Climate Change Adaptation Assessment for Transportation in Arctic Waters (CATAW) Scoping Study

SUMMARY REPORT

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September 2013

Transport Canada | Transports Canada

Available at **www.espg.ca/projects/arctic-shipping/**
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SUMMARY REPORT

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Executive Summary

This scoping study report presents the preliminary analysis of: 1) changing shipping movements in the Canadian Arctic from 1990 to 2011 by total shipping volume and vessel type, and 2) the relationship between changing shipping patterns and sea ice reduction and variability.

- There has been a significant increase in shipping volume over the past decade. Overall vessel counts increased by 40% from 2006 to 2007 and by 20% from 2007 to 2011. Accounting for annual variability, total vessel volume[1] has increased by more than 75% over the past decade.
- The most dramatic increase in marine activity involves the rapidly evolving pleasure craft industry (e.g., small vessel recreational boating), which is expected to continue to increase in the near future. The traffic categories of passenger vessels, government vessels and icebreakers, and bulk carriers are also on the rise.
- The shipping season is getting longer. Combined monthly vessel count trends for all vessels show statistically significant increases in travel during the shoulder season months of June and November. The shipping season is beginning earlier for some vessel types (e.g., Fishing Vessels, Tanker Ships) and extending later into November for other vessel types (e.g., General Cargo).
- During the shipping season (June 25 to October 15) sea ice in the NORDREG zone experienced declines of total ice, multi-year ice and first year ice over the period 1990–2011 that are statistically significant. Decreasing multi-year ice combined with increased prevalence of younger and thinner first year ice can increase ease of navigation. The greatest reductions in multi-year ice occurred in September through November.
- Shipping activity has increased in a stepwise manner coincident with the 2007 extreme ice minima, which has persisted in all summers since.

1 Vessel volume is the sum of the number of unique ships based on vessel name in the NORDREG zone in a given year or month

Sommaire

Le rapport de la présente étude de délimitation présente l'analyse préliminaire : 1) des changements dans la navigation commerciale dans l'Arctique canadien de 1990 à 2011 par volume d'expédition total et par type de navires, et 2) de la relation entre l'évolution des tendances en matière de navigation et la réduction et la variabilité des glaces de mer.

- Au cours de la dernière décennie, le volume de transport maritime a considérablement augmenté. Dans l'ensemble, le décompte des navires a augmenté de 40 % de 2006 à 2007 et de 20 % de 2007 à 2011. En tenant compte de la variabilité annuelle, le volume total des navires a augmenté de plus de 75 % au cours de la dernière décennie.

- L'augmentation la plus marquée de l'activité maritime touche l'industrie de la navigation de plaisance en pleine évolution (p. ex., navigation de plaisance des petits navires), qui devrait continuer à augmenter dans un avenir proche. L'activité des navires de passagers, des navires du gouvernement, des brise-glaces et des vraquiers augmente aussi.

- La saison de transport maritime se prolonge. Les tendances combinées des décomptes mensuels des navires pour tous les navires démontrent une augmentation statistiquement significative dans les déplacements pendant les mois de la saison intermédiaire de juin et de novembre. La saison de navigation commence plus tôt pour certains types de navires (p. ex., bateaux de pêche, bateaux-citernes) et se prolonge plus tard en novembre pour d'autres types de navires (p. ex., marchandises générales).

- Pendant la saison de navigation (du 25 juin au 15 octobre), les glaces de mer dans la zone NORDREG ont connu une diminution de l'accumulation totale de la glace, de la glace pluriannuelle et de la glace de première année au cours de la période de 1990 à 2011 qui est statistiquement significative. La diminution de la glace pluriannuelle combinée à une présence accrue de la glace de première année plus mince peut faciliter la navigation. Les plus grandes diminutions de glace pluriannuelle ont lieu entre septembre et novembre.

- Les activités de navigation ont augmenté graduellement et ont coïncidé avec les niveaux extrêmement bas de la glace de mer de 2007, qui ont subsisté lors de tous les étés depuis.

1 Le volume des navires est la somme du nombre de navires uniques selon le nom du navire dans la zone NORDREG au cours d'une année ou d'un mois donné.

1. Introduction

Sea ice in the Arctic is currently experiencing a decline in all months of the year (Serreze et al., 2007; Tivy et al., 2011; Comiso, 2012). This widespread decline has attracted considerable attention with respect to the possibility of an extended and less hazardous shipping season in Arctic waters (Stephenson et al., 2011). However, to date there has been little quantitative analysis of Arctic shipping trends, and no validated connections have been made between shipping activity and regional variability in changing Arctic sea ice cover. The main objectives of this scoping study are therefore to:

1) Examine changing patterns of shipping in the Canadian Arctic NORDREG zone from 1990 to 2011, by total shipping activity and vessel type;

2) Determine whether variability and trends in sea ice conditions within the NORDREG zone are related to any temporal changes in shipping activity.

