Fisheries and Oceans Canada / Pêches et Océans Canada

Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2015/020

Central and Arctic Region

Marine protected area network planning in the Western Arctic Bioregion: development and use of a classification system to identify ecological units as required planning components

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May 2015

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Hodgson, R., Martin, K., and Melling, H. 2015. Marine protected area network planning in the Western Arctic Bioregion: development and use of a classification system to identify ecological units as required planning components. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/020. v + 41 p.

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ABSTRACT

In order to meet Canada's obligations to the United Nations (UN) Convention on Biological Diversity (CBD), creation of a Marine Protected Areas Network (MPAN) following UN stipulated steps is required. This paper details the completion of step two from the UN CBD, which, in short, calls for marine areas to be biogeographically classified (hereafter referred to as eco-units) reflecting the types and diversity of ecosystems. It is important to note that step one was the creation of Ecologically or Biologically Significant Areas (EBSAs) and that step three will draw upon step one (biological focus) and step two (physical/habitat focus) in order to produce a set of potential MPAN sites or 'Priority Conservation Areas' as they are being called in Canada. Fisheries and Oceans Canada (DFO) is completing this task using its regionalized structure and 13 regional planning areas called bioregions. Here we deal with the classification of eco-units within the Western Arctic Bioregion. In this paper, we created a systematic approach to biogeographic classification based on available data, prioritization of information inputs based on use and citations in the literature, as well as results from several previous classifications by others, all combined using GIS based mapping and analysis. Scientific review of this approach was conducted to identify areas that could be affected by miss-prioritization of input data, missing information, and/or over-interpreted information, as well as to gain general scientific consensus on the overall nature and value of the resulting eco-unit areas. In all, eighteen eco-units were classified for the Western Arctic Bioregion, reflecting the scale of the exercise and the number of EBSAs created previously for this bioregion.

Planification du réseau d'aires marines protégées dans la biorégion de l'ouest de l'Arctique : élaboration et utilisation d'un système de classification pour déterminer les unités écologiques en tant qu'éléments nécessaires à la planification

RÉSUMÉ

Afin de respecter les obligations du Canada en vertu de la Convention sur la diversité biologique (CDB) de l'Organisation des Nations Unies (ONU), il faut créer un réseau d'aires marines protégées en suivant les étapes prescrites par l'ONU. Cet article décrit l'achèvement de l'étape deux de la CDB de l'ONU, qui, en bref, exige que les aires marines fassent l'objet d'une classification biogéographique (ci-après appelées « unités écologiques ») reflétant les types et la diversité des écosystèmes. Il est important de noter que la première étape consistait à créer des zones d'importance écologique ou biologique (ZIEB) et que la troisième étape s'appuiera sur l'étape 1 (accent biologique) et l'étape 2 (accent physique ou sur l'habitat) en vue d'établir un ensemble de sites potentiels aux fins du réseau d'aires marines protégées ou pour former des aires de conservation prioritaires, comme elles sont appelées au Canada. Pêches et Océans Canada accomplit cette tâche par l'entremise de sa structure régionalisée et des 13 zones de planification régionales appelées « biorégions ». Le présent document de recherche traite de la classification des unités écologiques de la biorégion de l'ouest de l'Arctique. Nous avons créé une approche systématique de classification biogéographique en nous fondant sur les données existantes, en hiérarchisant les renseignements selon leur utilisation et leur présence dans les ouvrages scientifiques, et en nous appuyant sur les résultats de plusieurs classifications précédentes effectuées par d'autres auteurs, le tout combiné à une analyse et une cartographie du SIG. Un examen scientifique de cette approche a été mené pour déterminer les zones qui pourraient être touchées par la mauvaise hiérarchisation des données, les données manquantes et les informations surinterprétées, ainsi que pour parvenir à un consensus scientifique sur la nature et la valeur globales des unités écologiques résultantes. En tout, dix-huit unités écologiques ont été évaluées dans la biorégion de l'ouest de l'Arctique, reflétant l'envergure de l'exercice et le nombre de ZIEB créées précédemment dans cette biorégion.

