

Temporal and Spatial Patterns of Ship Traffic in the Canadian Arctic from 1990 to 2015

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ABSTRACT. The limited availability of consistent, longitudinal data sources for marine traffic in Arctic Canada has presented significant challenges for researchers, policy makers, and planners. Temporally and spatially accurate shipping data that reveal historical and current traffic trends are vital to plan safe shipping corridors, develop infrastructure, plan and manage protected areas, and understand the potential environmental and cultural impacts of change, as well as for sovereignty and safety considerations. This study uses a recently developed geospatial database of ship traffic to provide the first synthesized overview of the spatial and temporal variability of different vessel types in Arctic Canada during the 26-year period from 1990 to 2015. This examination shows that, overall, the distance traveled by ships in Arctic Canada nearly tripled (from 364 179 km in 1990 to 918 266 km in 2015), that the largest proportion of ship traffic in the region is from general cargo vessels and government icebreakers (including research ships), and that the fastest growing vessel type by far is pleasure craft (private yachts). Spatial shifts in vessel activity over the last quarter century have favoured areas with active mine sites, as well as the southern route of the Northwest Passage. As a result, some communities, including Baker Lake, Chesterfield Inlet, Pond Inlet, and Cambridge Bay, are experiencing greater increases in ship traffic.

Key words: Arctic; marine transportation; shipping trends; climate change; Canada; GIS; Northwest Passage

RÉSUMÉ. La faible disponibilité de sources de données longitudinales cohérentes pour le trafic maritime de l'Arctique canadien pose d'importants défis aux chercheurs, aux responsables des politiques et aux planificateurs. L'existence de données d'expédition temporelles et spatiales précises qui révèlent les tendances historiques et actuelles du trafic s'avère essentielle pour planifier la sûreté des couloirs de navigation, aménager l'infrastructure, planifier et gérer les zones protégées, comprendre les incidences environnementales et culturelles potentielles découlant du changement et agir en fonction des considérations de souveraineté et de sécurité. Cette étude s'appuie sur une base de données géospatiale du trafic maritime récemment conçue pour fournir la première synthèse de la variabilité spatiale et temporelle de différents types de navires dans l'Arctique canadien au cours de la période de 26 ans allant de 1990 à 2015. L'étude démontre que, globalement, la distance parcourue par les navires dans l'Arctique canadien a presque triplé (passant de 364 179 km en 1990 à 918 266 km en 2015), que les navires de marchandises diverses et les brise-glaces gouvernementaux (y compris les navires de recherche) forment la plus grande partie du trafic maritime dans la région, et que le trafic des bateaux de plaisance (yachts privés) est, de loin, le trafic qui connaît le plus grand essor. Les changements spatiaux sur le plan de l'activité des navires au cours du dernier quart de siècle ont favorisé les zones ayant des sites miniers actifs, ainsi que la route sud du passage du Nord-Ouest. Par conséquent, certaines collectivités, dont celles de Baker Lake, Chesterfield Inlet, Pond Inlet et Cambridge Bay, connaissent une plus forte augmentation de la circulation maritime.

Mots clés : Arctique; transport maritime; tendances d'expédition; changement climatique; Canada; SIG; passage du Nord-Ouest

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INTRODUCTION

International marine trade in Canada was valued at \$205 billion in 2015 (Council of Canadian Academies, 2017), and it has been estimated that 90% of all goods that are manufactured and purchased globally are shipped at some point by sea (George, 2013). Canada has the longest

coastline in the world: it extends more than 200 000 km and connects three major oceans, the Pacific, Arctic, and Atlantic Oceans (CIA, 2017), making Canada highly reliant upon maritime trade and transport (Council of Canadian Academies, 2017). Within Canada, the Arctic region is perhaps most dependent on the marine transportation industry, as it consists of large island chains and remote

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continental shoreline that in many areas is accessible only by sea or by air.

Many types of marine vessels currently operate in the Canadian Arctic, each with distinct characteristics and cargo (Table 1). Communities across the territory rely heavily upon ships as a means of transporting goods to service the region, especially considering population growth and changing development needs of communities (Arctic Council, 2009; Prowse et al., 2009; Hodgson et al., 2013; Pelletier and Guy, 2015). Government, military, and research vessels are becoming more common in the region, and their presence will soon increase with the operationalization of a fleet of commissioned Arctic Offshore Patrol Ships (Royal Canadian Navy, 2017). With some of the largest untapped natural resource reserves in the world located in the Arctic, increased marine activity due to oil and gas exploration and extraction is also a possibility—especially considering current policy decisions to expand offshore exploration and exploitation in the United States areas of the Beaufort Sea (Guy, 2006; Prowse et al., 2009; Pizzolato et al., 2014; CBC, 2017). Small-scale commercial fishing operations within the Canadian Arctic are also expanding with the ongoing investment in small craft harbours and small boat infrastructure (Hodgson et al., 2013; Pizzolato et al., 2016). Marine tourism (both pleasure craft and passenger ships) has rapidly become popular over the past decade, and it is speculated that because of the allure of the Northwest Passage and the growing interest in “last chance” tourism, the demand will continue (Dawson et al., 2007, 2014, 2016, 2017; Lasserre and Pelletier, 2011; Hodgson et al., 2013; Lasserre and Têtu, 2015; Johnston et al., 2017).

It has been reported that over the past decade ship traffic in Arctic Canada has increased by more than 75% (Pizzolato et al., 2014, 2016; Dawson et al., 2017; see also Lasserre and Têtu, 2015; Eguíluz et al., 2016; Johnston et al., 2017). Much speculation has attributed observed increases in marine traffic to climate change, including a reduction in sea ice extent that has enlarged open water areas and increased season length by an average of five days per decade (Stroeve et al., 2014; see also Stephenson et al., 2011, 2013; Smith and Stephenson, 2013; Stephenson and Smith, 2015). The lengthening of the Canadian Arctic shipping seasons has occurred predominantly in the spring and fall seasons (Pizzolato et al., 2014) and within the central Arctic and Canadian Arctic Archipelago and the Northwest Passage (Sou and Flato, 2009; Khon et al., 2010; Haas and Howell, 2015; Laliberté et al., 2016; Melia et al., 2016). Pizzolato et al. (2016) specifically examined the correlation between changing sea ice conditions and shipping activity in these regions, finding a limited but increasing connection between these two factors over time. This finding supports the view that climate change is only one of a range of important factors influencing Arctic marine traffic trends. It could be argued these trends are equally (if not more) influenced by globalization, commodity prices, tourism demand, demographics, and societal trends (see Prowse

et al., 2009; George, 2013; Hodgson et al., 2013; Pelletier and Guy, 2015; Pizzolato et al., 2016; Council of Canadian Academies, 2017; Dawson et al., 2017).