The Canadian Arctic is of particular importance for understanding changes in shipping patterns due to the presence of the Northwest Passage and the Arctic Bridge shipping routes that could significantly shorten transport times between Asia and Europe. The completion of this scoping study provides a basis for the larger CATAW proposal, which seeks to extend preliminary analysis of shipping patterns in Arctic Canada by more closely examining spatial trends in shipping patterns and their relationships to changing sea ice conditions, possible future shipping and sea ice trends through the consideration of climate model projections, and by identifying optimal policy options to deal with changing conditions in Arctic shipping.

2. Data Description

2.1 Vessel (NORDREG) Dataset

The study area for this project has been bound to the Vessel Traffic Reporting Arctic Canada Traffic Zone (NORDREG zone), as outlined by the Department of Fisheries and Oceans Canada (Figure 1). Within this zone, an extensive record of Arctic marine transportation activities was acquired for 1990 to 2011 across all months of the year. The dataset includes position data upon entry and exit of the NORDREG zone, daily position at 1600 Coordinated Universal Time (UTC), in addition to vessel name, call sign, International Maritime Organization (IMO) number, and flag state (DFO, 2010). Vessel types were re-classified from the original 36 NORDREG classifications into 10 categories based on their purpose, and unique environmental threats posed to the surrounding marine environment as outlined by the Arctic Marine Shipping Assessment (AMSA, 2009) (Table 1). After extensive quality control of the dataset, 73062

reporting records were used in the analysis after the removal of records with insufficient date and spatial information. Additionally, the "Other" and "Oil and Gas Exploration/Exploitation" categories were not analyzed for specific vessel classification as they represented only 1 and 12 vessels respectively, but were included in the general monthly and annual vessel counts, leaving a total of 2113 vessels used over the 1990 to 2011 time period. The vessel counts reported are the unique counts of a vessel either monthly or annual based on the name of the vessel. For example, if a ship enters and exits the NORDREG zone multiple times in the same month, it will be counted as one vessel in that month.

Figure 1

Map of the NORDREG zone marine area boundary (CCG, 2012)

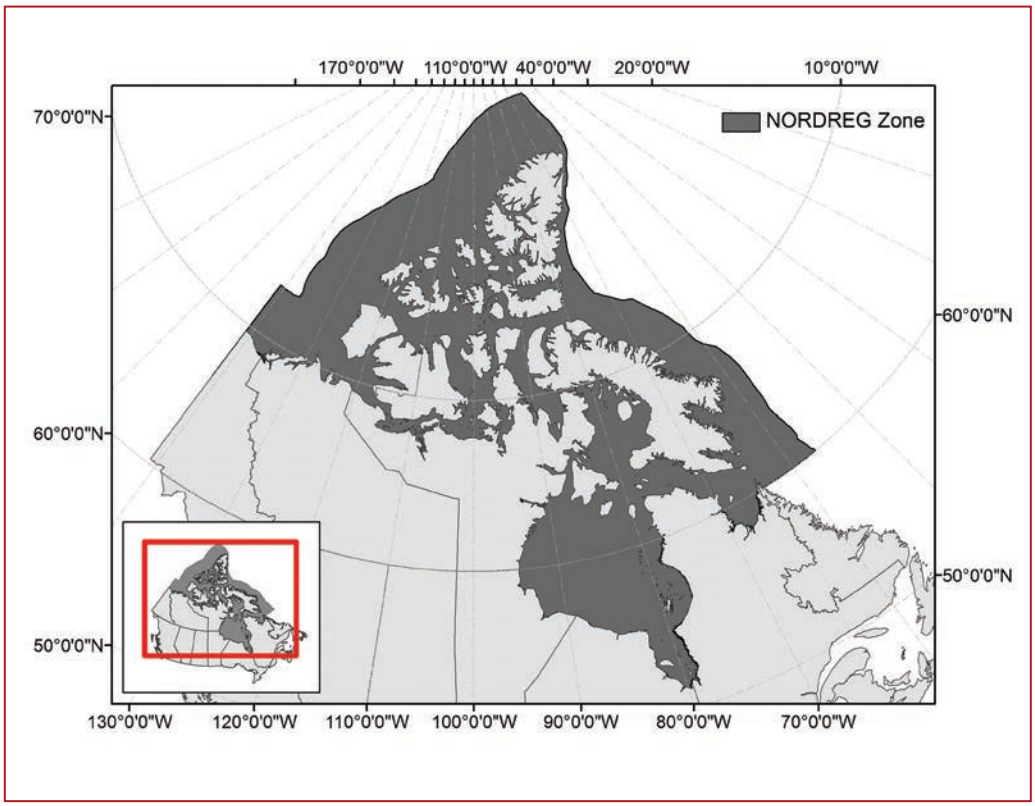


Table 1

NORDREG Vessel Type Classification grouped into 10 Categories outlined by AMSA (2009)

