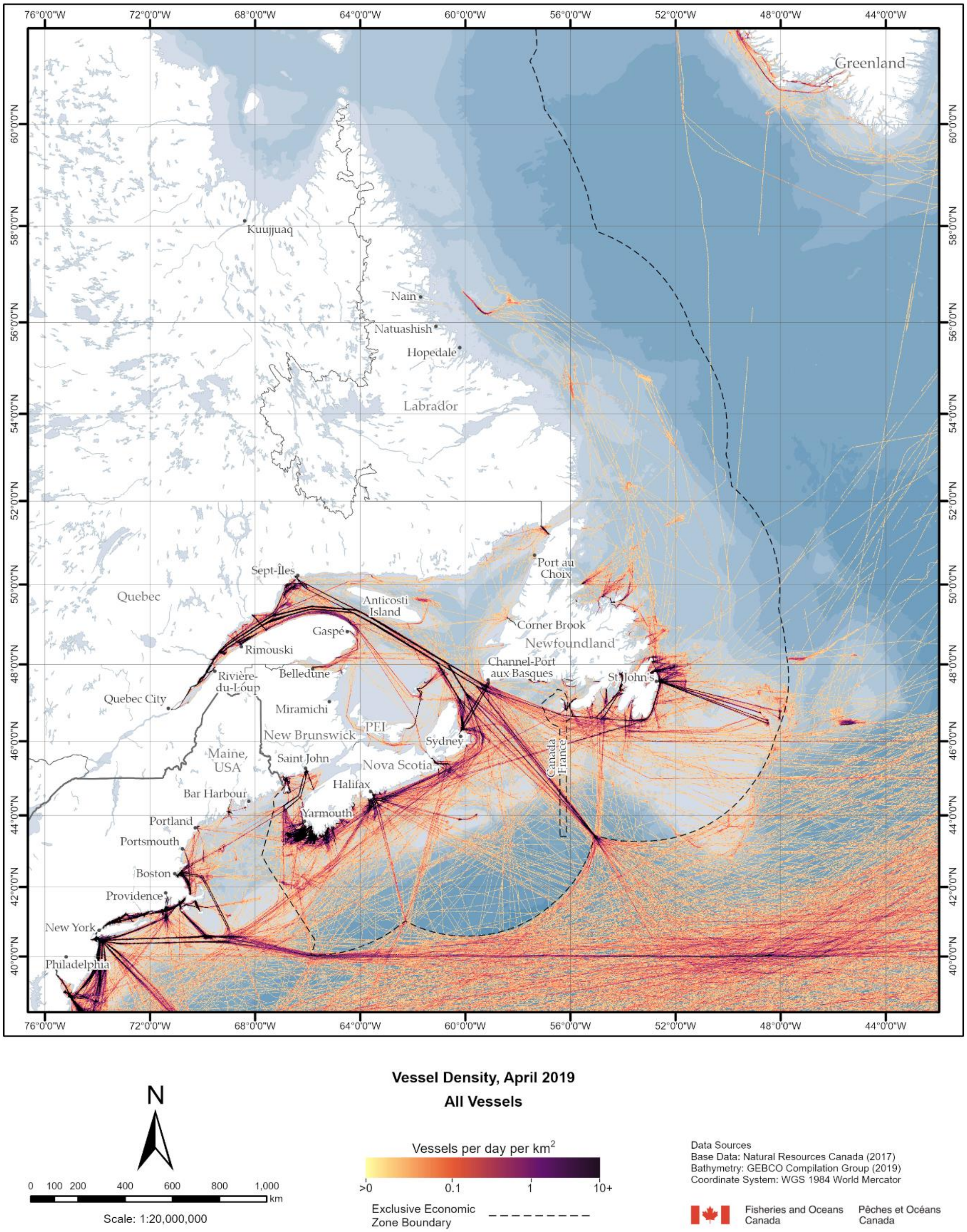

Figure 6. April 2019 All Vessel Density (Vessels/day/km^2)