BACKGROUND

Fisheries and Oceans Canada (DFO) is leading the development of Canada's Marine Protected Area Network (MPAN) in collaboration with efforts by provincial and federal departmental partners and stakeholders. These efforts follow Canada's international commitments under the United Nations (UN) Environment Programme (UNEP 2008) and the Convention on Biological Diversity (CBD) (United Nations 1992) as well as its domestic obligations under the *Oceans Act* (Government of Canada 1996). The scope of this task is large given that Canada's coastline is the longest in the world, therefore the planning for the MPAN has been broken down, first by Ocean (Atlantic, Arctic and Pacific) and then by high-level spatial units referred to as bioregions with 13 Bioregions in total (DFO 2009). DFO's Central and Arctic Region is responsible for five biogeographic regions in the Canadian Arctic. One of these bioregions, the Western Arctic Bioregion (WAB), is the focus of initial efforts to plan the Arctic portions of Canada's MPAN (Figure 1). Place names within this bioregion are identified in the Appendix. Many of the processes established during this initial focused effort are intended to be transferable to other Arctic bioregions. Given the nature of the Arctic from a scientific perspective (i.e., physical and biological processes, and data/knowledge state) and from a socio-political perspective (i.e., low population density consisting largely of Inuit and Inuvialuit communities within Comprehensive Land Claim Areas) methods developed in other regions and countries for planning conservation areas like those to be proposed under the MPAN are not directly transferable to the Arctic. The methods used in this study follow guidance provided in DFO (2010 and b), Government of Canada (2011), and DFO 2012).

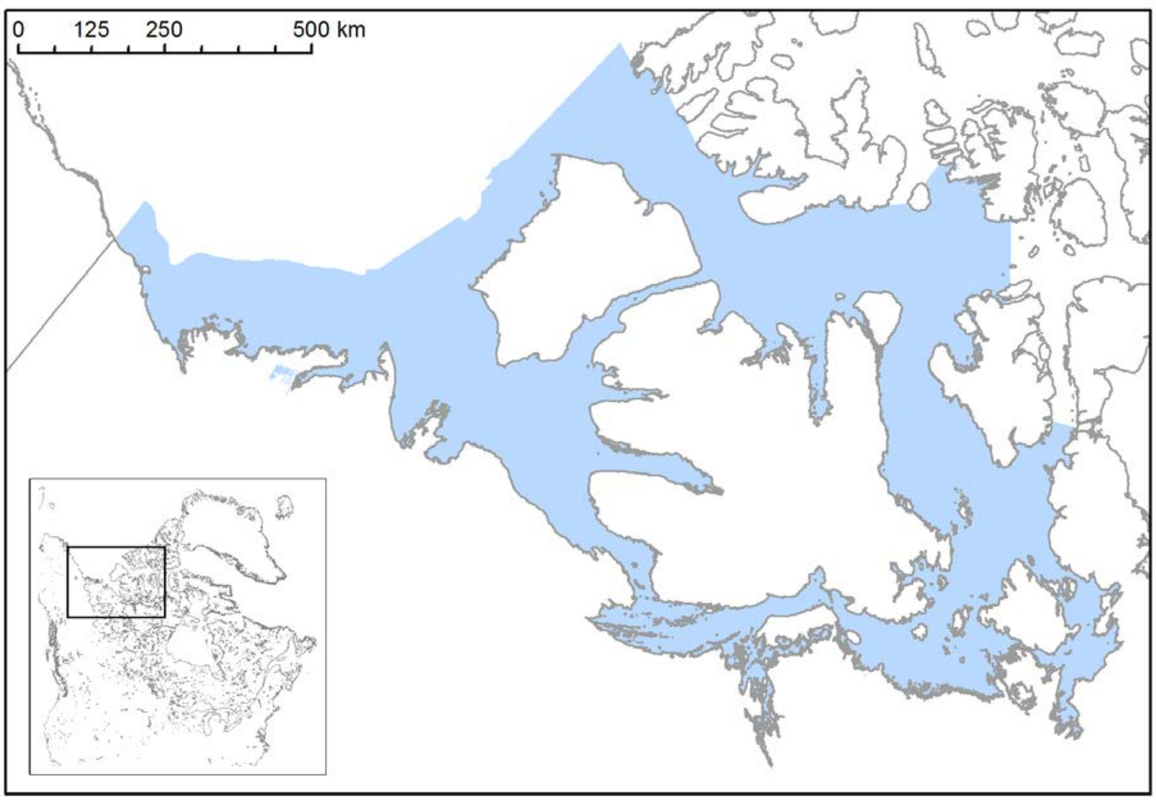


Figure 1. The Western Arctic Bioregion is delineated by the blue shaded area (from DFO 2009).This bioregion is bounded on the west by the Arctic Basin bioregion, the boundary between generally following the 200 m depth contour. It is bounded to the north and east by the Arctic Archipelago and Eastern Arctic bioregions, respectively.

