Arctic Hydrographic Risk Assessment
2023 Update & Revised Baseline

Daniel Devereaux, Jessica Murphy, LCDR Bart Buesseler, NOAA
Daniel.R.Devereaux@noaa.gov, Jessica.Murphy@noaa.gov, Bart.O.Buesseler@noaa.gov
NOAA Office of Coast Survey, Hydrographic Surveys Division

Introduction

An increase in maritime traffic in the Arctic, driven by new economic opportunities as sea ice retreats, has increased the need for hydrographic surveying and charting of the region to ensure safety of navigation and the environment. Even with receding ice, surveying the Arctic is logistically difficult, expensive, and time consuming. In an effort to more efficiently map Arctic waters, a risk-based model was developed in 2015 [1] to identify areas where the hydrographic survey need was the highest. Member states of the Arctic Regional Hydrographic Commission provided chart confidence data that was combined with depth data and vessel traffic to pinpoint areas of potential high risk to surface navigation to prioritize survey areas. This analysis was refreshed in 2018 [2] to capture progress and updates, and we continue that same analysis here with some slight modifications.

In the time since the last assessment in 2018, then called Arctic Hydrographic Adequacy[1], member nations have continued to work diligently in the Arctic region. New hydrographic surveys and reviews of existing data have updated survey confidence values and expanded existing holdings. While the COVID-19 pandemic temporarily slowed down many planned projects and vessel traffic, the overall activity and interest in the region has seen continued growth. Previous reports recognized the importance of developing a broad, risk-based model for nations with charting responsibilities in the Arctic to help prioritize charting efforts, as well as note progress over time. While other hydrographic offices have created other risk-based models that incorporate more specific variables, this analysis continues to use the existing generalized pan-Arctic model.

This report builds off of the prior success of the 2015 and 2018 reports, and uses the same general methods for the analysis. The scope is focused on the area within the EEZ of each Arctic member nation and uses the three variables of depth, survey confidence, and vessel traffic to identify areas of high risk. This update introduces the survey confidence data for Iceland, expands to cover the entirety of Greenland, uses a new resource for compiling and analyzing AIS data that resulted in different metrics for vessel traffic, and modifies the size of the analysis cells from 0.1° by 0.1° to standardized 1 km^2 cells.

[1] In the time since the initial study took place in 2015, the term "adequacy" has come to specifically relate to IHO's Publication C-55, as well as IHO SPI 1.2.2 and IHO SPI 2.2.1, which also use the term with specific definitions, context and understanding. Therefore, the authors of this report have updated its title to "risk assessment" in order to best reflect the objectives of this study and minimize confusion with other IHO initiatives.

The updated study area analyzed by this report covers approximately 13.4 M km^2, of which we find that there is CATZOC A, or high confidence in the survey data of 2.24% of the total area with an additional 4.25% that is at a CATZOC B level of confidence. While this only encompasses 6.49% of the Arctic region, it is important to recognize that only slightly more than one third of the region, 34.65%, sees high consequence vessel traffic. Of that area with high consequence traffic, more than half, 56.56%, has a risk that is considered medium to low concern as a result of CATZOC A and CATZOC B data. This shows that while the overall coverage of CATZOC A and CATZOC B data is sparse, the data we do have is supporting the bulk of the highly concentrated vessel traffic in the region.

Study Area

The study area was expanded from the previous studies from 2015 [1] & 2018 [2] which used the expanded definition of the Arctic by the U.S. Arctic research and policy Act that defines the Arctic to include all areas north of the arctic circle and all contiguous seas, including the Arctic Ocean and the Beaufort, Bering and Chukchi Seas; and the Aleutian chain (Figure 1). All areas within the EEZ of the member states of the Arctic Regional Hydrographic Commission (ARHC) which include Norway, Canada, Denmark, Russian Federation, and the US within this defined area (clipped to 66°33’), are considered for this analysis. Also included for the 2023 study is Iceland, who graciously provided CATZOC data, and the southern tip of Greenland, at the request of the ARHC in order to provide a holistic perspective of the island. No updated data was requested from Russia for this analysis and instead the data from the 2018 analysis was used. Due to this fact, the CATZOC and depth data for Russia is unchanged from the previous update.