Some attempts have been made to observe the overall trend toward increased shipping in the Canadian Arctic over the past decade (see Pelletier and Guy, 2012, 2015; Pizzolato et al., 2014, 2016; Lasserre and Têtu, 2015; Eguíluz et al., 2016; Johnston et al., 2017), but still little is known about the specific patterns and long-term trends that have emerged with regard to overall traffic, vessel type, region, and proximity to communities. Increases in marine traffic could be highly advantageous for the Canadian Arctic given the potential for enhanced economic development in mining, tourism, and fisheries, as well as for resupply services (Hodgson et al., 2013; Pelletier and Guy, 2015; Dawson et al., 2016). However, there are also significant risks, including the potential for vessel incidents, safety issues and security threats, environmental disturbances, degradation of historic or culturally significant sites, and negative outcomes for local residents, especially Inuit, who depend on the marine environment for subsistence and livelihoods (Kubat et al., 2006; Chircop, 2009; Brigham, 2011, 2013; Kelley and Ljubicic, 2012). In order for government, Inuit leaders, and regional communities to make effective decisions that support development of a safe and sustainable marine transportation industry in Arctic Canada, it is vital to have a comprehensive understanding of the evolution of marine traffic patterns over time. A better understanding of the long-term trends in Arctic shipping could also be useful in planning for protected areas, developing low-impact corridors, identifying places of refuge, and defining oil spill response needs, as well as to researchers examining environmental and human impacts on marine mammals, Arctic bird species, and significant ecological and cultural sites. The objective of this study was to establish the first comprehensive, longitudinal picture of the variability of maritime traffic in Arctic Canada for the 26-year period from 1990 to 2015. The variables examined are 1) overall activity, 2) vessel type, 3) regional spatial distribution, and 4) proximity to communities.

METHODS

The study area for this research is Canadian Arctic waters as defined by the Northern Canada Vessel Traffic Services (NORDREG) Zone, which includes two of Canada’s major northern shipping routes (the Northwest Passage and the Arctic Bridge), as well as the more recently established low-impact shipping corridors (see the PEW Charitable Trusts, 2016; Porta et al., 2017). The Northwest Passage connects the Atlantic and Pacific Oceans via Baffin Bay in the Eastern Arctic and the Beaufort Sea in the Western Arctic through two distinct routes: the Northern route and the Southern route. The Northern (deep-water) route extends through Parry Channel and terminates in M’Clure Strait, whereas the Southern (shallow-water)

TABLE 1. Description of vessel types found in Arctic Canada and their associated uses.¹

Classification	Description	Examples of ship types
Government vessels and icebreakers	<ul style="list-style-type: none"> • Vessels designed to move and navigate in ice-covered waters • Vessels with a strengthened hull, an ice-clearing shape, and the power to push through ice 	<ul style="list-style-type: none"> • Coast Guard vessels • Icebreakers (private, research, government) • Research vessels
Container ships	<ul style="list-style-type: none"> • Cargo ships that carry their load in truck-size containers 	<ul style="list-style-type: none"> • Cargo transport vessels
General cargo ships	<ul style="list-style-type: none"> • Ships that carry various types and forms of cargo 	<ul style="list-style-type: none"> • Community resupply ships • Roll on/roll off cargo ships
Bulk carriers	<ul style="list-style-type: none"> • Ships that can carry either oil or loose or dry cargo in bulk (but not simultaneously) 	<ul style="list-style-type: none"> • Timber carriers • Oil, ore carriers • Automobile carriers
Tanker ships	<ul style="list-style-type: none"> • Ships designed for bulk carriage of liquids or compressed gas 	<ul style="list-style-type: none"> • Oil, natural gas, and chemical tankers
Passenger ships	<ul style="list-style-type: none"> • Ships that carry passengers for remuneration 	<ul style="list-style-type: none"> • Ocean liners • Ferries • Cruise ships
Pleasure craft	<ul style="list-style-type: none"> • Recreational vessels that do not carry paying passengers 	<ul style="list-style-type: none"> • Motor yachts • Sailboats • Rowboats
Tugboats and Barges	<ul style="list-style-type: none"> • Tugboats: small boats designed for towing, pushing, or general work duties • Barges: Large, flat, non-propelled vessels to carry bulk cargo or mixed cargo 	<ul style="list-style-type: none"> • Resupply vessels • Bulk cargo transport vessels
Fishing vessels	<ul style="list-style-type: none"> • Vessels used in commercial fishing activity and small vessels (30–100 m long) used for fishing 	<ul style="list-style-type: none"> • Trawlers • Whaling boats • Fish-processing boats
Oil and gas exploration vessels	<ul style="list-style-type: none"> • Vessels designed specifically for exploration and extraction of natural gas and oil 	<ul style="list-style-type: none"> • Seismic, oceanic, and hydrographic survey vessels • Oil drilling/storage vessels • Offshore resupply vessels • Portable oil platform vessels • Other oil and gas support vessels

¹ Sources: Pizzolato et al. (2014) and Dawson et al. (2017).

route extends from Baffin Bay to the Beaufort Sea via Lancaster Sound through eastern Parry Channel, then south along the eastern coast of Prince of Wales Island, and lastly westwards along the southern coasts of Victoria and Banks Islands into the Beaufort Sea. The Arctic Bridge connects Europe and Eurasia to the currently closed Port of Churchill, Manitoba, through Hudson Strait and into Hudson Bay (Fig. 1). Excluded from this study is the Mackenzie River, Northwest Territories, which was only recently included in the NORDREG zone and where availability of shipping data is inconsistent over time.

Our current understanding of the specific and statistically significant longer-term changes in shipping trends in Arctic Canada is limited. The most precise global sources of data on spatial ship traffic are satellite-based systems such as the Automatic Identification System (AIS), which records data in real time at a second or millisecond time scale (e.g., exactEarth, ORBCOMM, Spacequest, Spire, VesselFinder). However, for the Canadian Arctic, the use of AIS data to analyze longitudinal trends currently poses two major challenges: 1) data are captured only from ships with AIS transponders that are turned on, and, 2) data are available only for the period since 2010. Similar

challenges exist with other satellite-based systems such as Long Range Identification and Tracking (LRIT), which like AIS, is useful for real-time tracking of larger vessels that tend to carry transponders, but lacks utility for longitudinal research applications, such as analysis of long-term geographic trends for multiple vessel types. Because of the identified limitations of AIS and LRIT data, in this study we use a geospatial database of shipping activities that was recently developed specifically for the Canadian Arctic region (see Pizzolato et al., 2014, 2016; Dawson et al., 2017).