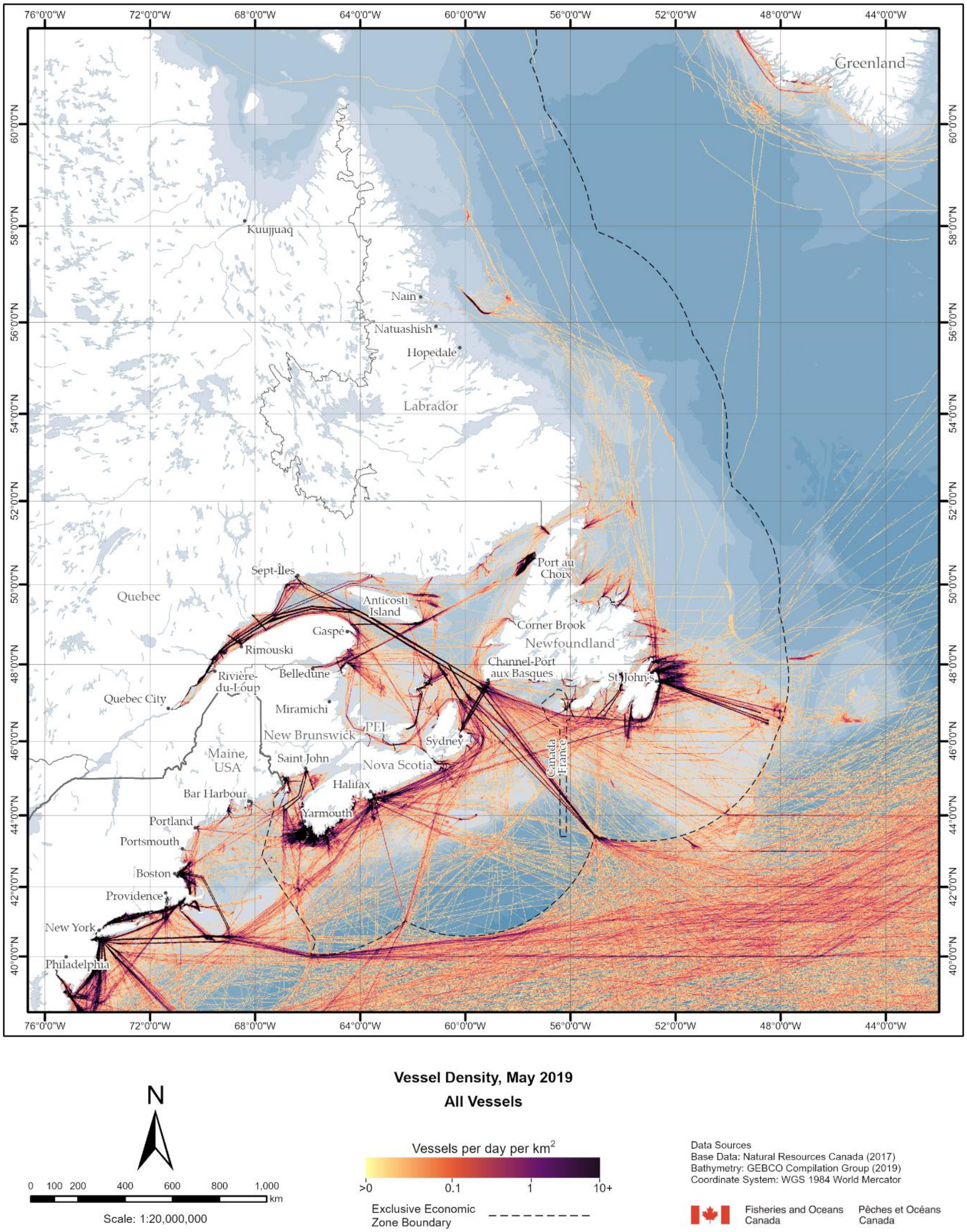

Figure 7. May 2019 All Vessel Density (Vessels/day/km^2)

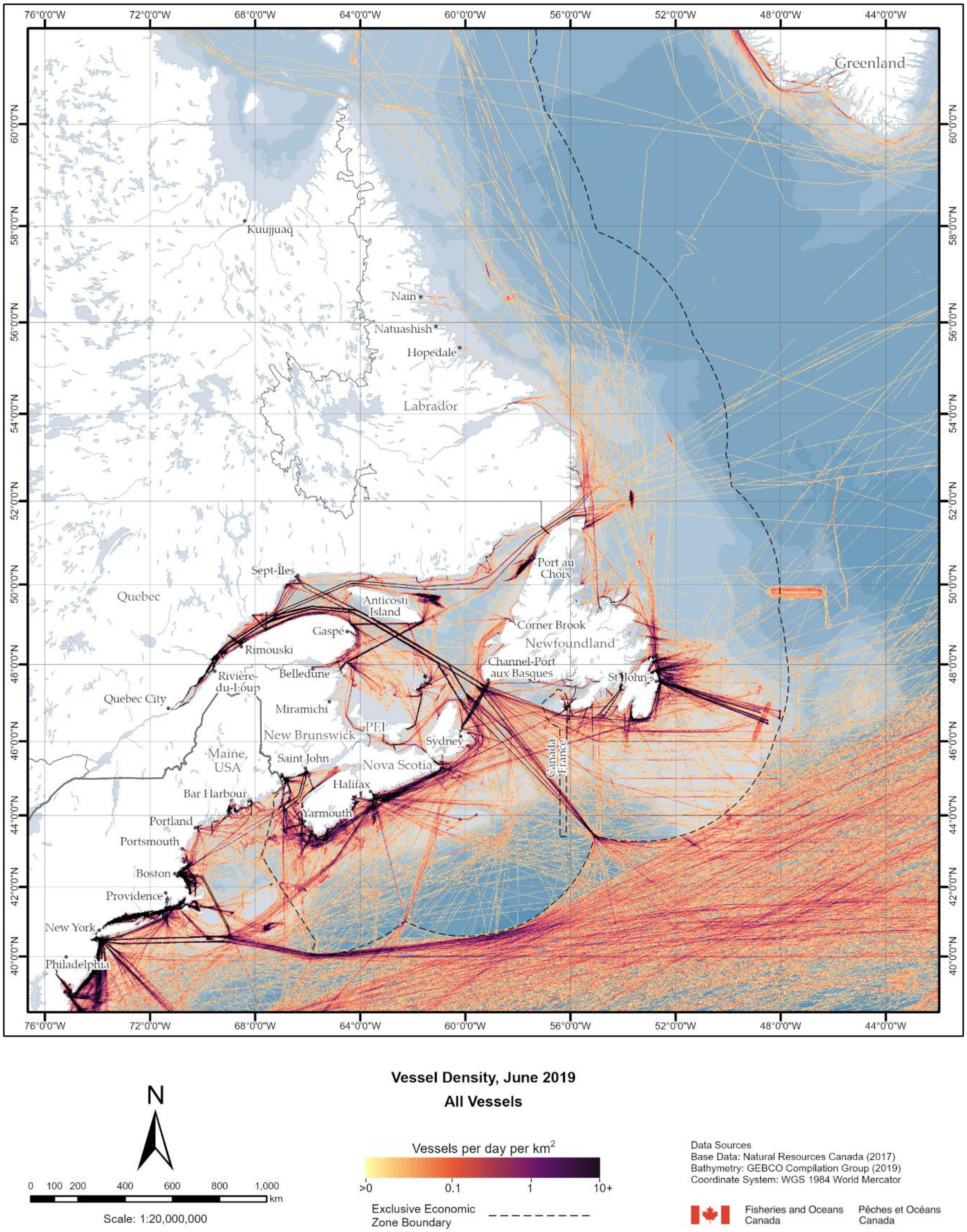

Figure 8. June 2019 All Vessel Density (Vessels/day/km^2)