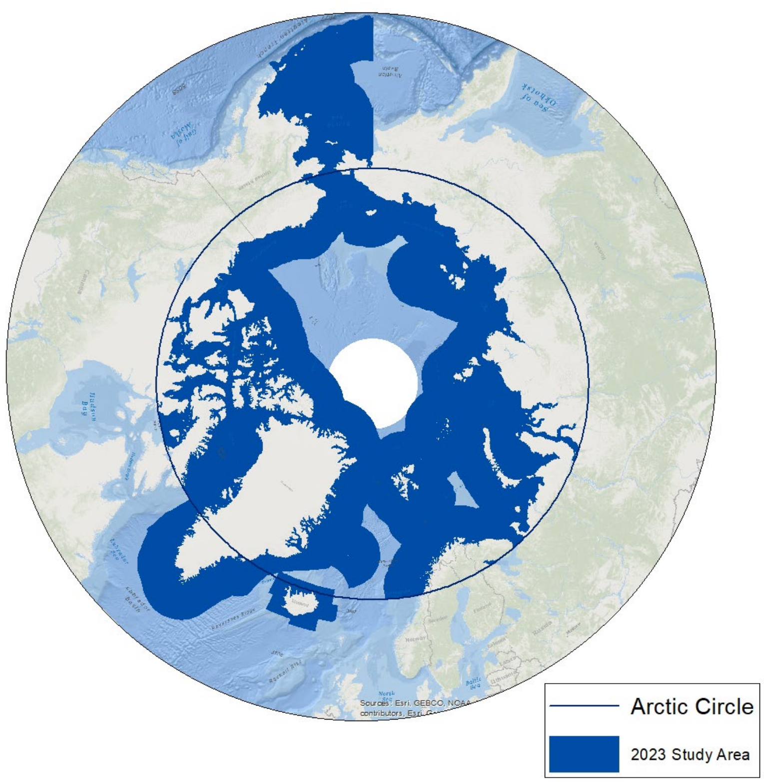

Figure 1: The 2023 study area with the inclusion of Iceland and all of Greenland.

Methods

As with the previous studies we use depth, survey confidence, and vessel traffic to assess the level of navigational risk. Shallow, poorly or unsurveyed areas, with dense vessel traffic are assumed to have the greatest navigational risk and the greatest need for survey data. Conversely deep areas, areas that are well surveyed, or areas with sparse vessel traffic are assumed to have low navigational risk and a lower survey need. We have followed the methods from the previous report closely in order to provide a standardized comparison while also providing a tool to monitor broad trends in areas of risk.

Survey Confidence

Survey confidence was assessed using Category Zone of Confidence (CATZOC) attributes obtained from Electronic Nautical Charts (ENCs). CATZOCs are assigned based on the equipment used, degree of accuracy, coverage type, etc. In order to do this, CATZOC A1 and A2 areas were combined into a single “CATZOC A” confidence level. Additionally, all CATZOC D areas were combined with Unassessed areas for a single “CATZOC U” area. Any areas in the EEZ of Arctic nations that were not categorized by hydrographic offices were given an unassessed confidence level. In the previous assessment, when CATZOCs were not available, they were inferred using the available information or attributed as “Unassessed” if not previously surveyed or no information was available. However, for this assessment, each hydrographic office provided full CATZOC information which was greatly appreciated (Figure 2 and Figure 3). We have also included the CATZOC data for Iceland, an improvement from the 2018 assessment. In order to provide the most direct comparison with the 2018 analysis, CATZOCs were summarized into the four confidence levels in Table 1, below.

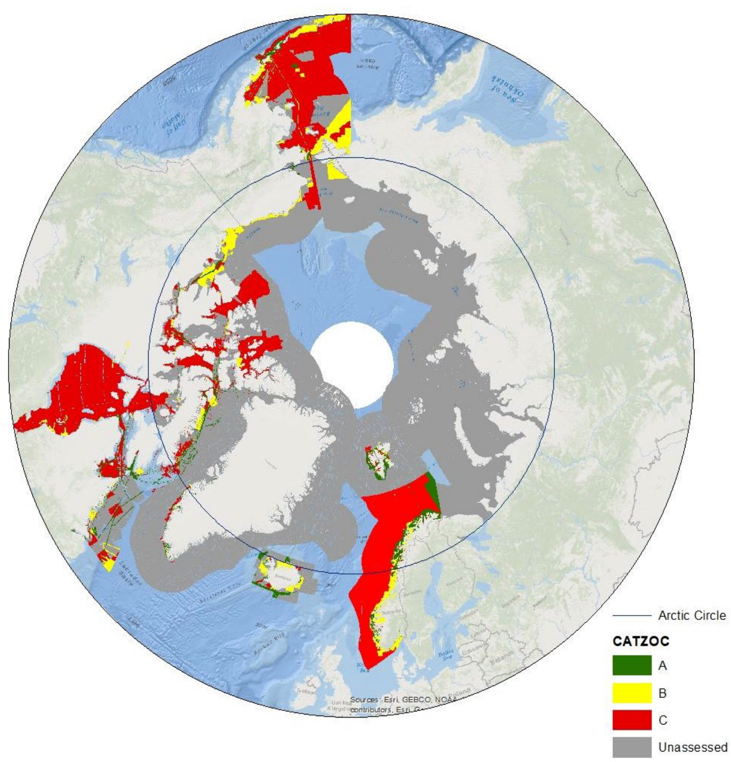

Figure 2: Survey Confidence based on published CATZOC data as provided by each hydrographic office.