The longitudinal geospatial dataset of shipping activity used in this study is based on the Canadian Coast Guard ship archive data for the NORDREG Zone from 1990 to 2015. The NORDREG dataset contains daily reports since 2010 of vessel locations at 1600 UTC for vessels subject to mandatory reporting. These mandatory reporting requirements apply to vessels that weigh 300 gross tonnes or more, vessels that are engaged in towing or pushing another vessel if their combined gross tonnage is 500 gross tonnes or more, and vessels that are carrying a pollutant or dangerous good or towing another vessel that is carrying a pollutant or dangerous good (Minister of Justice, 2010). Vessel positions are also included for those ships that

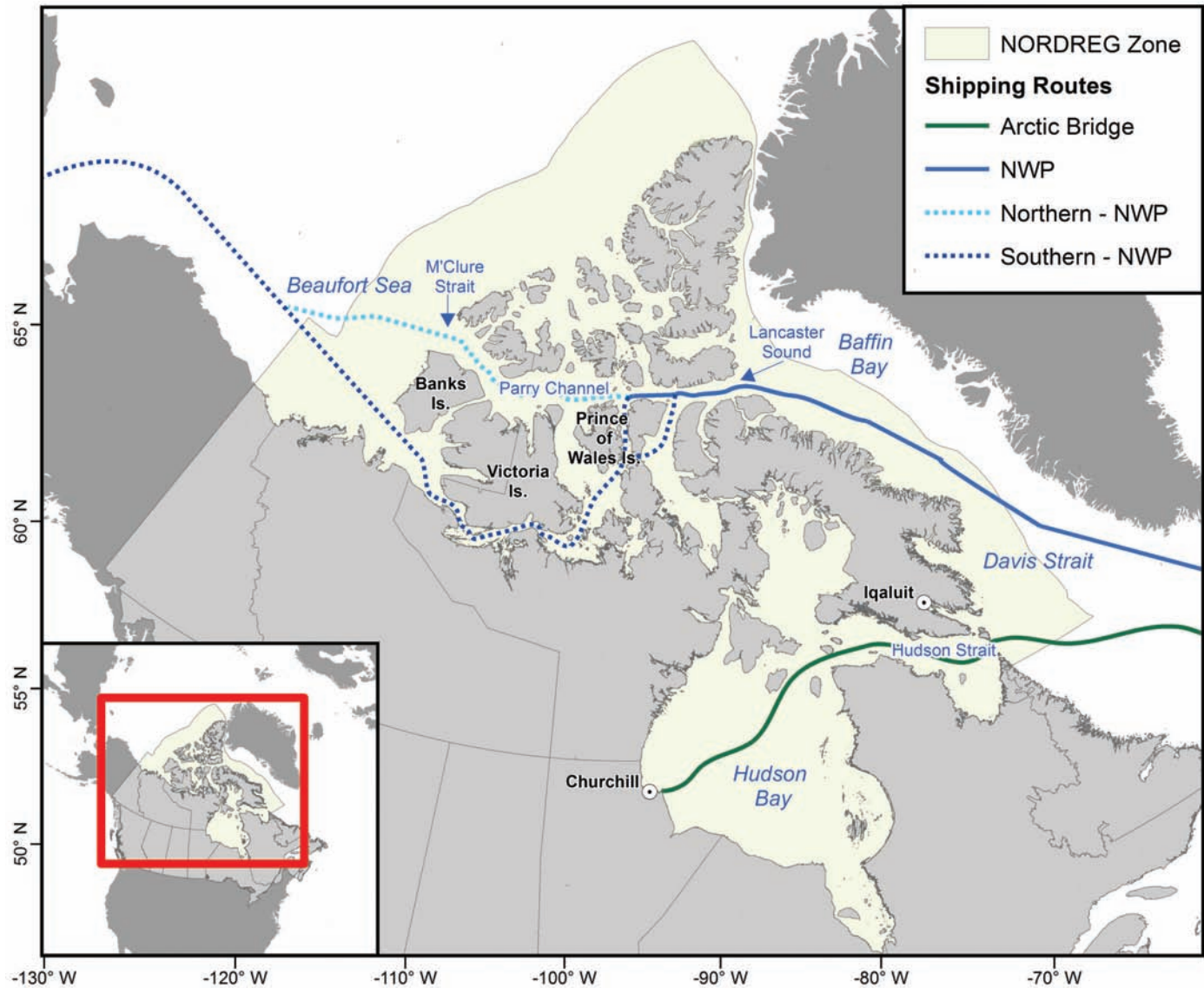


FIG. 1. Map of study area outlining major shipping routes: Northwest Passage Northern (N-NWP) and Southern (S-NWP), and Arctic Bridge (AB).

voluntarily report their locations within the NORDREG zone, mostly on a daily or sub-daily timescale. These positions were used to produce a geospatial database of reconstructed ship tracks in the Canadian Arctic from 1990 to 2015. A least cost path (LCP) approach, based on weighted cost surfaces of total sea ice concentration, bathymetry, and distance from land, was used to connect the points representing vessel positions. A complete description of the spatial dataset generation, including quality control and validation, is provided by Pizzolato et al. (2014, 2016).

The LCP-derived ship tracks from the longitudinal spatial database were extracted to the 25 km National Snow and Ice Data Center Equal-Area Scalable Earth Grid (EASE-Grid 2.0) by vessel type. We then calculated the length of each individual voyage segment (in km) within each 25 km × 25 km cell. A 25 km × 25 km grid over the entire Canadian Arctic domain provides a suitable

compromise between a comprehensive shipping activity inventory and the computational processing power that it takes to derive the ship tracks. Subsequently, the sum of all voyage segment lengths within each cell was calculated to provide a proxy for the amount of shipping activity that occurred within that cell each year. Using these gridded surfaces, we then produced maps comparing a baseline period (1990–2000) to three subsequent five-year periods (Phase 1: 2001–05, Phase 2: 2006–10, and Phase 3: 2011–15).

RESULTS

Temporal Trends

The total annual distance (km) traveled by all vessel types in Arctic Canada has almost tripled over the past 25