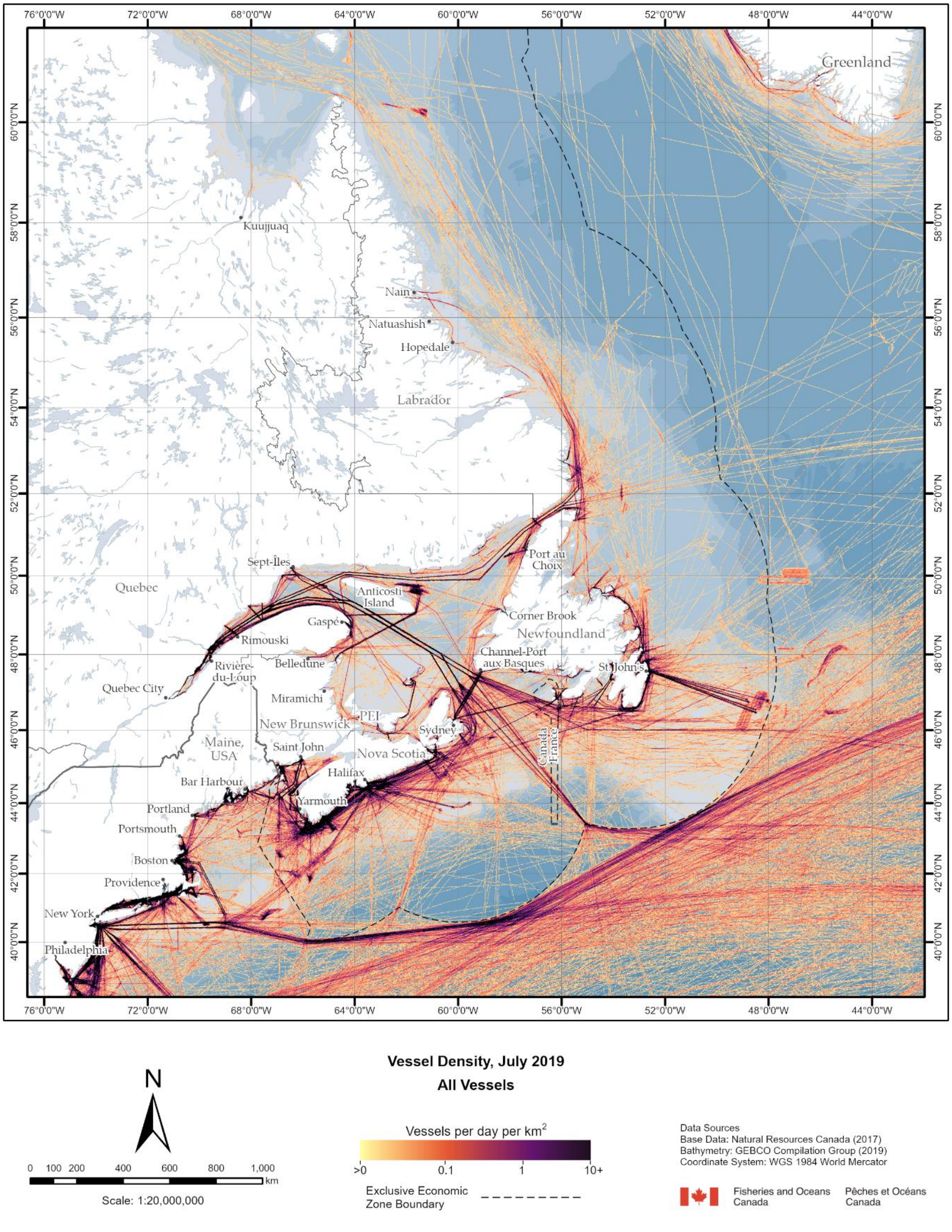

Figure 9. July 2019 All Vessel Density (Vessels/day/km^2)

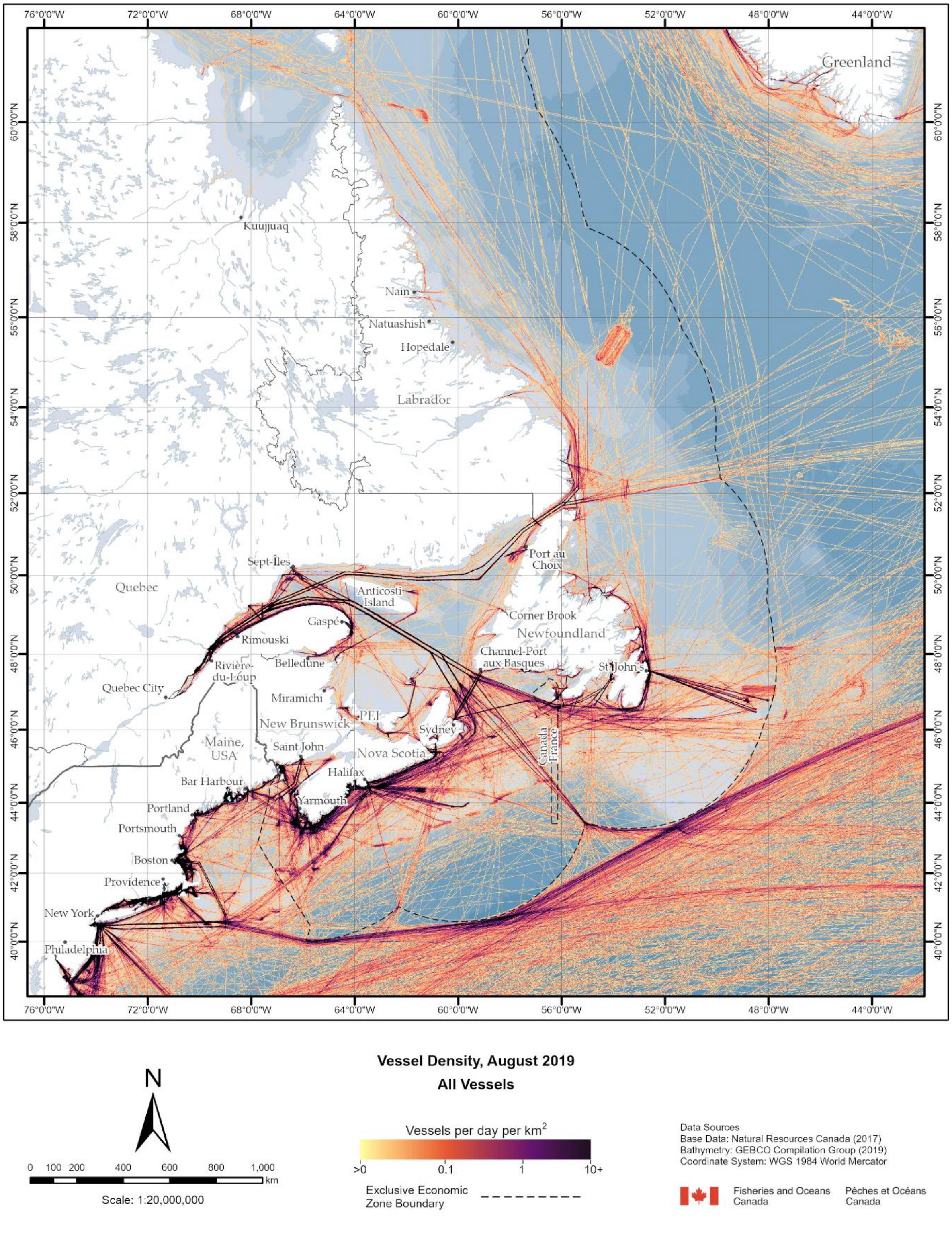

Figure 10. August 2019 All Vessel Density (Vessels/day/km^2)

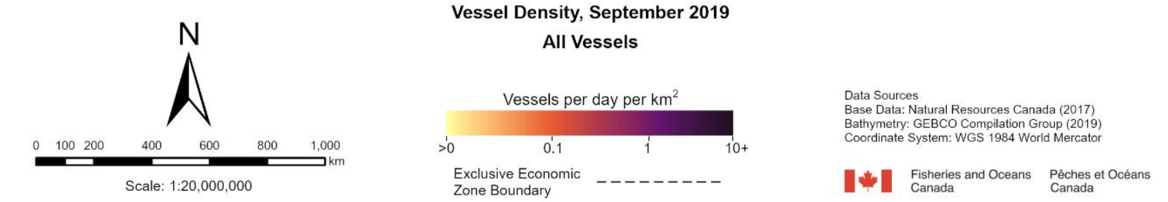

Figure 11. September 2019 All Vessel Density (Vessels/day/km^2)