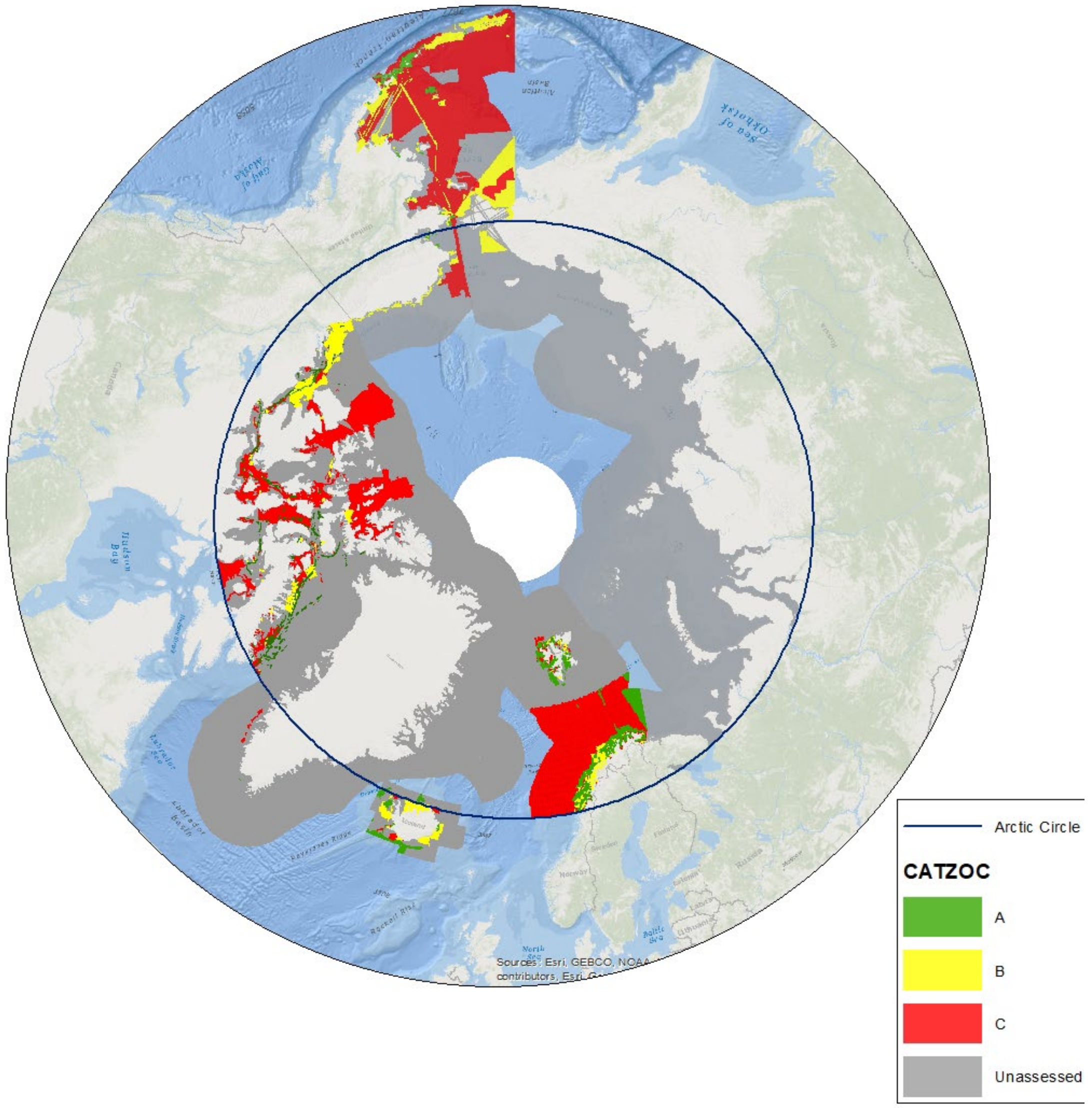

Figure 3: Survey Confidence data clipped to the 2023 Arctic Study area.

CATZOC Confidence Levels

	CATZOC A1 and A2	CATZOC B	CATZOC C	CATZOC U	Total
	Controlled, systematic survey with high position and depth accuracy. Data acquired with a multibeam, channel or mechanical sweep system.	*Controlled, systematic survey achieving similar depth accuracy to Category A surveys, but with less position accuracy. Data acquired using modern survey echosounder.*	*Opportunistic survey achieving low depth and position accuracy. Equipment not specified.*	*Category D and unassessed.*	
Total Area (M km^2)	0.30	0.57	2.36	10.19	13.42
% of Total Study Area	2.24%	4.25%	17.59%	75.93%	100.00%

Table 1: The percentage of area in the study area by CATZOC area.

Depth

In order to categorize the seafloor of the Arctic region, we divided the area into three depth bands: shallow, medium and deep. To accomplish this, we reused the depth bands from the 2018 analysis based on the General Bathymetric Chart of the Oceans (GEBCO) Web Map Service's depth layers. Depths were categorized into shallow, mid-depth, and deep as shown in Table 2, below. As with the previous studies, the depth bands were then subdivided into "simple" or "complex" seafloor assuming that a dynamic seafloor is more likely to change drastically and poses a greater danger to navigation. The flatter, more benign areas in the northern part of the Bering Sea (north of 57 degrees), the Chukchi Sea, the East Siberian Sea, and the Laptev Sea were categorized with a simple seafloor. Complex seafloor was attributed to everything else. For the purposes of this study, an area that is < 20 m deep in an area designated as a "simple" seafloor would be categorized as "shallow." Similarly, an area that is < 100 m as determined by the GEBCO depth layers in a "complex" seafloor area would also be categorized as "shallow". This allows our study to create broad depth categorizations while still accounting for the relative complexity of the Arctic region.

	Simple	Complex
Shallow	0-20 m	0-100 m
Mid-Depth	20-50 m	100-200 m
Deep	50 m +	200 m +

Table 2: Depth classifications for shallow and Complex seafloor areas.