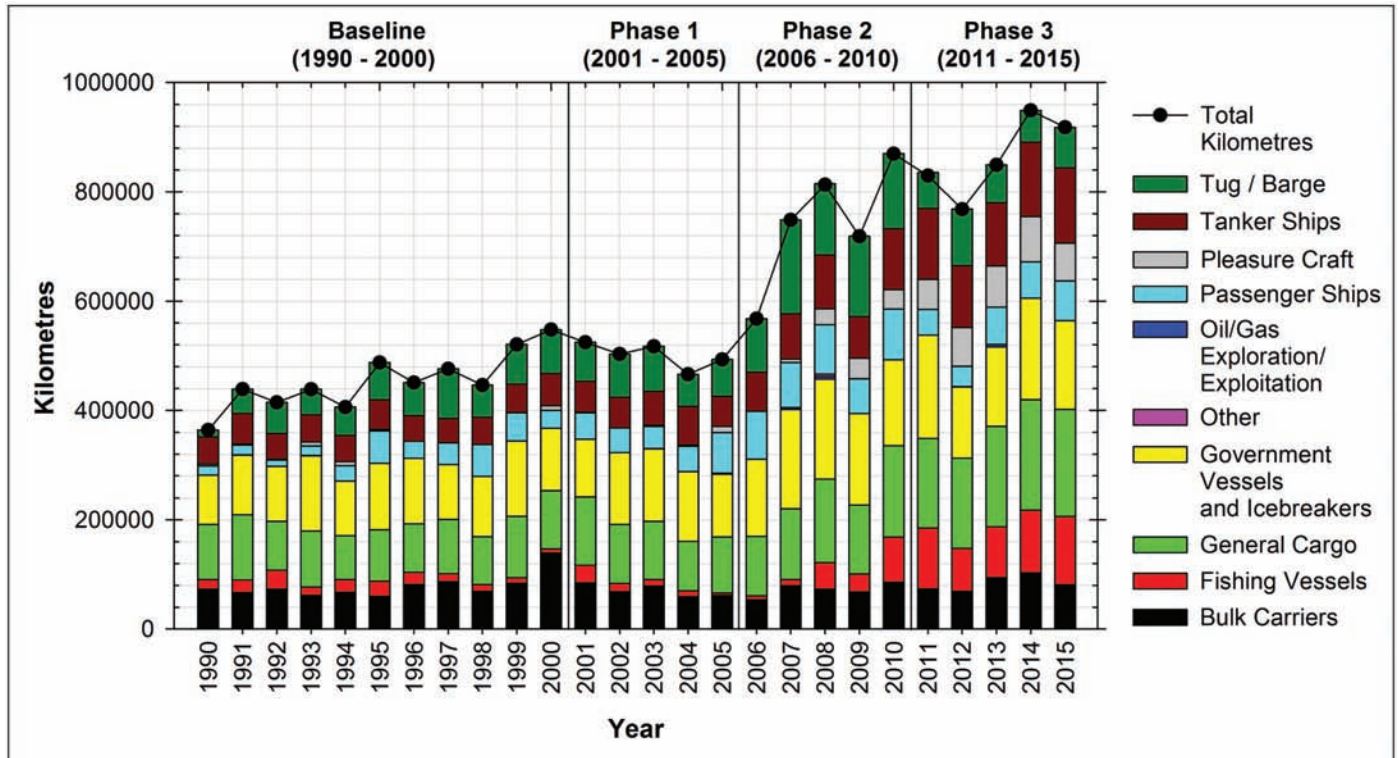


FIG. 2. Total kilometres traveled annually by all vessel types in the Canadian Arctic.

years, increasing from 364 179 km in 1990 to 918 266 km in 2015 (Fig. 2). The greatest distance in any single year within the record was traveled in 2014, when ships covered a record 948 871 km. Examination of the general trends across the study period (1990 to 2015) shows clearly that the baseline period (1990 to 2000) represents a relatively stable period with limited growth. Vessel traffic increased only slightly during this baseline period, but in general remained relatively steady: the annual distance traveled hovered between 364 179 km and 547 839 km, with an average of 453 898 km per year. Phase 1 (2001–05) was also a relatively stable period, with average annual kilometres traveled during this phase increasing only slightly from the baseline period, to a total average of 500 931 km (ranging from 466 101 km in 2004 to 524 766 km in 2001). Phase 2 (2006–10) was a period of rapid growth, in which the distance traveled by vessels in Canada's Arctic waters increased to an average of 743 548 km per year (ranging from 567 750 km in 2006 to 869 666 km in 2010). Phase 3 (2011–15) shows continued growth and development: traffic increased even more to an average of 862 881 km, which represents a 90% increase from the baseline period. Total kilometres traveled over the last five years of the record have consistently been the highest ever seen over the past quarter century. The record period exhibits interannual variability, but overall trends indicate a clear increase in shipping activity in Canadian Arctic waters that is consistent with the findings of other studies (Pizzolato et al., 2014, 2016; Eguiluz et al., 2016).

When considering the variability in shipping traffic by vessel type, it is clear that some vessel types are becoming more prevalent in the Canadian Arctic than others. Vessel type proportions of traffic based on kilometres traveled show significant differences from 1990 to 2015 (Fig. 2). In 1990, the largest proportion of vessels comprised general cargo ships (28%), government vessels and icebreakers (25%), bulk carriers (20%), and tanker ships (14%). Fishing and pleasure craft made up just 5% and 1%, respectively, of the total vessel traffic. By 2015, vessels in Arctic Canada included 21% general cargo ships, 18% government vessels and icebreakers, and 15% tankers. Fishing vessels represented 15% of total vessel distribution, and pleasure craft made up 8% (Fig. 2).

Comparison of the total kilometres traveled by each vessel type over the entire study period (1990 to 2015) indicates that general cargo (resupply) ships and government icebreakers (including research vessels) consistently travel the greatest distance each year (Fig. 2). From 1990 to 2006, general cargo vessels averaged just over 100 000 km annually, with limited variability. However, beginning in 2007 (notably a year of record low sea ice), general cargo activity began to increase. By 2010, the distance traveled annually by general cargo vessels increased to 167 165 km, and then to 202 260 km during the record highest year of 2014 (Fig. 2). Icebreaking and research activity have stayed relatively constant throughout the record, although some variability is observable, with a minor increase in average annual kilometres traveled in Phases 2 and 3. Tanker ships, fishing vessels, and pleasure craft (i.e., private yachts)