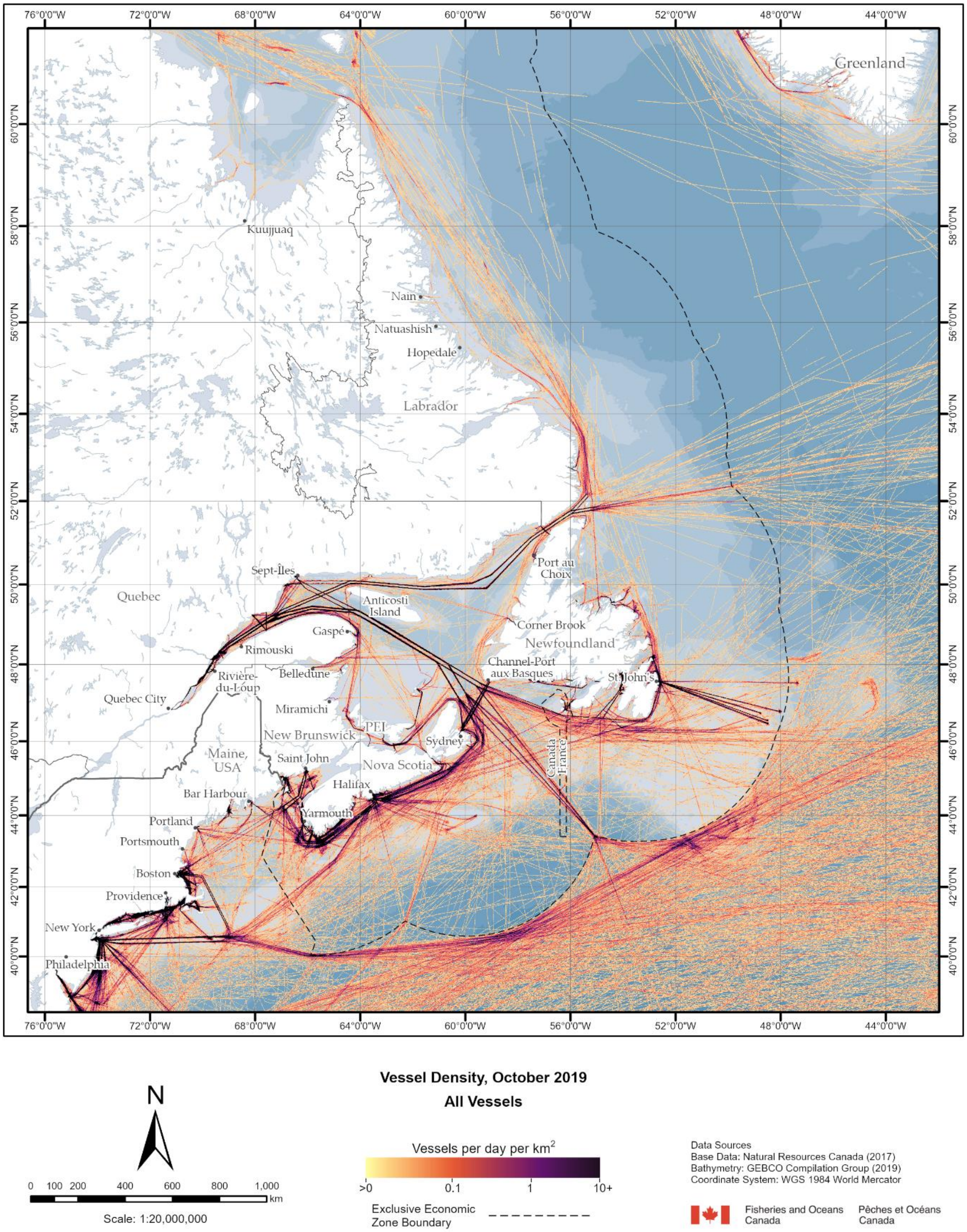

Figure 12. October 2019 All Vessel Density (Vessels/day/km^2)