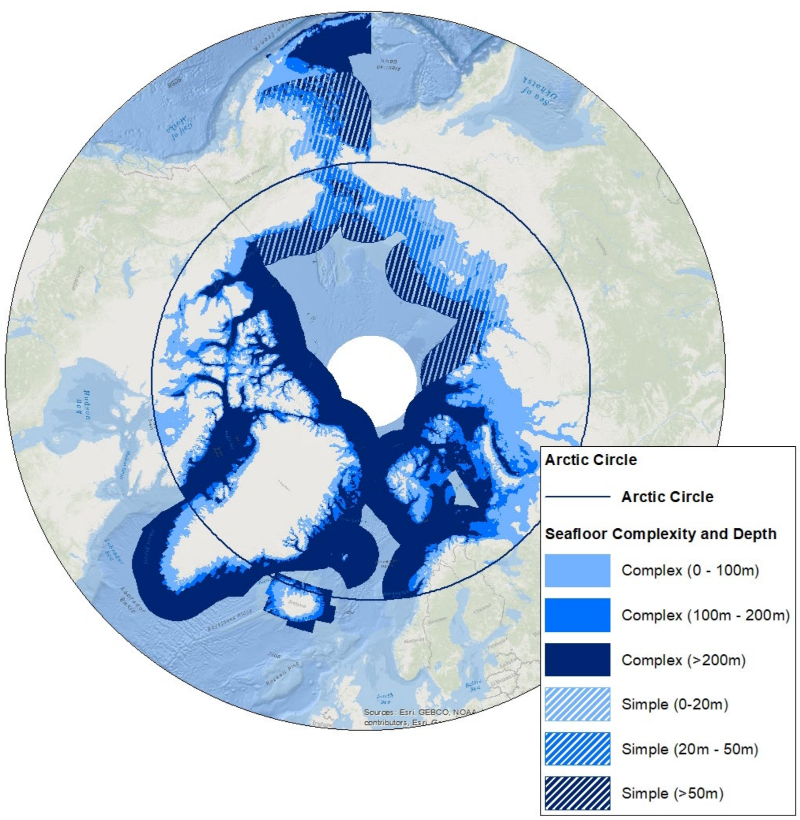

Figure 4: Depth areas based on seafloor complexity.

Areas of Potential Concern

CATZOCs were intersected with depth bands to develop areas of potential concern. As with previous reports, areas with high survey confidence have low concern in all depth bands; areas with shallow or mid-depth bands and CATZOC B or deep, unassessed areas were assigned as medium concern; shallow areas with low confidence have the highest concern.

Potential Concern for Navigation				
	Confidence Level			
	A	B	C	U
Depth Band				
Shallow	Low	Medium	High	High
Mid-depth	Low	Medium	High	High
Deep	Low	Low	Low	Medium

Table 3: Risk matrix used to assign areas of potential concern based on depth and survey confidence.

Based on the intersection of these variables, it was found that 36.74% of the study area is high concern, 47.39% is of medium concern, and 15.87% is of low concern. The values are fairly stable from the 2018 assessment, with a slight increase in areas of low concern. This is likely the result of additional survey activities in the arctic and recategorization of existing survey holdings. It is possible that this value would increase more with updated CATZOC data from Russia as those values are unchanged from the previous assessment.

Areas of Potential Concern by Depth

	High		Medium		Low		Total	
Depth Bands	M km^2	% of Study Area	M km^2	% of Study Area	M km^2	% of Study Area	M km^2	% of Study Area
Shallow	2.53	18.85%	0.21	1.56%	0.08	0.60%	2.82	21.01%
Mid-Depth	2.40	17.88%	0.12	0.89%	0.06	0.45%	2.58	19.23%
Deep	-	0.00%	6.03	44.93%	1.99	14.83%	8.02	59.76%
Total	**4.93**	**36.74%**	**6.36**	**47.39%**	**2.13**	**15.87%**	**13.42**	**100.00%**

Table 4: Summary of areas of concern by depth categorization.