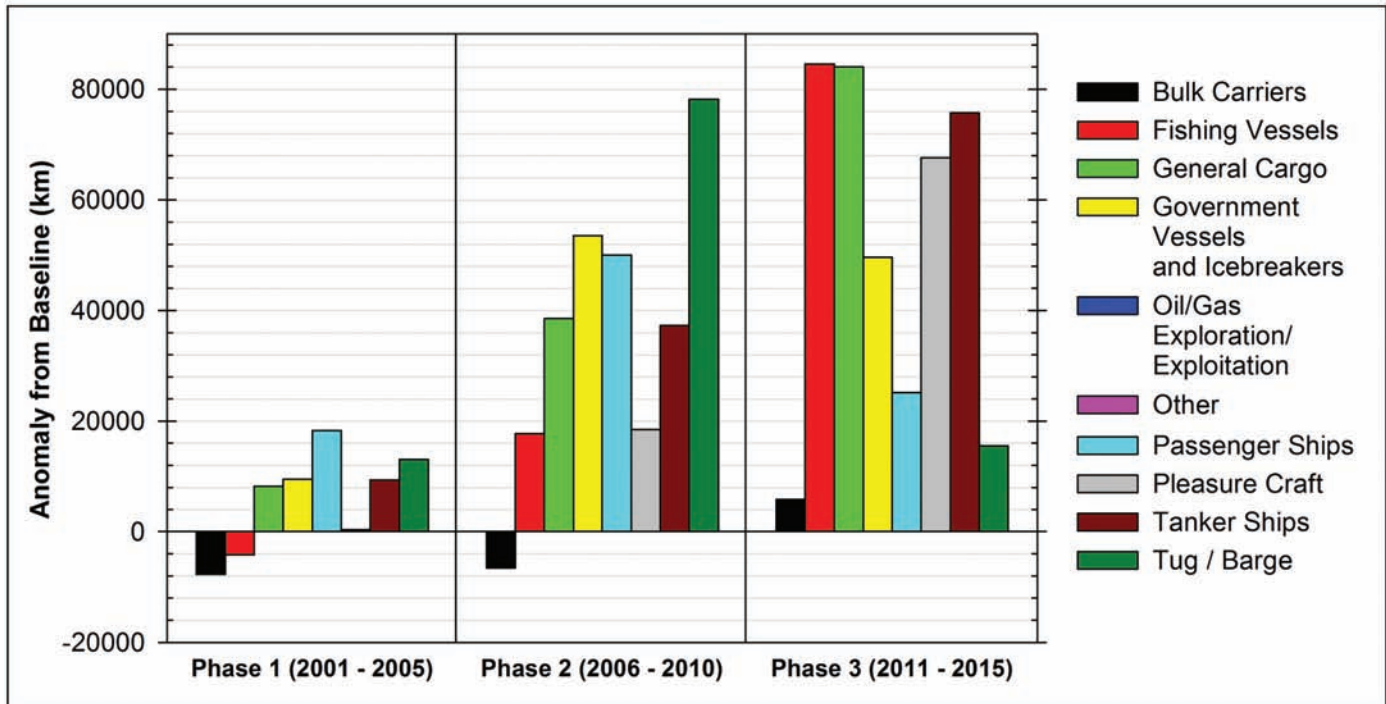


FIG. 3. Change in annual average kilometres traveled per year from baseline period (1990–2000) to Phase 1, Phase 2, and Phase 3 by vessel type.

notably increased their presence during Phases 2 and 3, while the slight decrease in passenger vessel activity in recent years is likely due to a known business merger and decommissioning of a regular vessel in 2013 (Fig. 2).

We also explored the change in average annual kilometres traveled by each vessel type during Phases 1 (2001–05), 2 (2006–10), and 3 (2011–15) compared to the baseline period (1990–2000) (Fig. 3). Bulk carrier activity decreased in Phases 1 (–10%) and 2 (–8%) but increased in Phase 3 (7%). Fishing vessel activity decreased in Phase 1 (–22%), increased in Phase 2 (93%), and then increased dramatically in Phase 3 (443%) relative to the baseline. This seemingly significant increase was likely due to recent investments made to support the local fisheries industry in the east Baffin region (CBC, 2013). Compared to the baselines, general cargo activity has steadily increased in all phases (by 8%, 39%, and 86%, respectively), while government vessels similarly increased (by 8%, 47%, and 44%, respectively). Passenger ship activity increased moderately in Phase 1 (55%) and more dramatically in Phase 2 (151%); in Phase 3, it declined slightly compared to Phase 2, but still was 76% higher compared to the baseline period. The Phase 3 slowdown in passenger ship growth was likely related to the 2010 decommissioning of the *MS Lyubov Orlova*, a vessel that had previously operated annually in the Canadian Arctic. The fastest growing sector of vessels in total kilometres traveled is pleasure craft, which increased slightly in Phase 1 (11%), more significantly in Phase 2 (625%), and then dramatically in Phase 3 (2288%). Tanker ship activity also increased from the baseline by 18%, 73%, and 149%, respectively, in the three five-year periods. Tug and barge activity increased by

22% in Phase 1, rose to 134% of the baseline in Phase 2 (likely because of the increased mining activity), and fell to 26% of baseline in Phase 3 (Fig. 3).

Figure 4 illustrates the spatial distribution of all vessel types during the baseline period and also calculates change from the baseline in total kilometres traveled for each of the three phases. In the 1990–2000 baseline period, vessel traffic was concentrated throughout Hudson Strait, with clear travel routes from the Strait to the east coast of mainland Nunavut and on to the Port of Churchill. High traffic intensity is also observed along the eastern coast of Baffin Island, through Lancaster Sound and into Queen Maud Gulf, with moderate intensity visible through Lancaster Sound to Resolute, as well as through Foxe Basin (Fig. 4A). In Phase 1 (2001–05), the decrease in total vessel traffic off the east coast of Baffin Island and to Resolute was likely related to a decrease in tankers and bulk carriers because of the closures of the Polaris (Cornwallis Island, near Resolute) and Nanisivik (Baffin Island, near Arctic Bay) mines in 2002. There was also a slight increase in traffic through Hudson Strait (Fig. 4B), which could be associated with the early stages of the Baffinlands Mary River mine project.

Compared to the baseline period, Phase 2 (2006–10) shows an even more dramatic intensification of traffic through Hudson Strait, with clear travel routes to communities in Ungava Bay and along the east coast of mainland Nunavut (Fig. 4C). There was also a clear increase in traffic through the southern route of the Northwest Passage and around the west coast of Prince of Wales Island that had not occurred earlier in the period of record, as well as a rebound of coastal traffic along the