Category	Original Classification in NORDREG Dataset
Bulk Carriers	Bulk Carrier, Grain Ship (Churchill)
Fishing Vessels	Fishing Vessels
General Cargo	General Cargo, Heavy Lift Ship, Heavy Load Vessel, Heavy Load Carrier Ship
Government Vessels and Icebreakers	CCG Icebreaker, Icebreaker, USCG(C) Icebreaker, USCG Cutter, CCG Vessel, Fisheries Patrol Vessel, CCG Navaids, SAR Vessel, Navy Ship, Fisheries Research Vessel
Oil/Gas Exploration/ Exploitation	Drill Ship, Drill Rig, Oceanographic Research Vessel, Seismic Research Vessel
Passenger Ships	Passenger Ships
Pleasure Crafts	Pleasure Craft, Sail/Row Boat, Row Boat, Pleasure Crafts, Home Made Boat
Tanker Ships	Chemical Tanker, Tanker
Tugs/Barges	Tug, Tug/Supply, Tug/Icebreaker, Self-Powered Barge, Powered Barge
Other	Cable Ship

On July 1, 2010, a change in NORDREG regulations required mandatory reporting for the following ships when they transit through the NORDREG zone (DFO, 2010): (a) vessels of 300 gross tonnage or more; (b) vessels engaged in towing or pushing another vessel if the combined gross tonnage is 500 or more; (c) vessels carrying, towing, or pushing a vessel carrying cargo that is a pollutant or dangerous good. Prior to 2010, the NORDREG reporting system was voluntary. However, Transport Canada and the Canadian Coast Guard estimated that 98% of ships participated in the NORDREG system voluntarily because of the advantages of services received from Canada for their compliance, such as icebreaking assistance, search and rescue, and ice information (Rompkey & Cochrane, 2008).

2.2 Sea Ice Dataset

The sea ice area data used in the analysis was acquired from the Canadian Ice Service Digital Archive (CISDA) that covers the entire NORDREG zone. This dataset contains weekly regional ice charts derived from surface observations and aerial and satellite reconnaissance for all months of the year extending from 1968 to present (CIS, 2007). The mean ice area derived for the shipping season uses weekly regional ice charts between June 25 and October 15 following Tivy et al. (2011). Sea ice area was investigated monthly, annually, and over the June 25 to October 15 shipping season using three different ice variables: total ice area, multi-year ice area (MYI), and first-year ice area (FYI), because each poses unique challenges to Arctic transportation activities (AMSA, 2009).

3. Methods

To assess the potential impact of the federal policy change that requires certain sized vessels to mandatorily report to NORDREG (see section 2.1), on the dataset of vessel volume that the policy change from voluntary to mandatory vessel reporting had, the Rodionov statistical regime shift detector was applied to the vessel report time series (Rodionov, 2004). The regime shift detector detects shifts of different time scales and magnitudes, and thus is able to identify the years in which a regime shift in the vessel report time series occurred (Rodionov, 2004).

Both the NORDREG shipping dataset and CISDA sea ice dataset did not meet the assumptions of statistical normality required for parametric linear trend analysis, which is used to determine relationships between variables such as shipping volume and sea ice variability. Therefore, trend analysis in this study was performed on the CISDA sea ice area and NORDREG shipping dataset using a non-parametric approach that removes the serial correlation, accounts for the non-normality exhibited by the datasets, and reduces the impact of extreme values and outliers in the time series. The Zhang method and the Theil-Sen approach were used to compute Sen's slope of the trend (Zhang et al., 2000).

Kendall's Tau correlation was then calculated for relationships between sea ice and vessel traffic in the NORDREG zone on monthly, annually, and shipping season timescales. The two-tailed T-test provided the significance of the correlations at both the 95% and 99% confidence intervals. Both the sea ice and NORDREG datasets were detrended prior to performing correlation analysis to ensure that any significant relationships were not due to a shared trend, but were driven by actual relationships between variability in the sea ice and marine vessel time series.