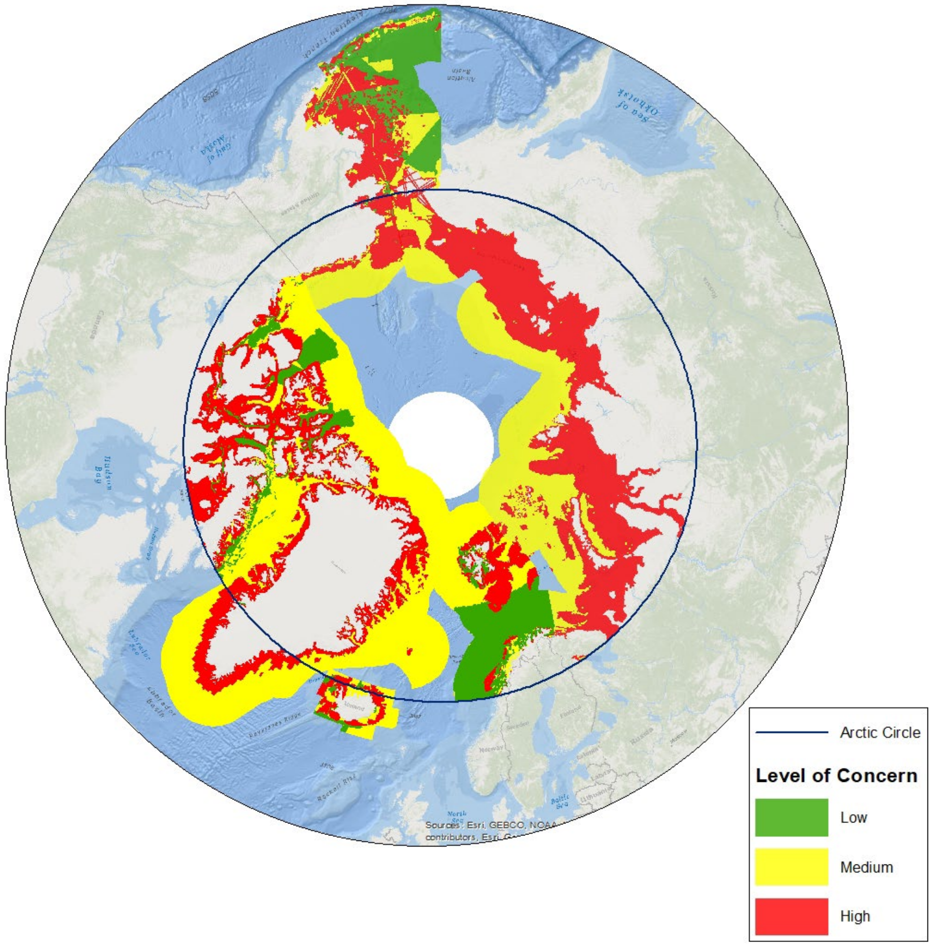

Figure 5: Areas of concern based on the intersection of CATZOC and depth/complexity data.

Vessel Traffic

At this point in the analysis, areas of highest concern have been determined by identifying areas where low survey consequence intersects with complex, shallow seafloor. In order to further refine the areas of concern, we integrated vessel tracklines into the analysis using vessel Automatic Information System (AIS) transmissions to determine the percentage of the study area with high vessel traffic over areas of concern. To compile the AIS information, we used the Global Maritime Traffic Density Service (GMTDS) which was compiled for our use by the MapLarge mapping group [3]. The GMTDS service takes raw AIS location transmissions and converts the sequential locations into vessel tracklines. The tracklines are then converted into traffic density rasters by summarizing vessel tracks through a grid of 1 km^2 time density grids. For our analysis, we filtered the AIS records so that only high consequence vessel tracklines were included. These high consequence vessel types that were included are cargo, tanker, icebreakers, passenger, fishing, and other deep draft vessels. Small, personal craft operating from local communities and with local knowledge were excluded from the AIS analysis in order to focus the analysis on vessels with the highest risk when transiting over areas of concern.

For the purpose of this update, we leveraged the GMTDS service to summarize total vessel hours in each grid over the course of the full 2022 calendar year. While this obscures seasonality, as this report evaluates *where* risks exist rather than *when*, this method of analyzing AIS traffic provides the best means for capturing both presence and absence of traffic across the entire pan-Arctic study area.

Size of Analysis Cell	Time Extent	Vessels Included	Unit of Analysis
1 km^2	2022 Calendar Year	High-Consequence: Tankers, Cargo, Fishing, Icebreakers, Passengers, etc.	Total Vessel hours in each analysis cell during 2022

Table 5: Summary of the parameters used to analyze the 2022 AIS traffic.

The previous report used 0.1° analysis cells to track the density of vessel tracklines over the Arctic region, a coarser resolution than the 1 km^2 vessel hour analysis grids that we received from GMTDS. In order for this report to provide a meaningful comparison and update to the previous report, we statistically analyzed the 1 km^2 GMTDS grids into CATZOC areas. For large CATZOC areas, we subdivided their areas so that no analysis cells exceeded the 0.1° of the previous report. Each of the analysis areas were then analyzed to determine the following measurements: average vessel hours per component grid, max vessel hours per component grid, and the sum of the vessel hours for all component grids. Of these measurements, the maximum vessel hours per component grid value was used for analysis as it represented the most conservative values (i.e. highlighted the highest risks). Much like how the least depth is used for a given area when charting, we looked at the maximum vessel hours per component grid in order to best highlight areas that contain higher density of vessel traffic and therefore higher potential risk.

The full data set is available to ARHC members for further investigations using more specific analysis methods tailored to specific areas of the Arctic. Furthermore, it is the hope by using these values that future assessments will more easily identify changes in annual traffic patterns and the resulting risks for navigation and the environment.

AIS Vessel Analysis

For the analysis, we first looked at the cumulative vessel hours across the study area (Figure 6) to determine the general vessel density over the study area and to begin to identify areas with little to no traffic over the course of the year. We then intersected the AIS data with the previously determined areas of concern in order to further refine areas of concern by traffic (Table 6). Doing so we find that over the whole study area, 34.65% of the area experiences at least some traffic (greater than 0 vessel hours). This represents an increase, driven in part from the increased study area, from the 2018 study that found 27% of the study area experienced at least some traffic. Of the 34.65% of the study area that sees at least some traffic, we find that 43.44% occurs in areas of high concern. This accounts for 15.05% of the entire study area and is a slight increase from the previous report that found 42% of traffic occurred in areas of high concern. Again, this change is partially driven by the increased study area. We also find that of areas with at least some traffic, 28.60% transits over areas of low concern. While areas of low concern only account for 9.91% of the total study area, well over a quarter of all traffic in the area transits through low concern areas. This is likely due to targeting modern surveys to areas of higher traffic as well as the fact that more than half, 59.76%, of the study area is within the “Deep” depth bands that were given a lower risk score.

