Risk-Based Methodology of Assessing the Adequacy of Charting Products in the Arctic Region

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INTRODUCTION

The relatively rapid retreat of impenetrable multi-year ice cover has made the Arctic region more accessible to surface navigation than ever before. This access comes largely in the form of marine transportation where existing sea routes could see more traffic and where new routes for transit and resource exploitation could open. Any expansion of maritime activity in the Arctic will increase the demand for navigational products.

The "Arctic" is generally considered the areas north of the Arctic Circle (66°33′45.6″ N), but can also include waters adjacent to it. This study included all waters north of the Arctic Circle as well as the Bering Sea down to the Aleutian Chain (Figure 1).

Currently, paper nautical charts are available for most parts of the Arctic (Figure 2, left). Unfortunately, in many areas, the presence of a chart is not a good proxy for "safe navigation". These products are often at such a small scale that they are only suitable for voyage planning as the underlying data may not support the requirements of modern navigation which includes precision positional accuracy and quality depth information. Coverage by large scale products are confined to small portions of the Arctic (Figure 2, right).

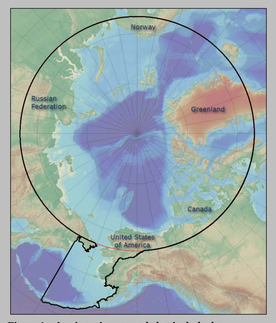

Figure 1 – Arctic region expanded to include the boundary defined by the U.S. Arctic Research and Policy Act. Note: background terrain model is a composite from data sources from IBCAO, GEBCO, NESDIS and NGDC.

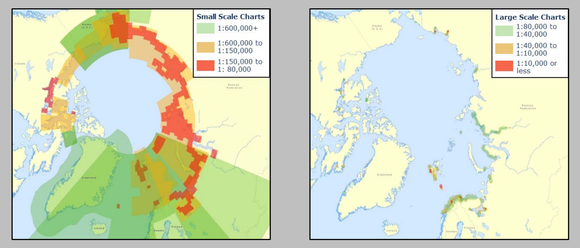

Figure 2 – Small scale nautical charts cover most of the Arctic; however these charts are only suitable for voyage planning (left). Larger scale nautical charts, suitable for most modern navigational needs, are only found in a small fraction of the Arctic (right) (image adapted from Hains, 2014).

In an effort to address some of these challenges that face all nations with interests in the Arctic, the countries of Canada, Denmark, Norway, the Russian Federation, and the United States of America (USA), formed the Arctic Regional Hydrographic Commission (ARHC) under the auspices of the International Hydrographic Organization in 2010 (as of 2014, Finland and Iceland are associate members of the ARHC). Given the high cost of collecting data in the Arctic, of particular interest to this group was the development of a methodology that could be used throughout the region to assess and analyze where risks to navigation are the highest. By identifying these areas, hydrographic offices can more efficiently apply resources to acquire the hydrographic information necessary to get better hydrographic products in areas where the need (or risk) is the greatest.

This poster presents a preliminary methodology developed to assess the adequacy of Arctic charting, based on risk, and discusses the results along with a way forward using these advanced methods. The data used in the analysis was provided by Canada, Denmark, Norway, and the United States, to whom the authors are most grateful.

METHODS

In developing a risk-based methodology of determining the adequacy of charting products in the Arctic (and by direct correlation, areas of greatest potential need for updated hydrographic data), three fundamental data sources were considered:

1. Confidence of existing hydrographic data
2. Water depth
3. Density of vessel traffic

The full data work flow is outlined in Figure 3 while a more detailed explanation of the developed workflow is described below.

Confidence of Existing Hydrographic Data

Independently, each of these data sources could be considered on a simple low-to-high risk continuum (Table 1).

Table 1 – Data types considered within this risk-based analysis. Each type is viewed on a relative spectrum of low-to-high risk.

Data type:	Relative Risk	
	Low	High
Confidence of Hydrographic Data	Newer; 'full' bottom coverage	Older; partial bottom coverage
Water Depth	Deep	Shallow
Density of Traffic	Light traffic	Heavy traffic

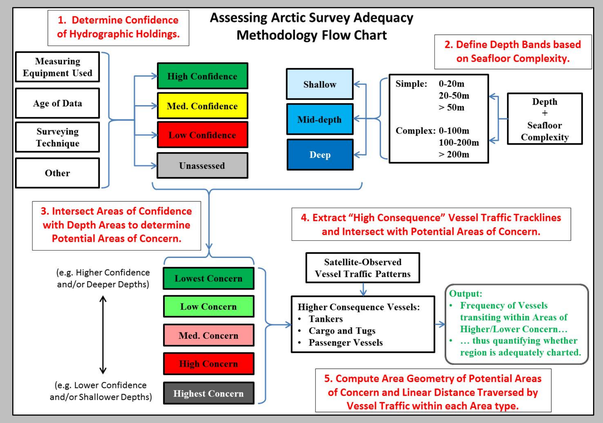

Figure 3 – Composite of data workflow for assessing charting adequacy based on confidence of hydrographic holdings, water depth (coupled with seafloor complexity) and vessel traffic patterns.