Key to the development of Canada's MPAN are its commitments under the 1992 UN Convention on Biological Diversity (CDB) (United Nations 1992, Article 8a) and subsequent decisions made by the Conference of the Parties to the CBD (COP) UNEP (2008) lays out the fundamental framework dictating how MPAN areas will be selected, including five Required Network Properties and Components and four initial steps to be taken when planning an MPAN.

Network properties and components are;

1) Ecologically and Biologically Significant Areas (EBSAs),
2) Representativity,
3) Connectivity,
4) Replicated ecological features, and
5) Adequate and viable sites;

Initial steps in development of MPAN areas are;

1) scientific identify EBSAs,
2) develop/choose a biogeographic, habitat, and/or community classification system,
3) use qualitative and/or quantitative techniques to identify potential areas of the MPAN, and
4) assess the adequacy and viability of selected sites.

Much has been written by others to place this guidance within a Canadian and regional context (DFO 2010, Jessen et al. 2011, DFO 2012, DFO 2013a, DFO 2013b). This paper focuses on Step 2 in the development of MPAN areas, although we continuously review the effect on the five Required Network Components and later steps in the development of the MPAN. Step 2 as written in Annex II states:

> "Develop/choose a biogeographic, habitat, and/or community classification system. This system should reflect the scale of the application and address the key ecological features within the area. This step will entail a separation of at least two realms – pelagic and benthic."

On the same note, DFO (2012) specifically tied the classification system for MPAN areas to achieving ultimate representativity and went further in stating that the classification system;

1) must be scientifically accepted,
2) must be accompanied by informative map(s), and
3) shall be used in the later scientifically supported decision-making to ensure selected MPAN areas adequately represent the planning units derived from the classification system.

Here we are following these suggestions literally, and thus this paper is the basis for;

a) describing the classification system used in the WAB,
b) documenting scientific acceptance of the system (by means of DFO's Canadian Science Advisory Secretariat (CSAS) scientific peer review processes), as well as
c) containing necessary informative maps.

Step 3 will be the focus of a companion paper that will select areas from within classification system units based on a separate analysis and will request scientific support of those areas also via a CSAS process.

As expressed in the UNEP statement above, scale is of critical importance to application and results of the classification system. The goal is that the system delineate a number of ecological units (here referred to as eco-units) of value to the intent of this scale of product – meaning a system that captures the spatial nature and diversity of marine ecosystems or habitats in the WAB without having to map them individually, as there are too many and not enough data. Inputs to the classification system are more closely akin to habitat parameters than to the eco-units themselves. For example, sea ice provides habitat for many animals and plants (e.g., Horner et al. 1992) and therefore, sea-ice information used in the classification system could be directly related to this type of habitat or this ecosystem. An eco-unit on the other hand uses many classification inputs (such as sea ice, bathymetry, etc.) to delineate an area representative of the dominant habitat inputs considered or combination of inputs specific to that area and scale.

For instance, an eco-unit may be delineated by the euphotic zone AND having no tidal influence AND may consist of waters within, and protected by, an archipelago. This does not mean that there is no sea-ice habitat within this eco-unit. It likely means only that the area met minimum criteria for delineation based on the prioritized inputs. Priority is based on dominance of particular parameters – for some areas habitat types can be more or less dominant – for example, an area may include estuarine influence as a habitat input, but depending on the type, scale and temporal influence of the estuary it may be the primary factor in delineation of the eco-unit or it may be second, third or fourth in importance relative to other more dominant factors. Therefore the classification system can be said to be an area-specific prioritization system derived from inputs that roughly reflect or act in proxy for habitat/ecosystem descriptors. Prioritization is based on available information and will be referenced accordingly. All available inputs are not used to delineate all areas because as shown by Roff et al. (2003), as few as four input parameters produced 11 separate classification areas which include more than 20 spatially isolated areas (See Figure 2). The number of output areas created from a classification system increases significantly with every new input dataset used; thus simplification would be required should too many input datasets be used indiscriminately.