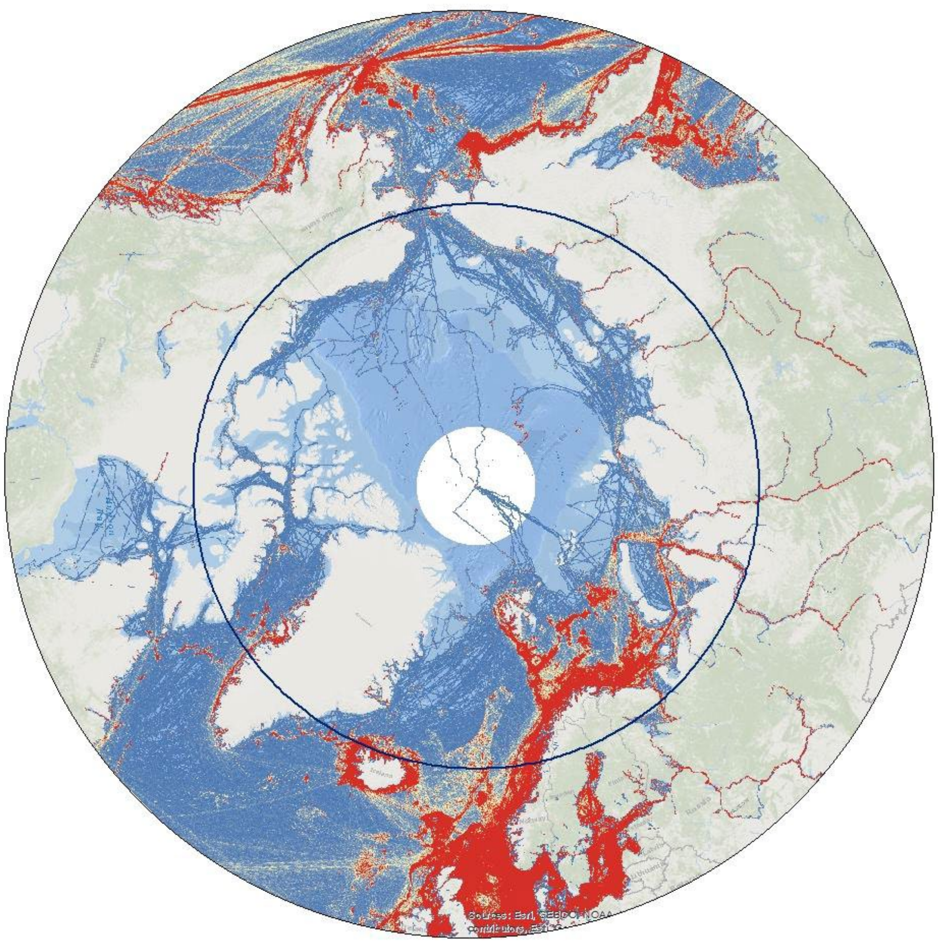

Figure 6: Vessel density for 2022 based on all recorded tracklines of high-consequence vessels.

While the presence of traffic provides a useful tool for determining areas of priority, we further analyzed the AIS traffic by providing a traffic threshold value to highlight areas that see higher traffic density. For this analysis, we developed a threshold value of 50 vessel hours (Table 7) which assumes an average use of a little over 4 hours a month per analysis cell. This threshold, while based on vessel hours and not simply vessel transits, provides a meaningful comparison with the 12-vessel threshold that was used in the 2018 report to identify areas of higher vessel density. Using the threshold of 50 vessel hours reduces the percentage of the study area that sees traffic from 34.65% to only 10.80% that sees higher vessel density. Of this reduced area with higher vessel traffic, 64.14%, occurs in areas of high concern. While this figure may initially sound alarming, the area that experiences this heavy traffic only accounts for 6.93% of the entire study area. This suggests that targeted survey efforts could have significant impacts in addressing the greatest risks in the region. Using this threshold provided a useful tool for comparing vessel density with the previous report, however, different threshold values could be further explored to refine vessel traffic patterns. Emerging tracklines could potentially be filtered by these thresholds so additional examination of the summative vessel hours (Figure 6) could be conducted to determine corridors of high consequence traffic.

The tables below provide the values of areas that see > 0.0 vessel hours as well as areas that experience a higher vessel density using the threshold value of 50 vessel hours. An image is also included of the identified risk areas based on the threshold of 50 vessel hours (Figure 7). Not all areas of priority are contiguous which may seem counterintuitive when thinking of vessel tracklines. However, this analysis is based on vessel hours so areas of higher concern that are detached from other areas of concern could be based on fishing operations, loitering vessels, or work in or near ice that requires slower vessel speeds.