4. Results

4.1 Shipping Trends and Variability

The record of Arctic marine transportation activities over the last 22 years in the NORDREG zone shows a mild decline in total volume between 1992 and 1996, relative stability between 1998 and 2000, and a rapid increase since 2007 (Figure 2). Unprecedented increases in vessel counts annually were observed for 2010 and 2011 (Figure 2). Annual vessel count trends increased for many vessel classes (e.g. Pleasure Crafts, and Government Vessels/ Icebreakers) increasing at a rate of 6 and 8 vessels per decade respectively (Table 2).

Figure 2

Total vessel counts in the NORDREG zone annually, 1990–2011

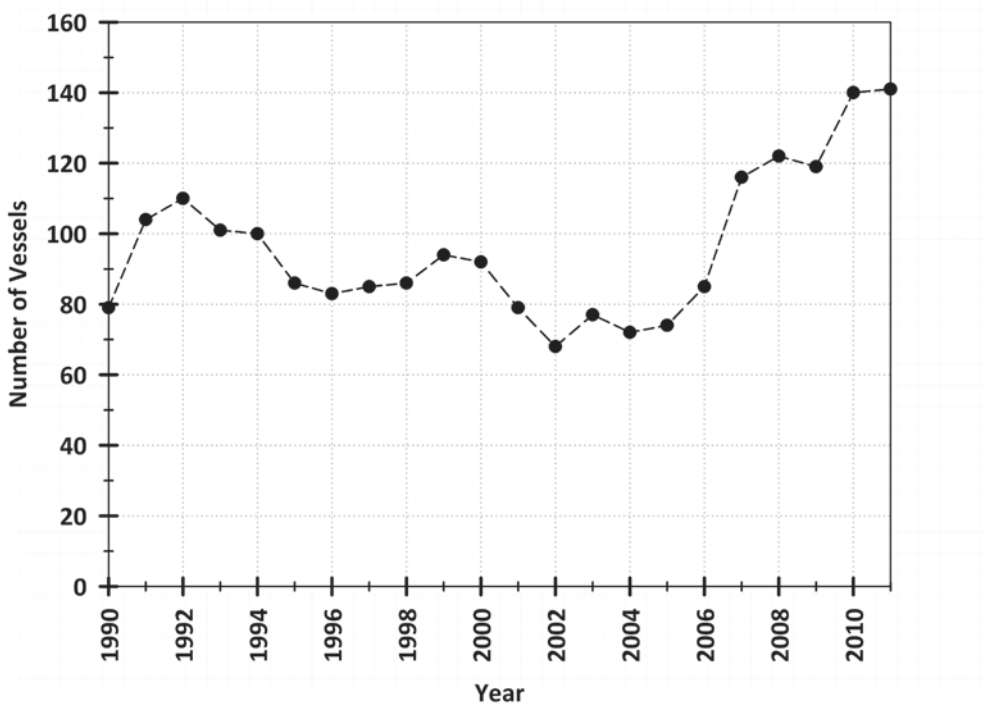


Table 2

Sen's slope decadal trends categorized by vessel types for vessel counts in the NORDREG zone, 1990 to 2011[a]

Vessel Type	Trend (Vessels Decade^{-1})
All Vessels	38
Bulk Carriers	**3**
Fishing Vessels	-3
General Cargo	1
Government Vessels and Icebreakers	**8**
Passenger Ships	**3**
Pleasure Crafts	**6**
Tanker Ships	5
Tug/Barge	3

a Bold values are significant at the 95% confidence level or higher

On a monthly basis, vessel trends since 1990 remained unchanged for all vessel types in January through May (Table 3). However, in the months of June through December, statistically significant increases occurred in almost all categories, ranging between 1 vessel per decade for ships such as Government Vessels and Icebreakers to as high as 6 vessels per decade in October for Tug/Barge (Table 3). Combined monthly vessel count trends for all vessels showed statistically significant increases of 7 vessels per decade in June, and 13 vessels per decade in November, indicating that the length of shipping season may be increasing (Table 3).

Annually, for all vessel counts and for all vessel types, there is a regime shift in the vessel count time series in 2007, which coincides with what, at the time, was a record low September ice minimum (Stroeve et al., 2008). The magnitude of the regime shift in 2007 provides evidence that the change in mandatory vessel reporting in 2010 did not artificially influence the time series trends in the dataset: if the changes in reporting resulted in a large increase in the number of vessels, we would have

seen the bulk of regime shifts occurring in 2010 or 2011, which is not the case (Figure 3). As noted earlier, this finding reinforces estimates made by Transport Canada and the Canadian Coast Guard that nearly all vessels notified the government of their presence when entering Canadian Arctic waters even before reporting was made mandatory (Rompkey and Cochrane, 2008).