Ultimately, all three of these sources were examined simultaneously using Esri ArcGIS; however, the heart of the analysis is based on the suppositions presented in Table 1.

The confidence of the data supporting the presently existing nautical charting products was assessed by classifying each member state's current hydrographic holdings as having high, medium, or low survey confidence based on the surveying technique and/or type of equipment used for each survey. This assessment of confidence was based on a number of the differing data sources, the confidence for data originating from factors including the acquisition equipment used, vintage of the survey data, and surveying technique employed. Because the United States and Canada were derived differently than those of Denmark and Norway as described in Table 2. Once delineated, the confidence of the hydrographic holdings can be visualized throughout the area of study. Figure 4 shows a sample visualization on the eastern side of the Bering Strait.

Country	Data Quality Metric	Confidence Level			
		High	Medium	Low	Unassessed
United States and Canada	CATZOC	**Category A:** Controlled, systematic survey with high position and depth accuracy. Data acquired using multibeam, channel, or mechanical sweep system.	**Category B:** Controlled, systematic survey achieving similar depth accuracy to Category A surveys, but with less position accuracy. Data acquired using modern survey echosounder.	**Category C:** Opportunistic survey achieving low depth and position accuracy. Equipment not specified	Unassessed
Norway and Denmark	Equipment Type	Multibeam echosounder	Singlebeam echosounder	Pre-acoustic survey equipment or equipment not specified	Unassessed

Table 2 – Metric used to assess the confidence level of hydrographic holdings

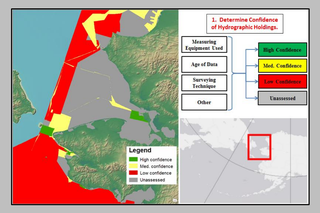

Figure 4 – Visualization of confidence of hydrographic holdings in region on the eastern side of the Bering Strait. Greens depict areas of high confidence (with contemporary coverage from modern sonars), while reds depict areas of lower confidence (pre-1940's data with partial bottom coverage).

Water Depth

The next layer for this analysis consisted of depth data extracted from both the International Bathymetric Chart of the Arctic Ocean (IBCAO) version 3.0 and the Southern Alaska Coastal Relief Model. Depth data was broadly extracted across the study area and then subdivided into various depth bands (as before, based on risk to surface navigation), taking into account each member state's local coastal geology, categorizing the seafloor as either "simple" or "complex.". Within the simple depth scheme, "shallow" was defined as 0-20 meters, "mid-depth" as 20-50 meters, and "deep" as exceeding 50 meters depth. This depth classification was applied to all U.S. waters, within the Exclusive Economic Zone, and north of 57 degrees (NOAA, 2012). The complex depth scheme was partitioned into the same depth bins (shallow, mid-depth and deep), but with a deeper depth threshold for each category.

Depth bins ranged from 0-100 meters for shallow areas, 100-200 meters for mid-depth areas, and exceeding 200 meters for deep areas. The complex depth scheme was applied to all waters around Canada, Denmark and Norway, as well as U.S. waters around the Aleutian chain (NOAA, 2012). A sample visualization of the depth bands, based on seafloor complexity, is shown in Figure 5.

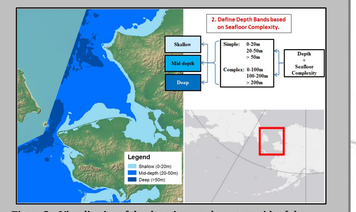

Figure 5 – Visualization of depth regions on the eastern side of the Bering Strait – a region characterized having a "simple" seafloor. Darker shades of blue depict deeper depths (and ultimately lower areas of risk).

Intersection of Confidence & Water Depth (Areas of Potential Concern)

Once the delineation based on survey confidence and depth was completed, the two map layers were intersected to delineate the areas of potential concern (Figure 6). Areas of potential concern were ranked from low to high based on their potential for navigational risk.

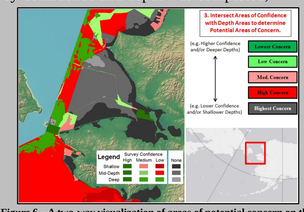

Figure 6 – A two-way visualization of areas of potential concern on the eastern side of the Bering Strait. Regions with some combination of high confidence bathymetry and/or deep depths are of relatively lower concern; whereas, regions of lower confidence bathymetry and/or shallower depths are of relatively greater concern.

Concern progressively increased from low to high as depths shoaled and/or local survey confidence decreased. Low concern was assigned to areas of high survey confidence, independent of depth; whereas, high concern was attributed to shallow areas with low survey confidence. Highest concern was assigned to areas with unassessed survey quality and progressively increased as depths become shallower.

Density of Vessel Traffic

These potential areas of concern were further prioritized based on vessel traffic. An area of high potential concern with correspondingly high vessel traffic should be considered as a highest priority with respect to acquiring updated bathymetric data. AIS data was obtained through ORBCOMM, a private provider of satellite AIS data throughout the world. AIS data spanned a time frame of one year between June 2012 and July 2013 and was subsampled to include those vessels denoted as higher confidence based on their potential for loss of life, property, and/or environmental integrity in the event of a disaster.