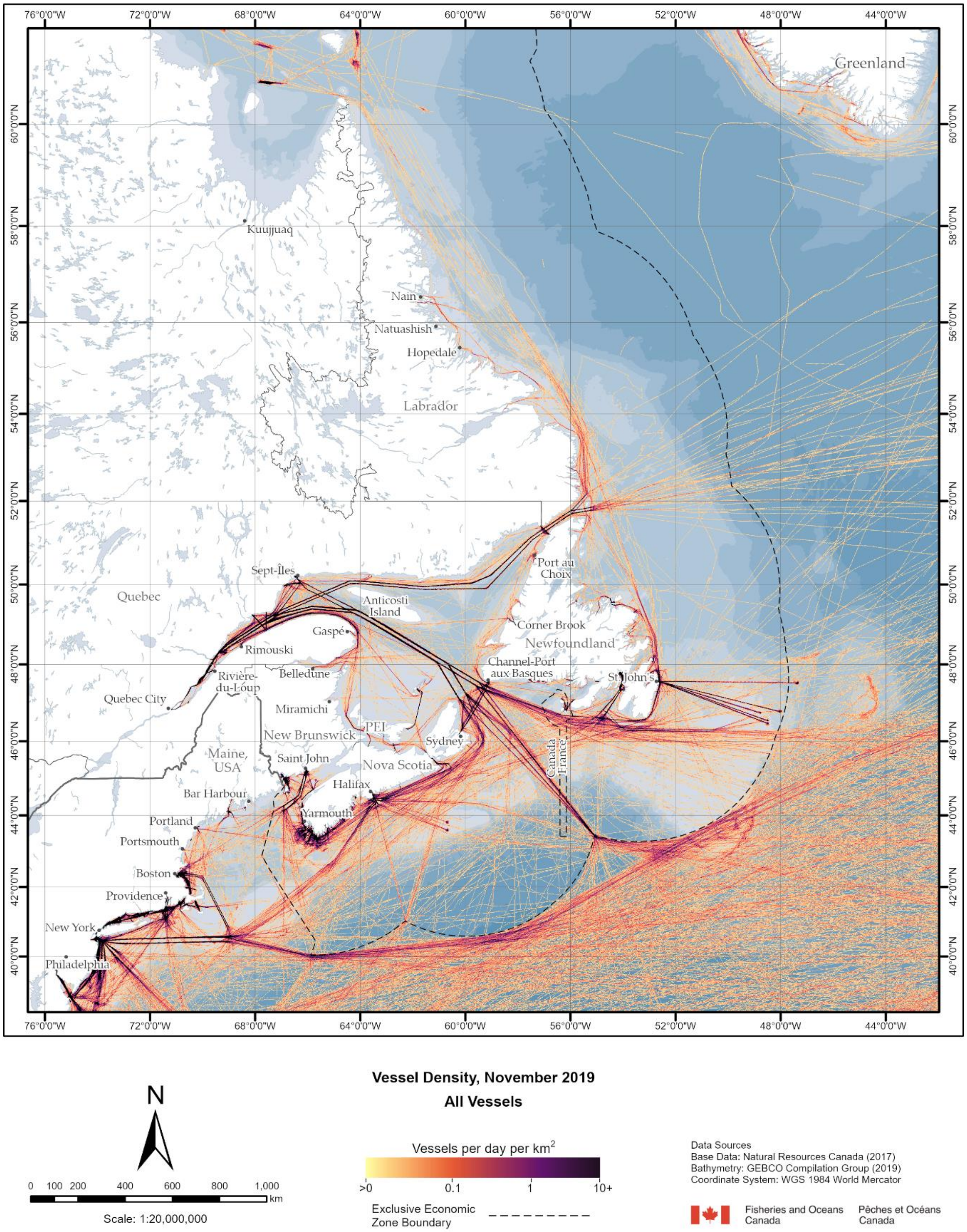

Figure 13. November 2019 All Vessel Density (Vessels/day/km^2)

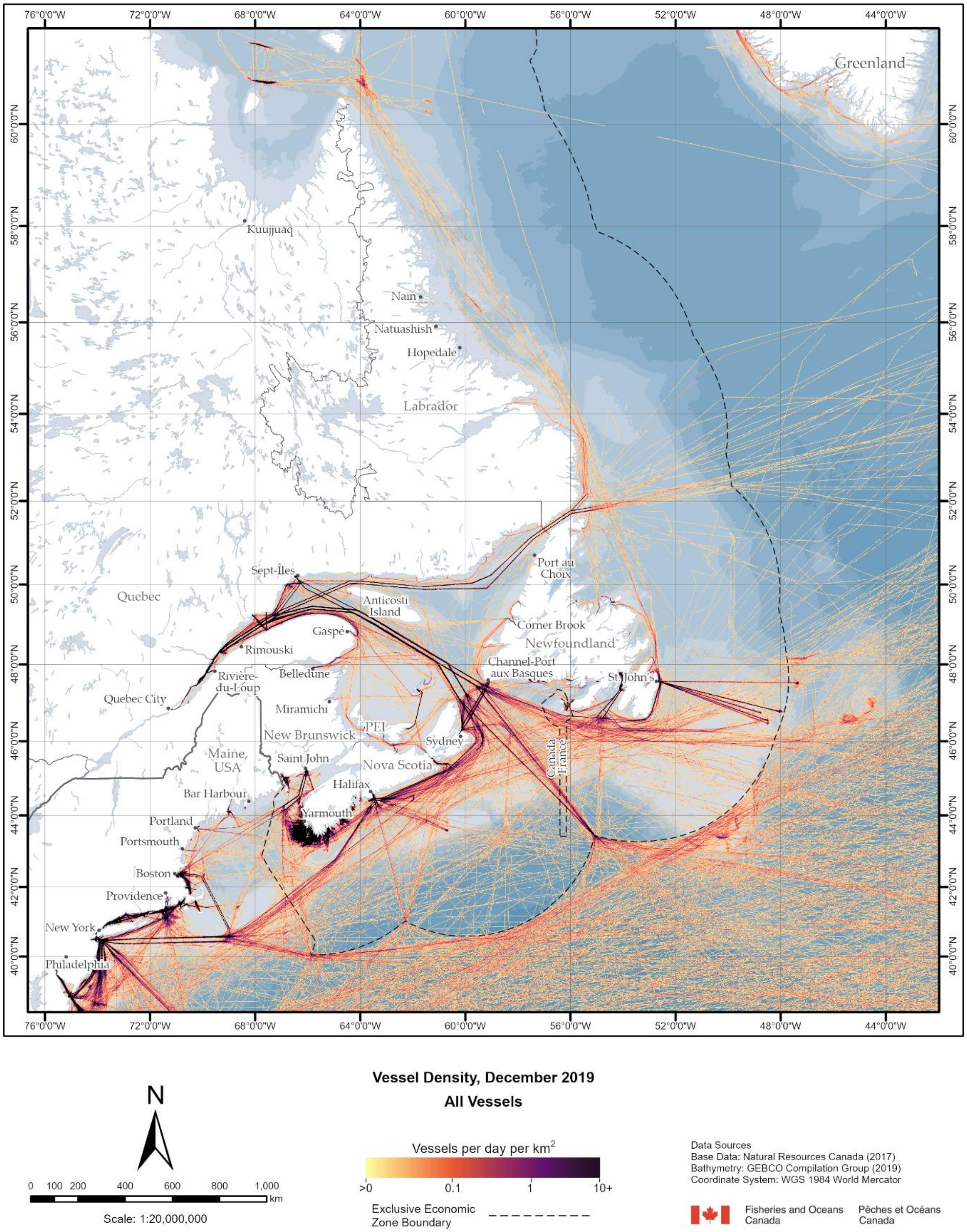

Figure 14. December 2019 All Vessel Density (Vessels/day/km^2)