Table 3

Sen's slope decadal trends for monthly vessel transits organized by vessel type in the NORDREG zone, 1990 to 2011[a b]

Vessel Type	Trend (Vessels Month $^{-1}$)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
All Vessel Types	-	-	-	-	0	**7**	**17**	26	28	17	**13**	1
Bulk Carriers	-	-	-	-	-	0	-1	0	0	2	1	0
Fishing Vessels	-	-	-	-	0	**4**	1	23	1	-2	6	0
General Cargo	-	-	-	-	-	0	1	0	1	**2**	**3**	-
Government Vessels and Icebreakers	-	-	-	-	-	**1**	**2**	2	**3**	**3**	1	0
Passenger Ships	-	-	-	-	-	-	**2**	**3**	**3**	0	-	-
Pleasure Crafts	-	-	-	-	-	-	**1**	**5**	**3**	0	-	-
Tug/Barge	-	-	-	-	-	0	**4**	2	2	**6**	**1**	-
Tanker Ships	-	-	-	-	-	**2**	**2**	4	7	1	**1**	0

a Bold values are significant at the 95% confidence level or higher
b No trend detected is denoted by "-"

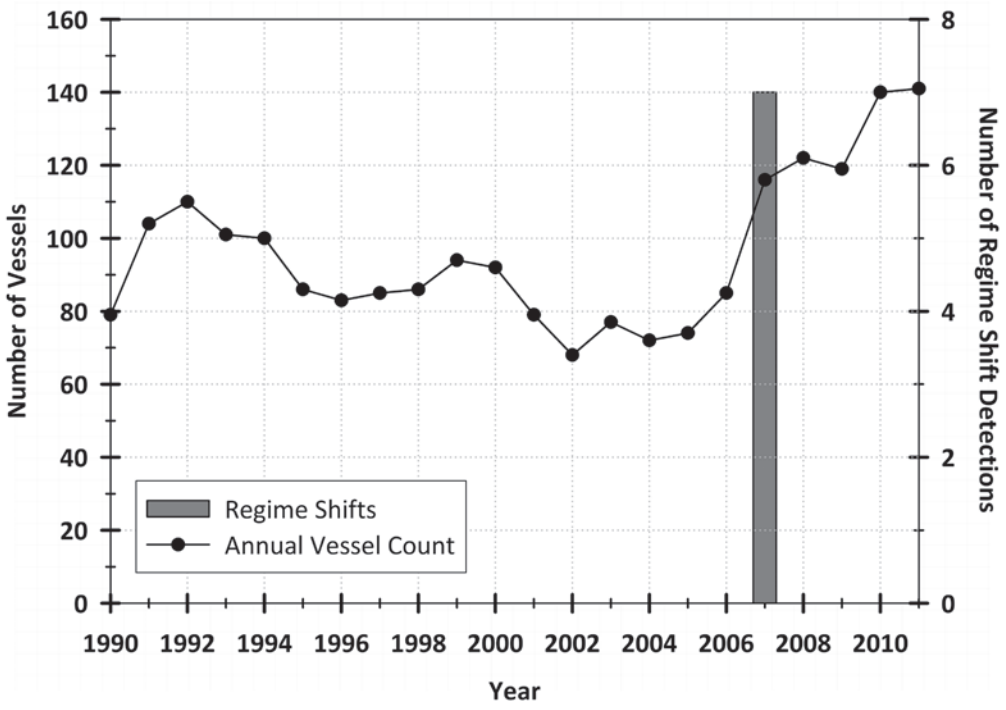


Figure 3

The number of regime shifts detected for annual vessel counts of the NORDREG dataset spanning from 1990–2011. The regime shift detection uses a Huber's weight of 2, at a minimum of 95% confidence level with regime cut-off lengths of 4, 6, 8, 10, 12 and 16 to capture regime shifts of different time scales and magnitudes.

4.2 Sea Ice Trends and Variability

Over the shipping season (June 25 to October 15), sea ice within the NORDREG zone from 1990–2011 experienced statistically significant declines of total ice, MYI, and FYI area at 26.3x103 km^2 per year, 18.5x103 km^2 per year and 10.7x103 km^2 per year, respectively (Table 5; Figure 4). The largest significant trends occur in July to November for total ice area (Table 4). Mean monthly MYI area cover in the NORDREG zone declined in all months of the year with the greatest reductions in August through December, with losses exceeding 15x103 km^2 per year (Table 4). This is an important result for shipping activities, as MYI represents the most hazardous ice type for vessels. Decreasing MYI and increasing FYI within the NORDREG zone underscores a pan-Arctic trend of thicker MYI being replaced by younger, thinner FYI (Stroeve et al., 2011), which can facilitate ease of navigation.