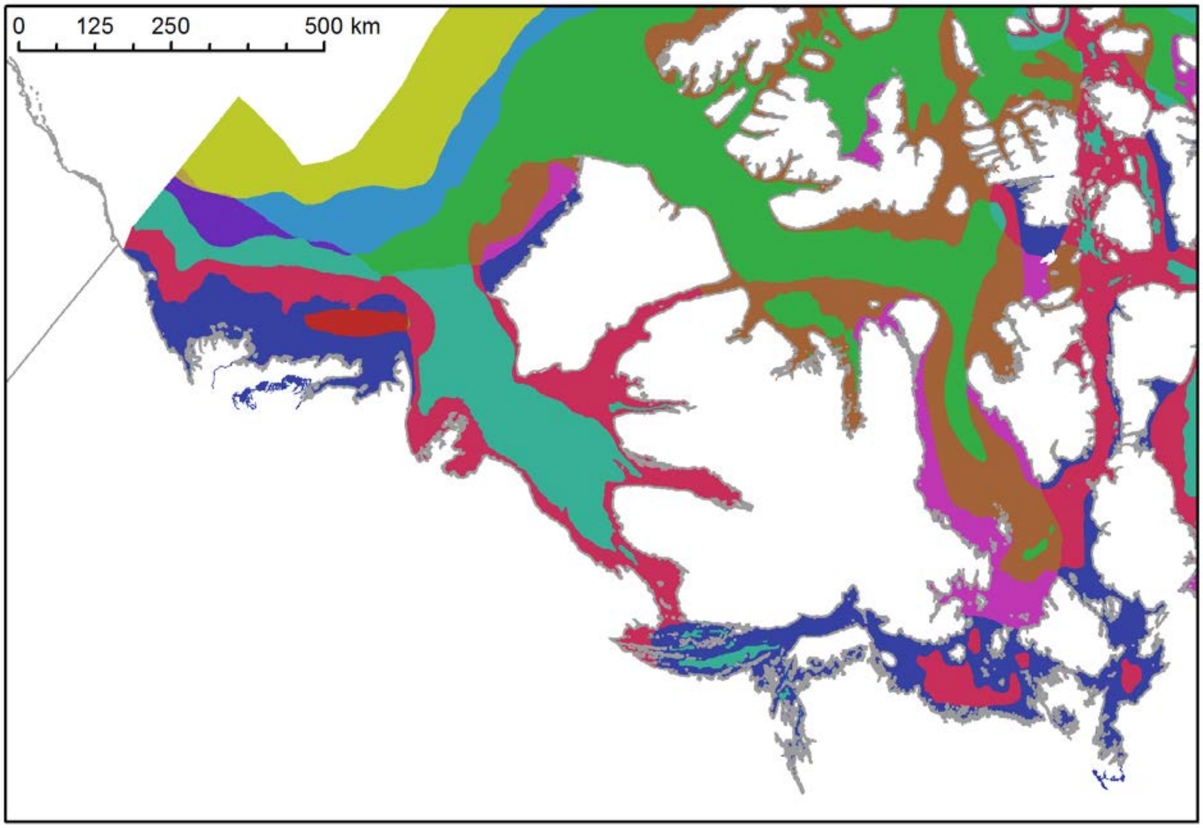


Figure 2. Eleven separate classification areas identified by Roff et al. (2003) for the Western Arctic Bioregion.

METHODS

INITIAL SUBDIVISION OF THE BIOREGION

An initial subdivision of the bioregion into eco-units followed a decision tree (similar to a dichotomous key) coupled with a GIS analysis. Since creation of eco-units is an intermediary spatial planning product in order to plan for Priority Conservation Areas (PCAs), the target scale of eco-units is intermediary between the scale of the bioregion and the ultimate scale of proposed PCAs. Each scale used in the planning process roughly changes by an order of magnitude (Bioregion = 100%, Eco-unit = 10%, PCA = 1%). This is an over-generalization, and specific areas are not used as strict delineation goals, however, this generalization provides a context for the scale-based planning process being attempted here. The decision tree used for eco-unit delineation within the WAB is outlined below:

1) Is there a dominant habitat feature in the area?