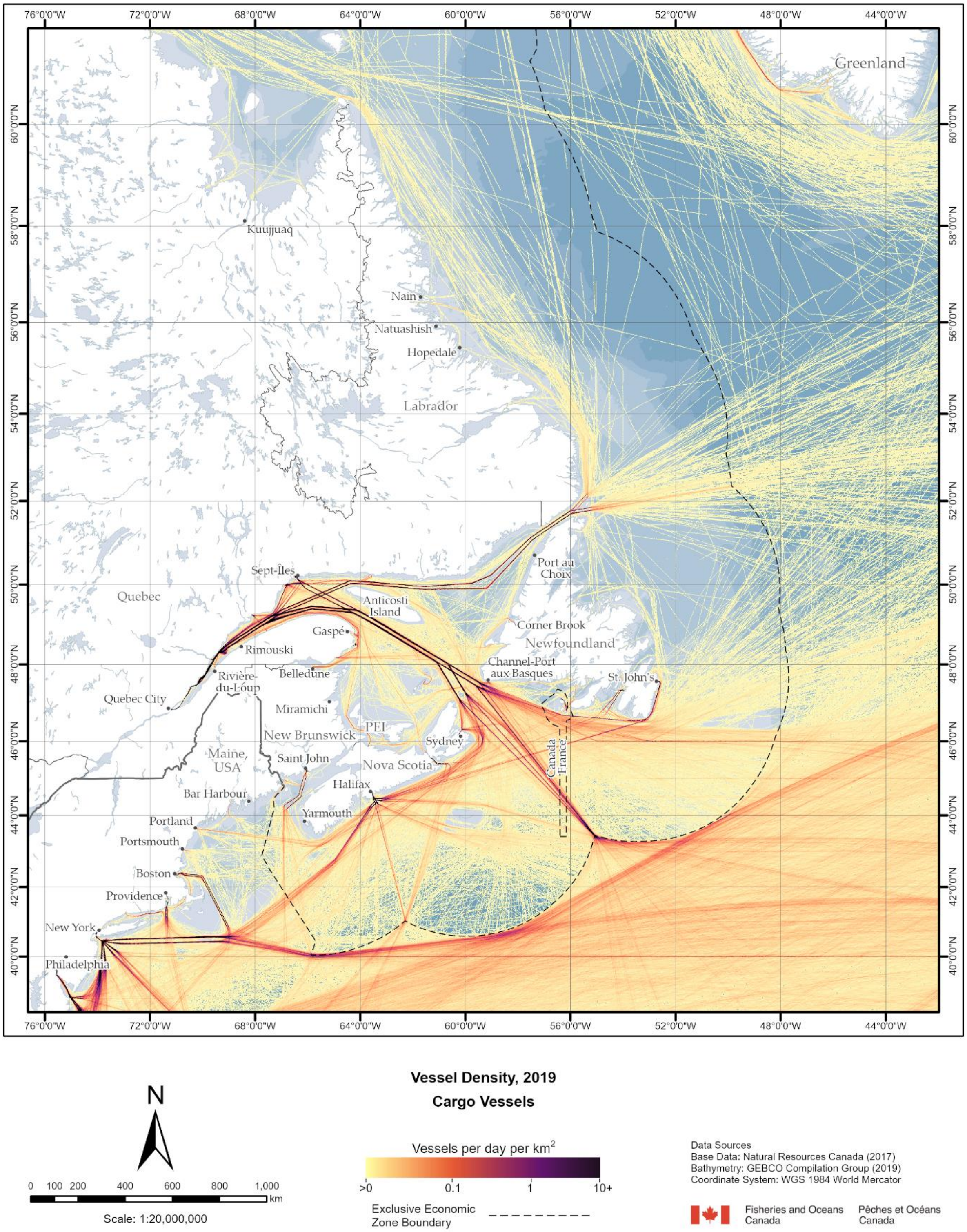

Figure 15. 2019 All Cargo Vessel Density (Vessels/day/km^2)

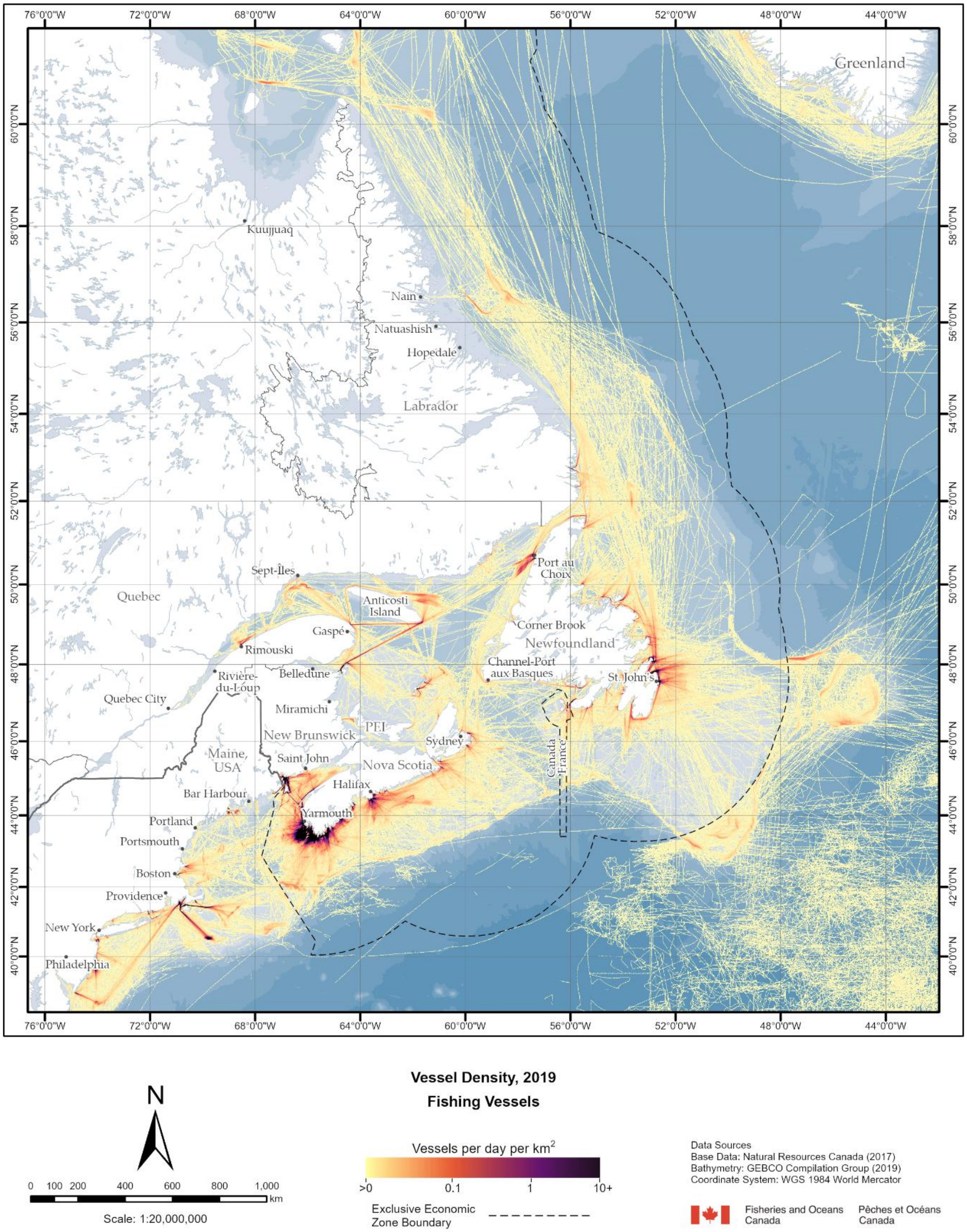

Figure 16. 2019 All Fishing Vessel Density (Vessels/day/km^2)