Table 4

Sen's slope trends, ice area km^2 $year^{-1}$, for mean monthly ice area within the NORDREG zone, 1990–2011[a]

Month	Trend Ice Area (x 10^3 km^2 $year^{-1}$)		
	Total Ice	MYI	FYI
January	**-9.1**	**-13.4**	1.8
February	**-8.3**	**-12.7**	-2.0
March	**-5.3**	**-13.6**	3.6
April	-3.2	**-13.8**	3.4
May	**-9.0**	**-11.7**	1.4
June	**-18.8**	-8.5	-5.0
July	**-31.5**	**-14.3**	**-18.8**
August	**-27.5**	**-17.0**	**-11.0**
September	**-22.6**	**-18.3**	**-5.2**
October	**-25.2**	**-20.8**	-2.8
November	**-23.9**	**-17.0**	-9.2
December	**-18.2**	**-16.2**	-10.2

a Bold values are significant at the 95% confidence level or higher

Table 5

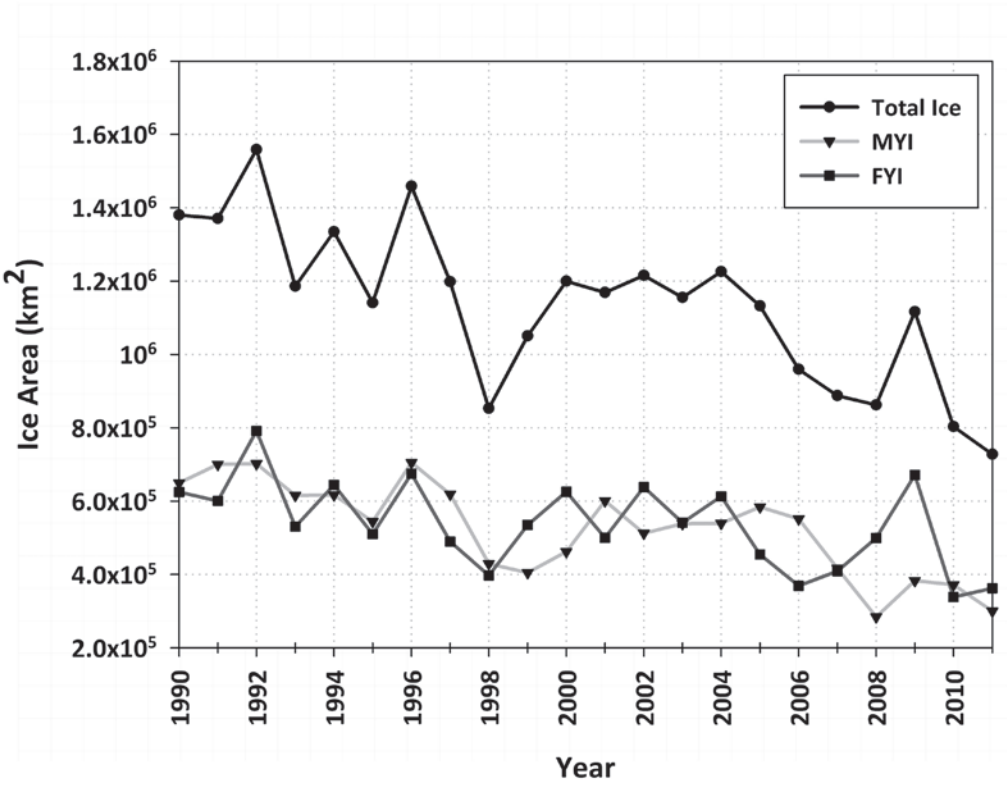
Sen's slope trends, ice area km^2 year $^{-1}$, for mean shipping season ice area (June 25 to October 15) within the NORDREG zone, 1990– 2011[a]

Ice Variable	Trend Ice Area (x 10^3 km^2 year $^{-1}$)
Mean Total Ice	**-26.3**
Mean MYI	**-18.5**
Mean FYI	**-10.7**

a Bold values are significant at the 95% confidence level or higher

Figure 4

Time series of shipping season (June 25 to October 15) mean total ice, multi-year ice (MYI), and first-year ice (FYI) area (km^2) for the NORDREG zone, 1990–2011.



4.3 Connection between Shipping and Sea Ice

Correlation analysis between sea ice and shipping activities was performed on monthly and shipping season data. On the shipping season timescale, this analysis indicated that total ice, MYI, and FYI area was only significantly correlated to annual vessel counts for Government Vessels and Icebreakers, Passenger Ships, and Pleasure Crafts (Table 6). On the monthly timescale, total ice, MYI, and FYI exhibited significant relationships to vessel type counts mostly through the traditional shipping season in the months of July through September (Table 7). The lack of significant correlations between decreasing sea ice and increased shipping activities during the shipping season is expected because shipping activities for the upcoming years are likely planned outside of the shipping season. Based on this interpretation of the correlation analysis, time lagged relationships between sea ice conditions and shipping activity should be explored.