For the WAB this includes but is not restricted to;

- Mackenzie Estuary,
- Mackenzie/Beaufort Shelf,
- Polynyas and Leads (winter/spring ice features),
- Persistent Ice (summer/fall ice features).
    a. Yes – GO TO 2
    b. No – GO TO 3

2) Do other habitat features coincide (e.g., > 90% overlap of the secondary feature with the primary feature) within the area in question?
    a. Yes – adjust (expand, contract) the boundary where necessary to accommodate coinciding habitat features and complete delineation (i.e., delineation will be based on two or more habitat features).
    b. No – finalize delineation based on scientifically defensible information.
3) Using available input data – isolate a definable area.
    a. If an area defined by appropriate data can be delineated at an appropriate scale THEN GO BACK TO 2
    b. no spatially appropriate area can be defined due to inappropriate or insufficient data THEN GO TO 4
4) If areas remain – undertake a Residual Area Analysis.
    a. If insignificant in size (<2% of the bioregion), include by expanding neighbouring eco-units with the least fixed boundaries.
    b. If significant in size examine neighbouring eco-unit characteristics and determine the unique aspects of each area – Use these criteria to define as a potential eco-unit THEN GO TO 5
5) Finalize All Eco-units.
    a. After all potential eco-units are labeled and no other residual areas exist – are there spatially disconnected areas with the same or similar defining characteristics?
        i. Yes – can a case be made (based on geospatial properties – or scientific information) that these areas are in fact part of the same eco-unit? Keep in mind that not all spatially disconnected areas may have representation in protected area strategies/planning. If this may be problematic, then a case should be made for separate eco-units. Finalize one or more eco-units.
        ii. No – delineate as separate eco-units.

ECO-UNIT REVIEW AND VERIFICATION

Areas resulting from the process outlined above were reviewed by scientific experts. This review highlighted potential issues related to the use of data (e.g., misapplication or prioritization of data inputs) and missing data. Alterations were made to data layers and eco-units were re-delineated. That is, inputting areas back into the classification system at steps 1 and 2.

Note that the use of the decision tree above cannot be separated from the use and manipulation of information within a GIS analysis. In the same sense, the classification system is not a GIS tool that can be implemented or automated based on information inputs alone.

DATA INPUTS

Bathymetry and Derived Data Layers

The General Bathymetric chart of the Oceans (GEBCO)(IOC et al. 2003 modified with Jakobsson et al. 2012) was used as the source data to extract depth classes (0-20 m, 20-100 m, 100-200 m, 200-500 m, >500 m) (Figure 3).