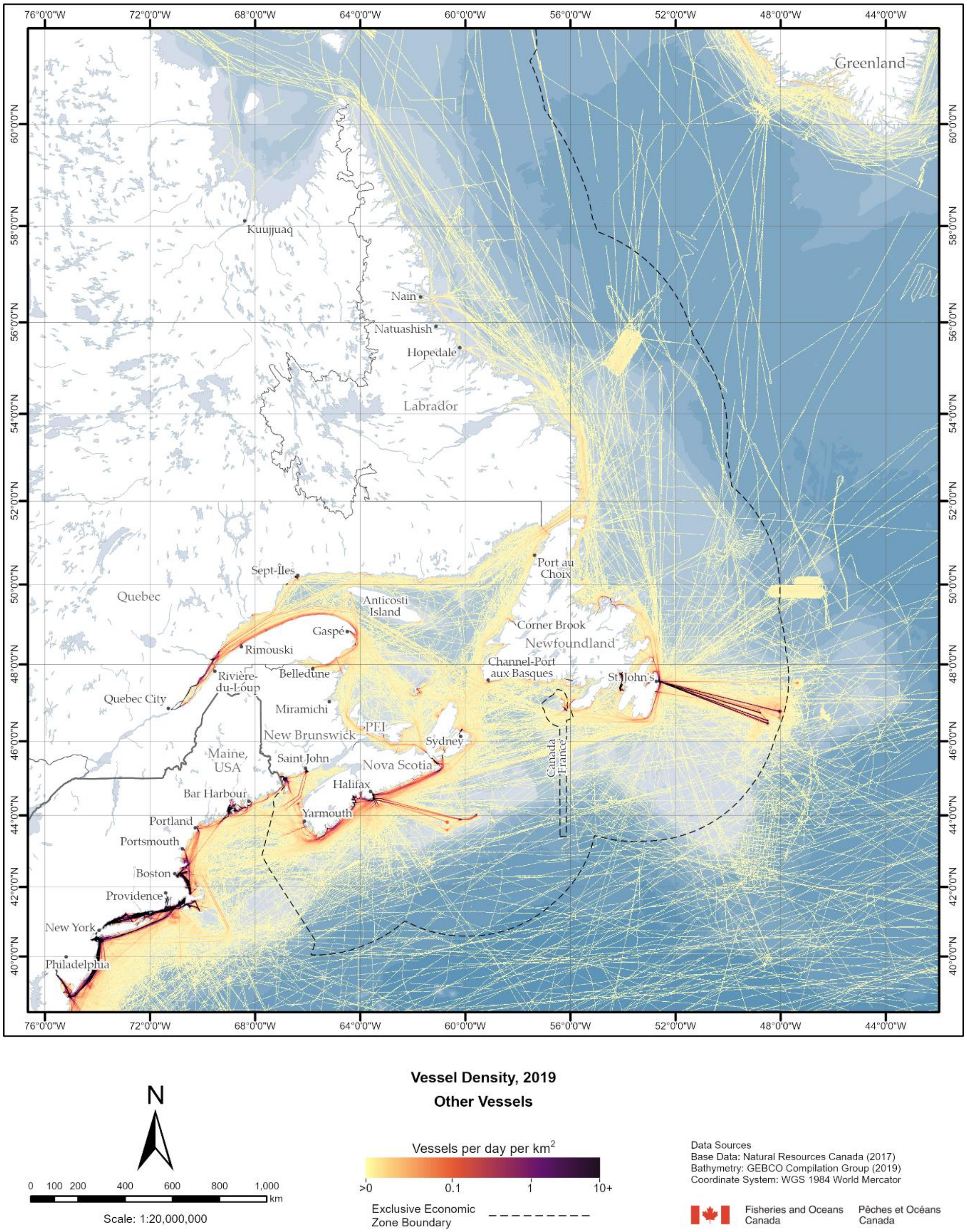

Figure 17. 2019 All ‘Other’ Vessel Density (Vessels/day/km^2)

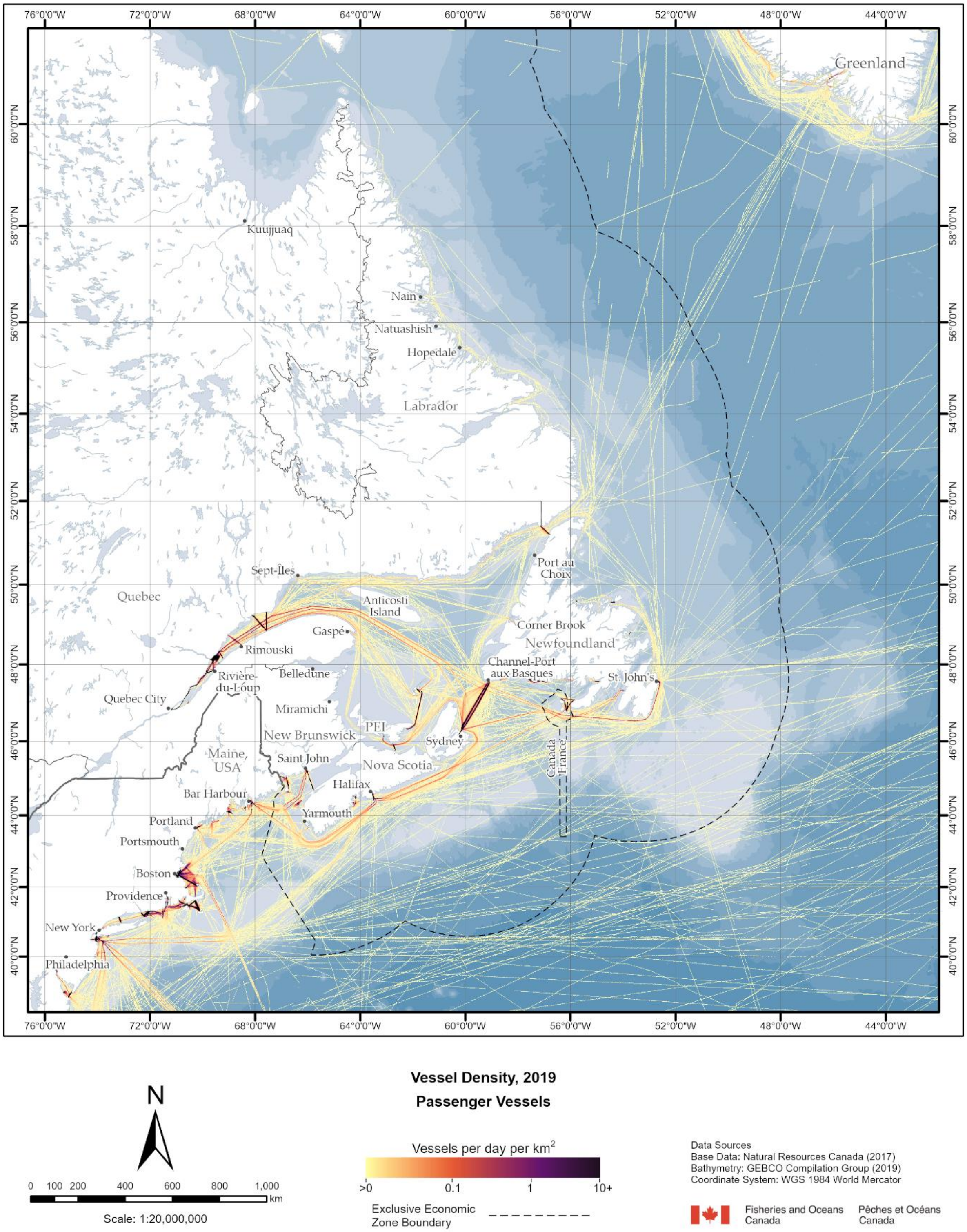

Figure 18. 2019 All Passenger Vessel Density (Vessels/day/km^2)