Table 6

Kendall's Tau correlations for mean total, multi-year ice, and first-year ice in the shipping season, June 25 to October 15, to annual vessel counts for 9 different vessel type categories within the NORDREG zone, 1990–2011[a]

Vessel Type	Ice Area (km^2 $year^{-1}$)		
	Total Ice	MYI	FYI
Bulk Carriers	-0.01	-0.10	0.08
Fishing Vessels	-0.15	-0.13	-0.04
General Cargo	-0.21	**-0.37**	-0.07
Government Vessels and Icebreakers	**-0.33**	**-0.33**	-0.16
Passenger Ships	**-0.43**	**-0.41**	-0.26
Pleasure Crafts	-0.03	-0.10	0.08
Tanker Ships	-0.17	-0.17	0.01
Tug/Barge	-0.20	-0.12	-0.11
All Vessel Types	-0.28	-0.26	-0.10

a Bold values are significant at the 95% confidence level or higher

Table 7

Kendall's Tau correlations for CISDA monthly mean total, multi-year ice, and first-year ice, to monthly vessel counts for 11 vessel type categories within the NORDREG zone, 1990-2011[a]

Area (km^2 $year^{-1}$)	Vessel Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Ice	All Vessel Types	-0.22	-0.06	0.13	-	-0.15	-0.08	-0.22	-0.19	-0.13	-0.02	-0.01	-0.24
	Bulk Carriers	-0.21	-0.06	0.13	-	-0.06	0.18	-0.03	-0.06	0.03	0.30	**-0.40**	-0.01
	Fishing Vessels	-0.22	-0.06	-	-	-0.11	-0.20	-0.19	-0.21	0.00	-0.04	0.04	-0.20
	General Cargo	-	-	-	-	-	0.02	-0.12	**-0.33**	-0.29	-0.16	0.10	-
Total Ice	Government Vessels and Icebreakers	-	-	-	-	-0.03	-0.11	0.17	-0.13	-0.28	-0.20	-0.11	0.01
	Passenger Ships	-	-	-	-	-	-	-0.23	**-0.33**	-0.25	0.06	-0.09	-
	Pleasure Crafts	-	-	-	-	-	-	-0.08	-0.07	0.15	0.00	-0.12	-
	Tug/Barge	-	-	-	-	-	-0.03	-0.04	-0.04	0.00	-	0.16	-0.14
	Tanker Ships	-0.21	-0.06	0.13	-	0.00	0.26	-0.21	-0.01	-0.17	0.01	-0.18	-0.26
	All Vessel Types	-0.01	0.06	0.03	-	-0.07	-0.11	**-0.39**	**-0.43**	-0.18	-0.12	-0.30	-0.18
	Bulk Carriers	0.00	0.06	0.03	-	-0.02	0.08	-0.18	-0.27	0.00	0.19	-0.13	-0.16
	Fishing Vessels	-0.01	0.06	-	-	-0.05	-0.13	-0.13	**-0.33**	-0.01	0.06	-0.28	-0.13
	General Cargo	-	-	-	-	-	-0.21	-0.25	**-0.48**	**-0.33**	-0.26	-0.10	-
MYI	Government Vessels and Icebreakers	-	-	-	-	0.05	0.05	0.26	-0.17	**-0.41**	**-0.37**	-0.29	0.13
	Passenger Ships	-	-	-	-	-	-	-0.19	**-0.38**	-0.22	-0.16	-0.03	-
	Pleasure Crafts	-	-	-	-	-	-	**-0.35**	-0.21	0.07	0.22	0.00	-
	Tug/Barge	-	-	-	-	-	0.05	-0.29	-0.25	-0.06	-	0.00	0.00
	Tanker Ships	0.00	0.06	0.03	-	0.06	0.09	-0.27	-0.24	-0.19	-0.05	-0.29	-0.08
	All Vessel Types	**-0.35**	-0.17	-0.08	-	0.00	0.00	-0.13	-0.06	0.16	-0.19	0.18	-0.13
	Bulk Carriers	**-0.34**	-0.17	-0.08	-	-0.05	0.08	0.08	0.07	0.06	0.06	-0.02	0.13
	Fishing Vessels	**-0.35**	-0.17	-	-	0.01	-0.09	-0.16	-0.16	0.20	-0.21	0.19	-0.13
	General Cargo	-	-	-	-	-	0.19	-0.07	-0.19	0.11	-0.30	-0.02	-
FYI	Government Vessels and Icebreakers	-	-	-	-	0.04	-0.14	0.11	-0.15	0.03	-0.26	0.05	-0.12
	Passenger Ships	-	-	-	-	-	-	-0.13	-0.06	-0.25	-0.10	-0.02	-
	Pleasure Crafts	-	-	-	-	-	-	0.13	-0.11	0.26	-0.05	-0.05	-
	Tug/Barge	-	-	-	-	-	-0.04	-0.06	0.00	0.13	-	0.00	-0.10
	Tanker Ships	**-0.34**	-0.17	-0.08	-	0.01	0.11	-0.15	0.06	0.14	-0.18	-0.02	-0.01

a Bold values are significant at the 95% confidence level or higher.
b No correlation is identified by "-".