Areas of Potential Concern with High Consequence Traffic

	High			Medium			Low			Total		
Depth Bands	M km^2	% of Study Area	% of Traffic Area	M km^2	% of Study Area	% of Traffic Area	M km^2	% of Study Area	% of Traffic Area	M km^2	% of Study Area	% of Traffic Area
Shallow	1.19	8.87%	25.59%	0.14	1.04%	3.01%	0.07	0.52%	1.51%	1.40	10.43%	30.11%
Mid-Depth	0.83	6.18%	17.85%	0.09	0.67%	1.94%	0.06	0.45%	1.29%	0.98	7.30%	21.08%
Deep	-	0.00%	0.00%	1.07	7.97%	23.01%	1.20	8.94%	25.81%	2.27	16.92%	48.82%
Total	**2.02**	**15.05%**	**43.44%**	**1.30**	**9.69%**	**27.96%**	**1.33**	**9.91%**	**28.60%**	**4.65**	**34.65%**	**100.00%**

Table 6: Summary of areas of concern based on 2022 AIS traffic in areas with > 0.0 vessel hours.

Areas of Potential Concern with High Consequence Traffic - Vessel Hours > 50 per Analysis Cell

	High			Medium			Low			Total		
Depth Bands	M km^2	% of Study Area	% of Traffic Area	M km^2	% of Study Area	% of Traffic Area	M km^2	% of Study Area	% of Traffic Area	M km^2	% of Study Area	% of Traffic Area
Shallow	0.74	5.51%	51.03%	0.08	0.60%	5.52%	0.05	0.37%	3.45%	0.87	6.48%	60.00%
Mid-Depth	0.19	1.42%	13.10%	0.04	0.30%	2.76%	0.02	0.15%	1.38%	0.25	1.86%	17.24%
Deep	-	0.00%	0.00%	0.15	1.12%	10.34%	0.18	1.34%	12.41%	0.33	2.46%	22.76%
Total	**0.93**	**6.93%**	**64.14%**	**0.27**	**2.01%**	**18.62%**	**0.25**	**1.86%**	**17.24%**	**1.45**	**10.80%**	**100.00%**

Table 7: Summary of areas of concern based on 2022 AIS traffic with a threshold of 50 vessel hours per analysis cell.