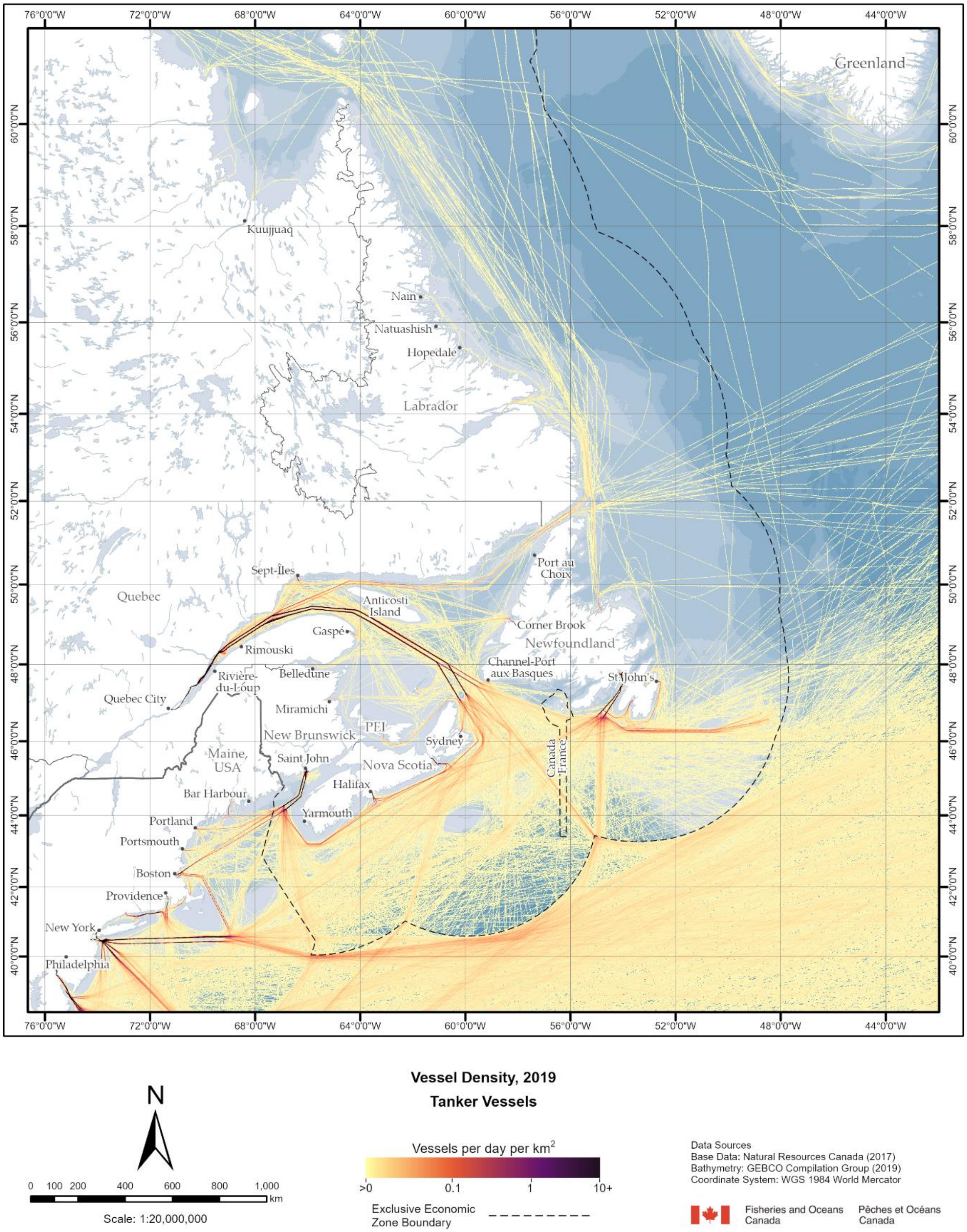

Figure 19. 2019 All Tanker Vessel Density (Vessels/day/km^2)

Table 1. Examples of the types of vessels included in each category. Note that this is not a comprehensive list of all types in each category.

Vessel Classifications	Vessel Type Examples
Cargo	General Cargo, Vehicle Carrier, Livestock, Carrier, Container Ship, Reefer, Bulk Carrier, Cement Carrier, Ore Carrier, and other similar classes.
Fishing	Factory Trawler, Fish Carrier, Fishing Vessel, Trawler, and other fishing specific vessels.
Passenger	Ferry, Ro-Ro Cargo, Ro-Ro/Passenger Ship, Passenger Ship (Cruise), High Speed Craft, and other similar classes.
Tanker	Asphalt/Bitumen Tanker, Chemical Tanker, Crude Oil Tanker, LNG/LPG Tanker, and other similar classes.
Other	Any class not covered by the above categories, (i.e., Anchor Handling Vessel, Articulated Push Tug, Pusher/Tug, Towing Vessel, Tugs, Cable Layer, Dive Vessel, Dredger, Floating Storage/Production, Wing in Ground, Anti-Pollution, Icebreaker, Law Enforcement, Military Ops, Pilot Vessel, Research/Survey Vessel, SAR, etc.)

Table 2. Breakdown of % of the number of tracks by vessel type and month. Calculated from total AIS tracks for each vessel type and timeframe divided by yearly totals.

	All	**Cargo**	**Fishing**	**Other**	**Passenger**	**Tanker**
2019	100.00	9.71	20.20	46.25	18.61	5.23
January	5.68	0.69	1.23	2.39	0.99	0.38
February	4.82	0.54	0.88	2.17	0.90	0.34
March	5.86	0.77	1.16	2.42	1.09	0.42
April	6.69	0.74	1.75	2.52	1.22	0.45
May	9.50	0.86	2.86	3.69	1.60	0.49
June	10.09	0.84	1.96	4.84	1.99	0.46
July	12.77	0.92	2.09	6.94	2.29	0.53
August	13.13	0.92	1.76	7.59	2.36	0.50
September	10.13	0.84	1.56	5.22	2.09	0.43
October	8.02	0.97	1.42	3.44	1.74	0.45
November	6.30	0.84	1.28	2.60	1.19	0.39
December	6.99	0.79	2.23	2.43	1.16	0.39

Table 3. Breakdown of individual vessels by class based on the number of unique MMSI numbers detected within the study area throughout 2019.

Vessel Type	Number of Active Vessels
All	21264
Cargo	4239
Other	11599
Fishing	2478
Passenger	784
Tanker	2164