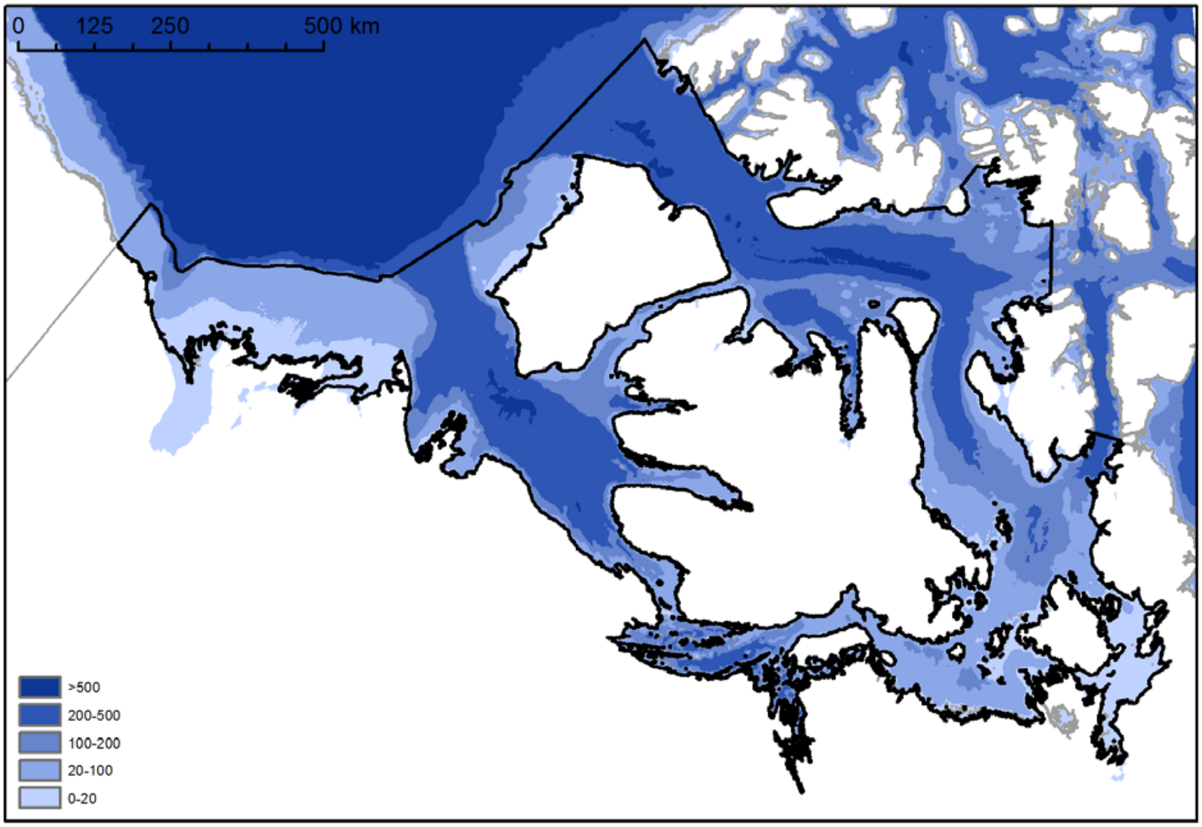


Figure 3. Bathymetry of the Western Arctic Bioregion (GEBCO) showing depth ranges in metres. The solid lines delineate the Western Arctic Bioregion (from DFO 2009).

To aid in the delineation of some areas, it was useful to have a simplified data layer illustrating the morphology or slope of the sea bed. Shaded maps of continuous bathymetry and/or classified (categorized) maps can be misleading because shading/colour choices can highlight or mask underlying data depending on the shading system used. A classification system such as the one presented in this paper works best when data inputs are categorical (discrete classes of data as opposed to continuous data). Bathymetry classes shown in Figure 3 were used as simplified discrete inputs to the classification system in place of the original continuous bathymetric dataset. However, the loss of data during this simplification masks other potentially important characteristics that are contained in the original data. One of these characteristics is the gradient or slope of the seabed. Using the GEBCO bathymetry data (IOC et al. 2003) the slope of the seabed was calculated, then classified based on natural breaks. This was then simplified using zonal and neighbourhood statistics and converted to a polygon file for use in delineation of eco-units. Figure 4 illustrates the raw output of the slope function with the final simplified polygon of high slope areas overlaid. Clear boundaries created through this process can be used to delineate areas, including areas of high slope or areas that are associated with basins or shelves. This input is therefore used not to establish the importance of a feature but simply to help delineate a feature of accepted importance. An example of this would be the North Victoria Island Shelf eco-unit.