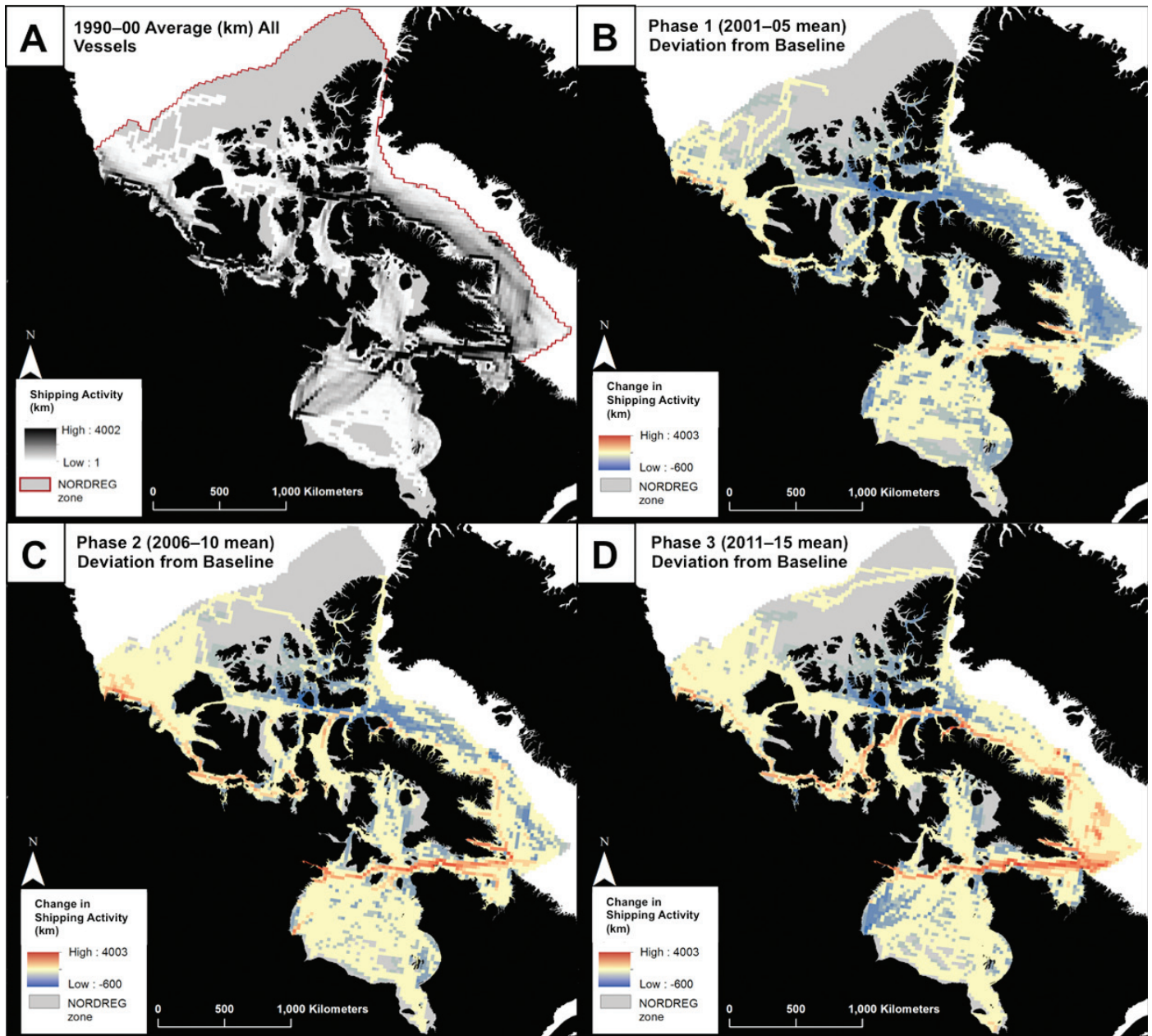


FIG. 4. (A) Annual kilometres traveled by all vessel types (Baseline: 1990–2000); (B) Phase 1 (2001–05 mean) deviations from baseline; (C) Phase 2 (2006–10 mean) deviations from baseline; and (D) Phase 3 (2011–15 mean) deviations from baseline.

eastern coast of Baffin Island. At the same time, further declines in traffic were observed in and around Baffin Bay and also around Resolute and Nanisivik (Fig. 4C).

Relative to the baseline period, vessel traffic in Phase 3 (2011–15), displayed a significant intensification through Hudson Strait towards Baker Lake that was possibly due to increasing traffic associated with the opening of the Meadowbank Gold mine north of Baker Lake in 2010 (Fig. 4D). There was also an increase in traffic along the eastern coast of Baffin Island, greater than that seen in Phase 2. Finally, there continues to be a clear increase in traffic through the southern route of the Northwest Passage that is attributable to overall traffic but also to increases in tourism activity (i.e., passenger vessels and pleasure craft) (Fig. 4D).

Spatial Patterns

There are marked variations in spatial distribution by vessel type. The most concentrated vessel type is fishing vessels, which are currently restricted almost entirely to southeastern Baffin Island (Fig. 5). This pattern likely reflects the commercial fisheries present in locations such as Iqaluit and Pangnirtung, combined with the fact that most fishing vessels are not ice-strengthened, which restricts their activities to waters with the lowest sea ice concentrations. Fishing activity was higher during the baseline period, with a distribution similar to the present one, compared to Phases 1 and 2, when fishing activity was low and highly concentrated along the southeast coast of