Once these higher consequence vessel tracklines are developed, they can then be rendered atop the earlier areas of potential concern (Figure 7). The presence, or lack thereof, of vessel traffic within the various areas of potential concern can assist in better informing a survey priority scheme. Higher navigational risk is attributed to shallow, poorly surveyed areas with dense vessel traffic; as opposed to deeper, well-surveyed areas with sparse vessel traffic. Further, the adequacy of navigational products within the Arctic can begin to be assessed relative to current navigational needs, by both measuring the size of the aforementioned areas of concern, and the linear miles of vessels transiting within these areas of higher/lower concern

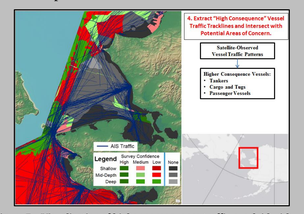

Figure 7 – Visualization of higher consequence traffic overlaid with areas of potential concern on the eastern side of the Bering Strait. Presence (or lack thereof) of traffic helps dictate which areas of higher potential concern should considered for addressing first.

RESULTS AND INTERPRETATIONS

When the first three steps of the preceding methodology are applied to the full Arctic dataset, the initial picture is troubling (Figure 8). Within the study area, 80% of the waters (5.8 million km2) could be characterized as medium to highest concern (sum of pink, red and black regions); whereas, only 20% of the waters (1.4 million km2) are of lower concern (sum of green regions). However, the regions of potential concern are only half of the story; we must understand where vessels are navigating to get a true sense of the adequacy of Arctic charting. While 80% of the waters could be characterized as medium to highest concern, only 23% of all traffic is within these waters; conversely, 77% of all traffic is occurring within the 20% of the regions of lower concern.

Taking this further, while only 5.6% of the study area has been surveyed by the most up-to-date sonar systems (Figure 8 – High confidence), 47.1% of all surface navigation occurs within this region. This disproportionately high amount of navigation within these well-surveyed waters is likely the confluence of two factors: 1) hydrographic offices are focusing their efforts where mariners are navigating, and 2) mariners are navigating where there is high confidence bathymetry. These observations can help steer future survey priorities.

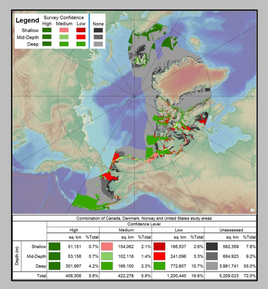

Figure 8 – Areas of potential concern throughout the Arctic. Within the table, entries further to both the bottom and left represent areas of lower concern (e.g. high confidence with deep depths); whereas entries higher and to the right represent areas of highest concern (e.g. unassessed confidence with shallow depths).

CONCLUSIONS AND FUTURE WORK

Preliminary analysis of this work suggests that there are still vast portions of the Arctic that are not adequately surveyed for the present use, implying there is navigational risk. That written, a disproportionate amount of traffic transits within the relatively smaller areas that do have modern bathymetric coverage. This is likely due to a two-fold effect of hydrographic organizations focusing their surveying efforts in areas with higher traffic densities, and mariners altering their transit routes (as practicable) to ensure that they are navigating on the most up-to-date coverage available.

Given the scope of the problem, there is no definitive next step with regard to where to direct one's surveying efforts, and likely each nation will draw their own conclusions based upon further analysis; however approaching the problem from the perspective of navigational risk is a prudent first step. For the 2015 field seasons, NOAA and the Office of Coast Survey (OCS) are taking two steps: 1) diverting resources to Port Clarence and Kotzebue Sound, regions which are relatively shallow, poorly surveyed, and heavily transited (Figure 9), and 2) partnering with the USCG to better develop offshore transit corridors, to provide mariners with known safe passages (mitigating the need to survey everywhere, and instead focusing on getting the mariner safely from Point 'A' to 'B') (Figure 10).

A final note of caution with regard to interpreting AIS data: all AIS data analyzed in this report was acquired in the 2012-2013 time frames. Generally speaking, AIS data will only reveal where vessels have been transiting, not where vessels will be transiting. Portions of this proposed methodology will fall short when applied to regions like emerging traffic lanes due to receding ice cover. To that end, even areas of high potential concern, that do not have heavy traffic patterns (at present), should not be lightly dismissed from consideration for future survey work.

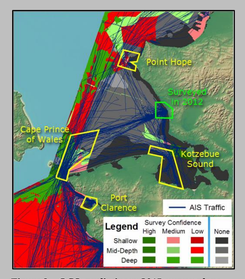

Figure 9 – OCS, preliminary 2015 survey plans for the Arctic region.

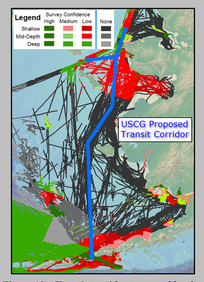

Figure 10 – Transit corridor proposed by the U.S. Coast Guard, and scheduled for investigation by NOAA's Office of Coast Survey in 2015.

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