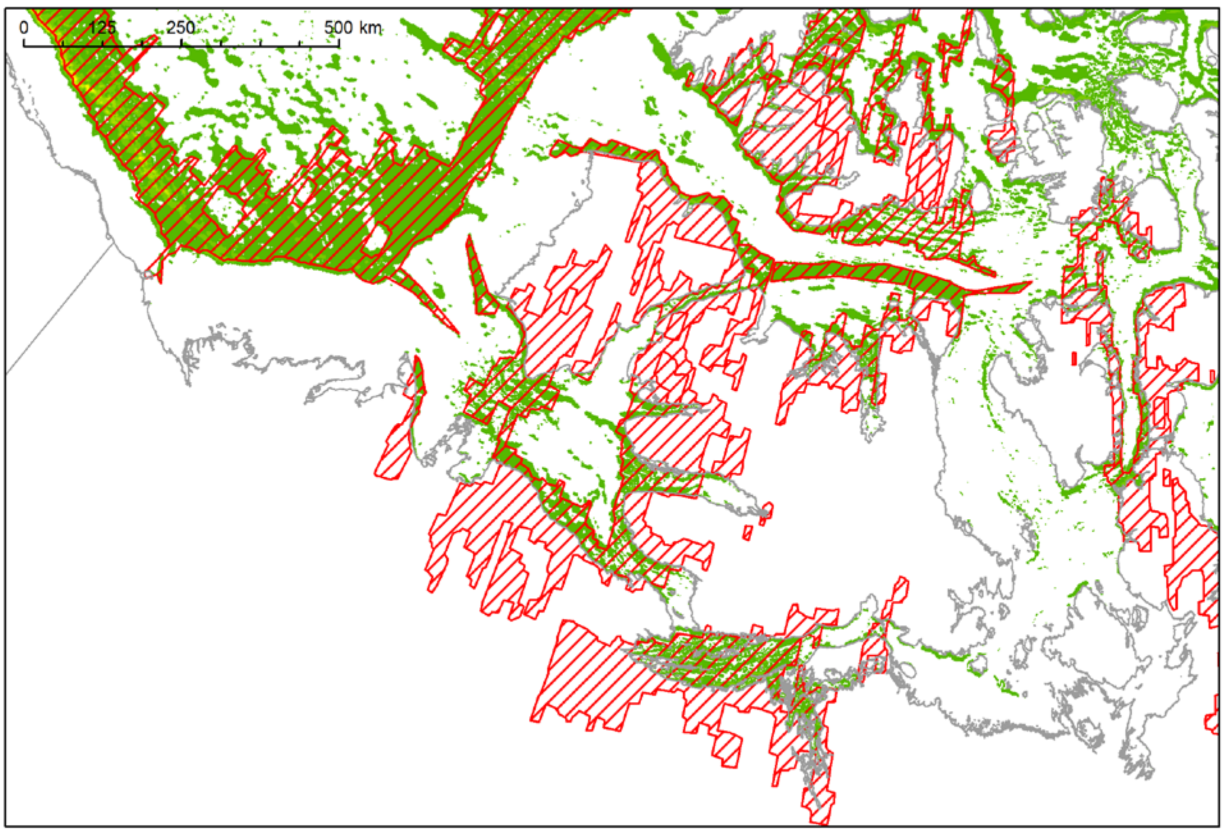
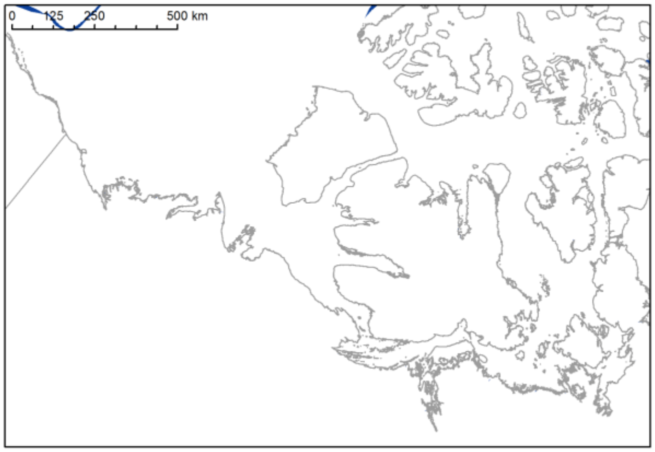


Figure 4. Seabed slope, original raw output of the slope function shown in green shading, simplified polygon of high slope areas on both land and water are shown as red hash lines. Areas without colouring are areas of relatively low slope.