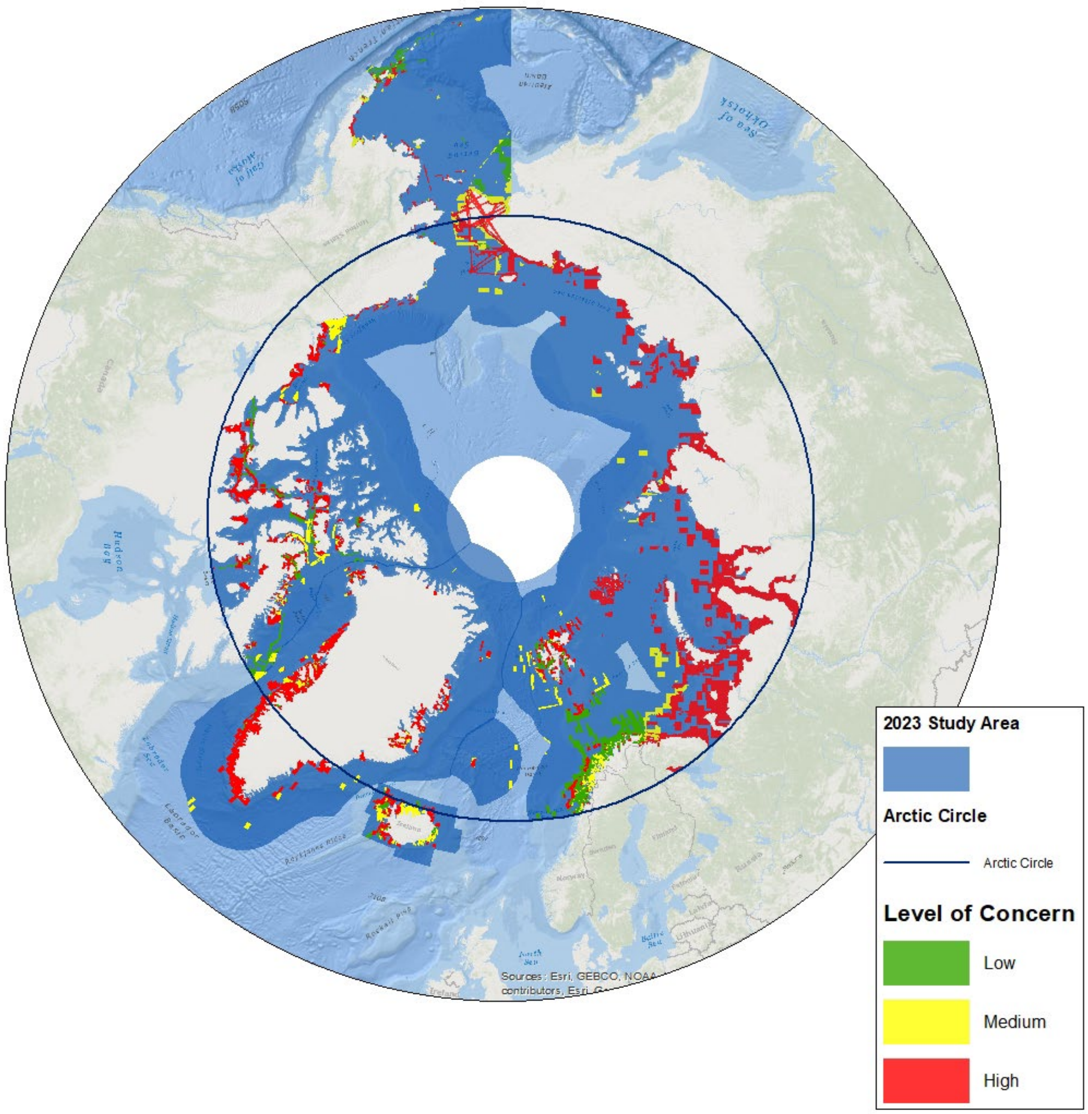

Figure 7: Areas of priority based on survey confidence, depth/seafloor complexity, and a threshold of 50 vessel hours during 2022.

Discussion and Conclusions

While the situation remains rather stark with 43.44% of traffic transiting areas of high concern, there is cause for optimism. Unlike the 2018 report, this report relied exclusively on CATZOC attribution thanks to the diligent work by hydrographic offices to evaluate their data holdings. While there are still large swaths of uncategorized seafloor, this standardization to CATZOC represents a large step forward in our understanding of Arctic bathymetry. Furthermore, recognizing that our highest use (>50 hours) and highest concern area only amounts to 6.93% of the total area, this strongly suggests focused survey efforts can have dramatic impacts in the safety of the Arctic region.

It is also important to recognize the various technologies available, beyond crewed vessels, that could greatly improve our hydrographic knowledge of the region. While technologies such as Satellite Derived Bathymetry (SDB), for example, may not have the resolution to classify an area as low concern, they may have the resolution required to reduce the concern from high to medium. Continuing to evaluate and leverage all available technologies will support our efforts to make incremental progress in this challenging region.

While this report included additional areas in its evaluation, a separate analysis was conducted that performed a comparison to the 2018 study area and results (Table 8). This year to year comparison showed an increase in Arctic vessel traffic, with the largest growth in percentages of traffic in low concern areas than high concern areas, apparently at the expense of medium concern areas. While it is difficult to make any direct conclusions from this broad overview, especially considering the COVID-19 pandemic took place during this time period, it does suggest that nations are proactively responding to the risks through surveys and analysis of data holdings. While much work remains to be done, we are making progress.

Difference Between 2018 and 2023 Reports for Areas of Potential Concern with Traffic

	High			Medium			Low			Total		
Depth Bands	Δ M km^2	Δ % of Study Area	Δ % of Traffic Area	Δ M km^2	Δ % of Study Area	Δ % of Traffic Area	Δ M km^2	Δ % of Study Area	Δ % of Traffic Area	Δ M km^2	Δ % of Study Area	Δ % of Traffic Area
Shallow	0.36	2.61%	4.42%	0.04	0.14%	1.36%	0.06	0.49%	1.44%	0.46	3.24%	7.22%
Mid-Depth	0.17	0.26%	-2.53%	0.09	0.73%	1.16%	0.06	0.49%	1.44%	0.32	1.47%	0.06%
Deep	-	0.00%	0.00%	(0.02)	-0.66%	-7.29%	0.41	2.83%	1.02%	0.39	2.17%	-6.28%
Total	**0.53**	**2.87%**	**1.88%**	**0.11**	**0.20%**	**-4.78%**	**0.53**	**3.80%**	**3.89%**	**1.17**	**6.87%**	**1.00%**

Positive values indicate an increase from 2018 to 2023, negative values indicate a decrease

Table 8: Summary of the differences with the 2018 report in areas with at least some traffic (>0.0 vessel hours).

Additionally, during the course of this report a number of items were identified that fell outside the time and scope of this project yet still warrant consideration.

- The methodology of this report specifically excludes seasonality to provide a broad, general overview of risk in the Arctic. Given the highly seasonal nature of vessel traffic, however, this should be an area to consider for future reports, particularly as CATZOC and traffic data continues to improve in availability and resolution.
- The metrics this report used for vessel traffic, hours within a certain grid cell, include all types of activities such as transiting, loitering, anchoring, and fishing. As each of these activities has a different risk profile, it is possible that various data types are over-inflating the density values thereby inflating the calculated risk. Detailed analysis of these different types of activities and a more accurate risk representation fell outside the scope of this report, however represents an opportunity for future reports or separate studies to address.
- Vessel traffic and the resulting risk profiles they create do not correlate directly into consequences and impacts, as a grounding and oil spill adjacent to a major port would have a vastly different outcome than one offshore of a small coastal indigenous community. While there are metrics that can be used to account for some of these differences, such as distance to response organizations, there are no such similar metrics for impacts to subsistence hunting/gathering or cultural activities. As studies of the Arctic region continue, developing a better understanding of the social and cultural impacts associated with identified maritime navigation risks would further support the prioritization of survey activities within the region.

References

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[3] "GMTDS: Data of Global Maritime Traffic Density Service." *GMTDS | Data of Global Maritime Traffic Density Service*, MapLarge, globalmaritimetraffic.org/gmtds-data.html. Accessed 7 Mar. 2023.