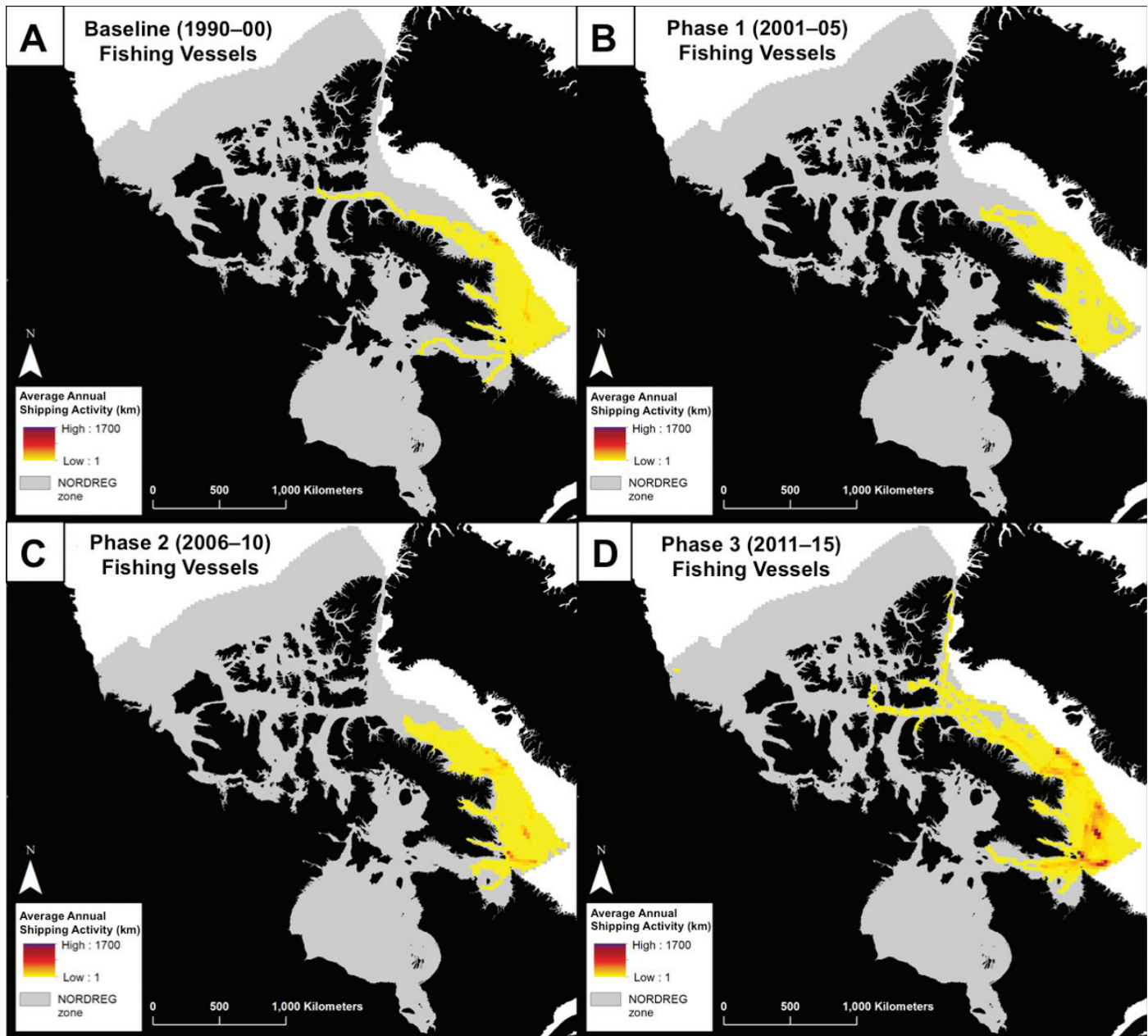


FIG. 5. (A) Annual kilometres traveled by fishing vessels (Baseline: 1990–2000 mean); (B) Phase 1 (2001–05 mean); (C) Phase 2 (2006–10 mean); and (D) Phase 3 (2011–15 mean).

Baffin Bay. Fishing is now taking place farther north than ever before and expanding into Lancaster Sound and as far west as Resolute and Little Cornwallis Island. Fishing vessel traffic has also been notably more intense in recent years in the eastern part of Hudson Strait and the southern area of Baffin Island.

Bulk carriers are also limited spatially, and are found primarily along the Arctic Bridge route to Churchill and to the mines along the southern edge of Hudson Strait (e.g., Deception Bay). There have only been two transits of the Northwest Passage (southern route) by a bulk carrier, which occurred in 2013 (*Nordic Orion*) and in 2014 (*MV Nunavik*). Considering their supportive role in moving cargo, tugs and barges are also limited to more southerly areas, particularly

around Hudson Strait and James Bay, as well as the region around the head of the Mackenzie River.

Most other vessel types are found throughout the Canadian Arctic, albeit with the strongest concentrations in more southerly waters. For example, the patterns for general cargo and tanker ships are very similar, being closely related to the locations of communities and reflecting their annual resupply routes. The vessel type with the greatest spatial variability is government vessels and icebreakers, which were found throughout the study area, including areas such as the northern Northwest Passage where few to no other ship types are found because of the severe sea ice conditions present there.

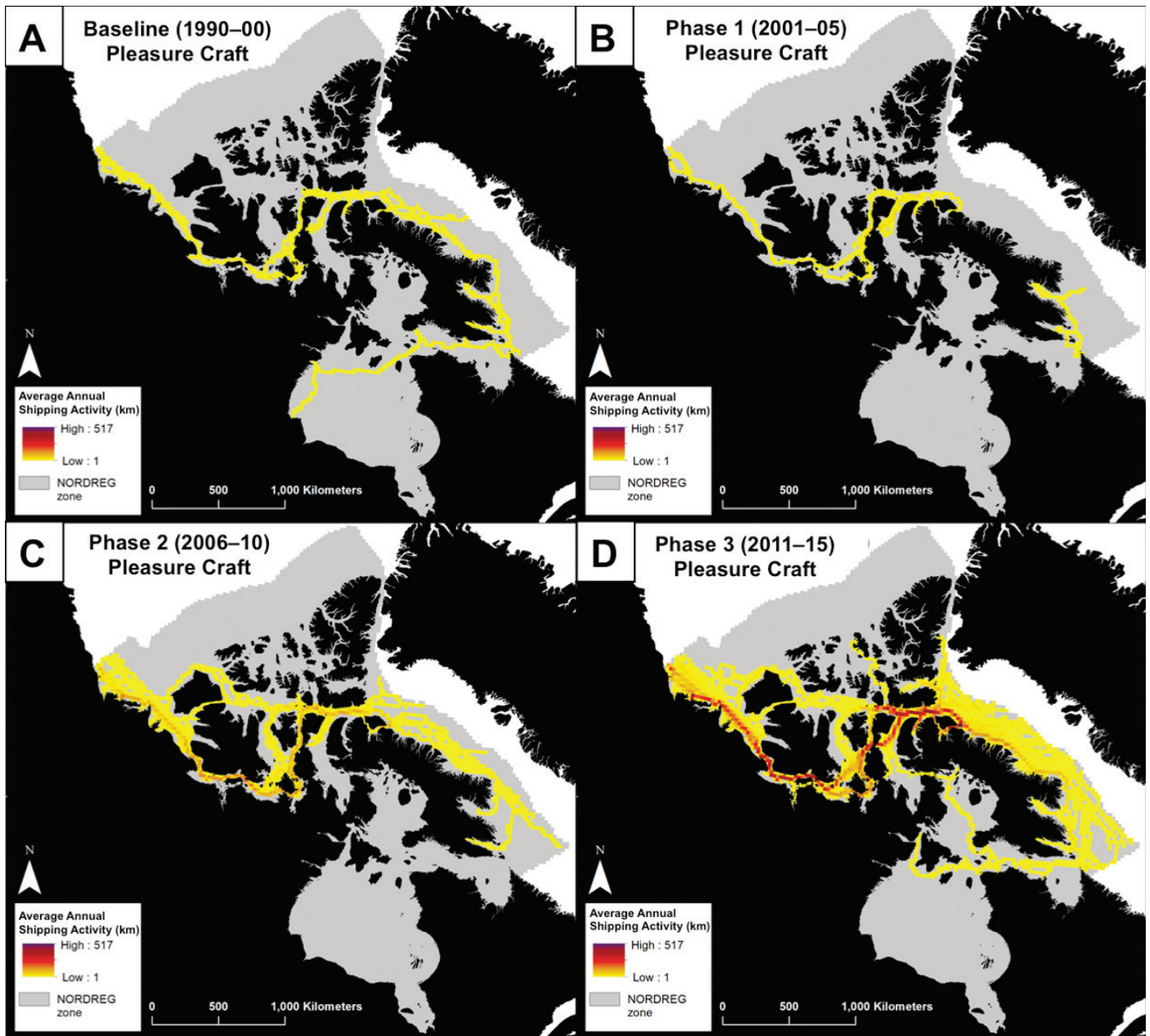


FIG. 6. (A) Annual kilometres traveled by pleasure craft (Baseline: 1990–2000 mean); (B) Phase 1 (2001–05 mean); (C) Phase 2 (2006–10 mean); and (D) Phase 3 (2011–15 mean).