5. Conclusions

This scoping study had two objectives; 1) identifying total change in historic Arctic shipping volume in Canada by vessel type, and 2) determining whether there are any obvious trends between the historic changes in shipping volume (overall and by vessel type) and changes in sea ice conditions within the NORDREG zone. The analysis determined the following:

- There has been a significant increase in shipping volume over the past decade. Overall vessel counts increased by 40% from 2006 to 2007 and by 20% from 2007 to 2011. Accounting for annual variability, total vessel volume has increased by more than 75% over the past decade.
- Rapid increases in vessel counts began in 2007 and unprecedented increases in vessel counts were observed in 2010 and 2011.
- Annual vessel count trends for many vessel classifications are increasing, with Pleasure Crafts and Government Vessels and Icebreakers increasing at a rate of 6, and 8 vessels per decade respectively.
- Pleasure Crafts are currently the second fastest growing vessel type in the Canadian Arctic with a trend of 6 vessels per decade. Given that vessels of this size are not required to report to NORDREG or provide their itinerary to authorities it is quite possible that the rate of growth is even greater.
- Combined monthly vessel count trends for all vessels showed statistically significant increases in travel during the months of June and November, indicating that the length of the shipping season is increasing.
- Within the shipping season (June 25 to October 15) sea ice within the NORDREG zone from 1990–2011 experienced statistically significant declines of total ice, multi-year ice (MYI) and first-year ice (FYI).
- Mean monthly MYI area cover in the NORDREG zone declined in all months of the year with the greatest reductions in September through November. This is an important result for shipping activities as MYI represents the most hazardous ice type for vessels.
- Decreasing MYI and a slower rate of decreasing FYI within the NORDREG zone underscores a pan-Arctic trend of thicker MYI being replaced by younger/thinner FYI, which can facilitate ease of navigation.

6. Further Analysis Planned through Proposed CATAW Study

Using this newly prepared historic shipping dataset several additional analyses can be completed within the proposed larger CATAW study. First, the data will be configured spatially using GIS software, which will allow ship track maps to be generated (e.g.,. by total volume, by vessel type, by year, by specific location, etc.). Once this database is prepared, other data from the region that is relevant for the development of the Arctic shipping industry can be integrated into the database including, for example, ship accident data, known navigational hazards, traditional hunting areas, and special sites and protected areas. A comprehensive database of this magnitude would allow for analyses to be conducted in order to better understand potential shipping hazards, to contribute to policy and infrastructure development decisions, and to provide the basis for a broad-level marine spatial planning exercise.

Second, additional analysis will be performed on the database to understand historic shipping patterns by specific regions. This will include a detailed analysis for individual regions as well as within specific shipping routes such as Hudson Bay, the Northwest Passage, and the Arctic Bridge. These more detailed analyses could provide valuable information for the federal government's initiative to generate and refine strategic shipping corridors over the next few years.

Third, additional analysis can be performed to examine the implications of sea ice for Arctic shipping. Integrating estimates of the melt season length (using the dataset of Markus et al., 2009) and surface temperature will help provide a more holistic view of the changing ice regime in the Canadian Arctic and allow potential relationships between those variables and their impact on Arctic shipping activities to be identified. Analyzing spatial variability in vessel activity is also important with respect to MYI, which will still flow into the Northwest Passage and other shipping routes as the transition to a sea ice-free summertime Arctic continues (Stewart et al., 2007; Howell et al., 2009). The analysis of lag correlations between shipping activities and sea ice conditions in the previous year may also uncover noteworthy relationships between Arctic shipping activities and the changing Arctic environment, especially considering shipping companies often plan activities in advance of knowing each season's ice conditions. Future shipping scenarios can also be established using GCM (global circulation models) and the statistical relationships found in this scoping study.

Fourth, optimal policy options and adaptation strategies to deal with changing conditions in Arctic shipping (i.e. from the perspective of local residents, ship operators, policy-makers, and other stakeholders) will be established through a planned multi-stakeholder consultation and comprehensive policy Delphi process.

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