Passenger ships and pleasure craft are unique in displaying little activity in Hudson Strait and Hudson Bay and much more activity in more northerly areas, such as along the eastern side of Baffin Island and the southern route of the Northwest Passage. This reflects the preferred destinations for expedition tourism and, for some, the prime locations for spotting wildlife (Dawson et al., 2014, 2016). Pleasure craft, in particular, is the vessel category that has changed the most dramatically in terms of kilometres traveled and spatial distribution and is by far the fastest growing vessel type currently operating in the region (Fig. 6). During the baseline period, the annual average distance traveled by pleasure craft was just 2590 km. This figure rose to 2836 km in Phase 1, then increased five-fold to 13 580 km by Phase 2 and reached

a record 52 799 km in Phase 3. Pleasure craft are now highly concentrated throughout the Northwest Passage, in both the northern and southern routes (but with higher intensities in the south). They are also venturing farther north than ever before, and are forging new and unique routes along the western side of Baffin Island.

Local residents living in Canadian Arctic communities have expressed increased concern about the potential impacts of observed increases in shipping activity throughout the region (Stewart et al., 2011, 2013, 2015; PEW Charitable Trusts, 2016; Carter et al., 2017). Until now, understanding the distribution of shipping traffic nearby communities has been challenging to obtain. To investigate the changes in ship traffic surrounding communities, we

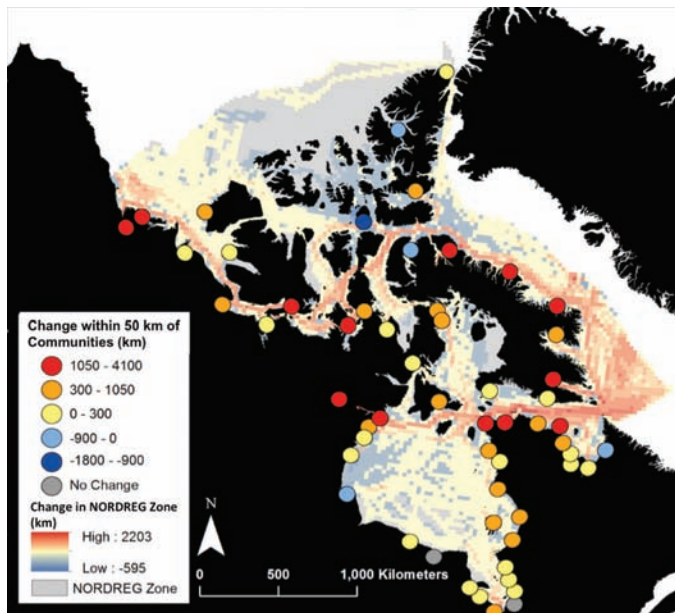


FIG. 7. Changes in vessel traffic (kilometres traveled per year) between the baseline period (1990–2000) and Phase 3 (2011–15). Red dots represent communities with the greatest increase in shipping traffic; orange dots, those with moderate increases; and yellow dots, those with low increases. Blue dots represent communities experiencing a decrease in vessel traffic.

compared shifts in vessel traffic from the baseline period (1990–2000) to Phase 3 (2011–15) within 50 km of each coastal community in Arctic Canada (Fig. 7).

The community of Pond Inlet experienced a near tripling of vessel traffic activity, representing the greatest increase in annual traffic of any Canadian Arctic community, from 2067 km per year in the baseline period to 6188 km per year in Phase 3). This increase around Pond Inlet is mainly attributable to increases in tourism vessels, bulk carriers, and tanker traffic related to the Mary River mine. Chesterfield Inlet and Baker Lake had the second- and fourth-highest increases in vessel traffic, which were also related to increases in tanker ships and general cargo ships servicing the Meadowbank Gold Mine. Cambridge Bay had the third-highest increase in vessel traffic (baseline 1286 km per year, compared to 5616 km per year in Phase 3), which can be explained by the increasing number of vessels transiting the Northwest Passage, including pleasure craft, passenger ships, general cargo ships, and tanker ships. Resolute Bay experienced a decline in ship traffic, which is likely related to the closure of the Polaris and Nanisivik Mines in 2002, but also to the tendency of sea ice to block shipping routes in the area (see Howell et al., 2009; Haas and Howell, 2015). Finally, reductions in ship traffic are expected in the Hudson Bay region because of the closure of the Port of Churchill in 2017.

CONCLUSION

Overall vessel traffic in the Canadian Arctic has increased markedly in the past decade, and total shipping

distance almost tripled from 1990 to 2015, with a steep increase in distance traveled over the period 2006 to 2008 (Fig. 2). Vessel types that particularly increased in terms of kilometres traveled include bulk carriers, passenger ships, government vessels, and pleasure craft (Figs. 2 and 3). The spatial distribution of vessels remains consistently focused on the more southerly and easterly parts of the region; however, passenger ships and pleasure craft are considerably more evident in more northerly areas including throughout the Northwest Passage (Fig. 6, also see online Appendix 1: Figs. S1 to S7). Government vessels show the greatest spatial variability and are found throughout the region. Most communities ($n = 49$) have experienced an increase in shipping since 1990, although the communities of Pond Inlet, Baker Lake, Cambridge Bay, and Chesterfield Inlet experienced the largest increases. Some communities, such as Churchill and Resolute, have experienced decreases in vessel activity, mostly related to the closure of mines and other resource-based activities.

This analysis confirms that shipping in the Canadian Arctic is evolving; ship patterns reflect the needs of communities and government agencies, the opportunities for resource extraction (including fishing) and tourism, the opportunities presented by changing environmental conditions, and in some cases, they also reflect regulatory mechanisms (see Dawson et al., 2014, 2017; Porta et al., 2017). While the Northwest Passage might never present the level of opportunity presented by the Northeast Passage for trans-Arctic shipping, the opportunities for improved access are being realized by particular vessel categories. In order to manage these changes in appropriate ways, by providing services and infrastructure, all levels of government require a good understanding of the patterns and trends based on evidence of historic temporal and spatial trends (Pizzolato et al., 2014, 2016; Eguiluz et al., 2016). This paper represents the first synthesized overview of the temporal and spatial evolution of ship traffic by vessel type in the Canadian Arctic from 1990 to 2016, providing valuable insight into marine transportation development across Arctic Canada. Not only will this analysis help in the broader description and explanation of changing shipping patterns in the Arctic, but it will also provide a stronger foundation for policy decisions and strategic infrastructure development in Arctic Canada.

APPENDIX 1

The following figures are available in a supplementary file to the online version of this article at:

<http://arctic.journalhosting.ucalgary.ca/arctic/index.php/arctic/rt/suppFiles/4698/0>

FIG. S1. Average annual distance (km) traveled by bulk carriers.

FIG. S2. Average annual distance (km) traveled by general cargo vessels.

FIG. S3. Average annual distance (km) traveled by government vessels and icebreakers (including research ships).

FIG. S4. Average annual distance (km) traveled by oil and gas exploration or exploitation vessels.

FIG. S5. Average annual distance (km) traveled by passenger ships.

FIG. S6. Average annual distance (km) traveled by tanker ships.

FIG. S7. Average annual distance (km) traveled by tugs and barges.

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