Sea-Ice Data and Derived Data Layers

Absence of sea ice in isolated areas within regions dominated by seasonal or permanent ice cover creates important habitat for species that require access to open water (e.g., marine mammals, marine birds). Polynyas are areas of open water and thin ice that persist in areas of much thicker surrounding ice during winter (and perhaps year-round in perennial-ice areas), and can be created and driven by water, wind, currents and ice dynamics and are of critical importance to many species and ecosystems (Smith and Barber 2007, Stirling 1980, Stirling and Cleator 1981). Annually re-occurring polynyas and leads provide a predictable general location and unique characteristics sufficient to define and delineate eco-unit areas. Typically we would like to use a spatially and temporally variable parameter such as sea-ice to support but not define delineation of eco-units, especially given recent and potential future changes in seasonal sea ice. While timing of ice freeze-up and break-up may change and the type of ice may change (i.e., multi-year ice versus seasonal ice), the arctic ecosystem will still be dominated by sea-ice in winter. Therefore, given the seasonal nature and importance of polynyas and leads, there is sufficient justification for identifying these areas as eco-units even though their presence may only be a fraction of the annual cycle and their location fluctuates annually. To delineate these areas we used 30-year average ice-climate data (1981-2010) from the Canadian Ice Service (2011) as the basis for GIS mapping. Ice frequency data (frequency of ice occurring at a given time and location based on 30-year historical data i.e., 100% indicates ice was present every year of the 30 years on that date and at that location) were examined during early spring to detect the increasing probability of open water (seen as a decrease in ice frequency) associated with polynyas and leads. April showed a clear pattern of decreased ice frequency in areas known to have annually re-occurring polynyas and leads. The <93.1% ice frequency (>6.9% frequency of open water) category also exhibited clearly defined boundaries associated with the expected patterns of polynyas and leads. The end of April showed the clearest pattern of reduced spring ice frequency (see Figure 5b). Areas with ice frequency of < 93.1% at the end of April were therefore extracted from the CIS dataset and used as a proxy to delineate polynyas, leads and early breakup areas (Figure 6). So, any area that had ice present less than 93.1% of the time was considered as potentially having open water at that time of year. It is worth noting however, that the likelihood of all three areas shown on Figure 6 occurring at the same time (or even during the same year) is small. Historically, forces dictating the location and timing of leads and polynyas in this area result in similar probabilities of the same lead/polynya showing up at different locations (i.e., the Bathurst polynya may form off Cape Bathurst or Cape Parry).

a)



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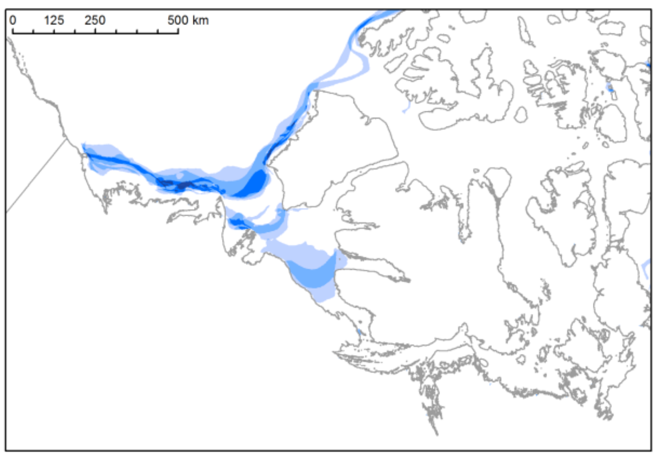

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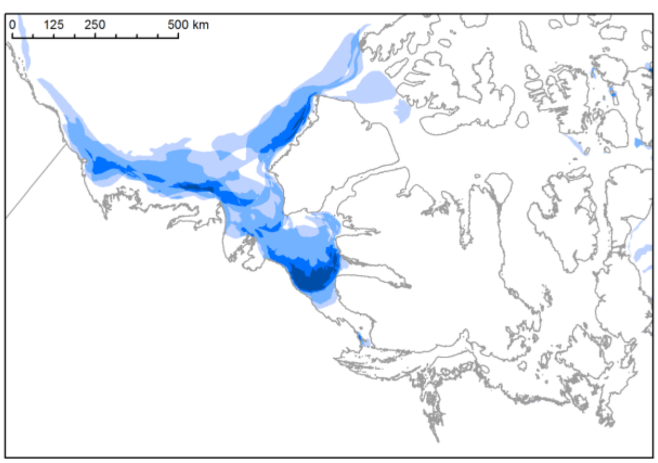


Figure 5. Spring sea ice frequency (a) April 2, (b) April 30, (c) May 14, showing <97% average annual ice frequencies on this date based on a 30-year average (CIS 2011). <97.1% (light blue), <93.1% (medium blue) and <90.1% (dark blue).

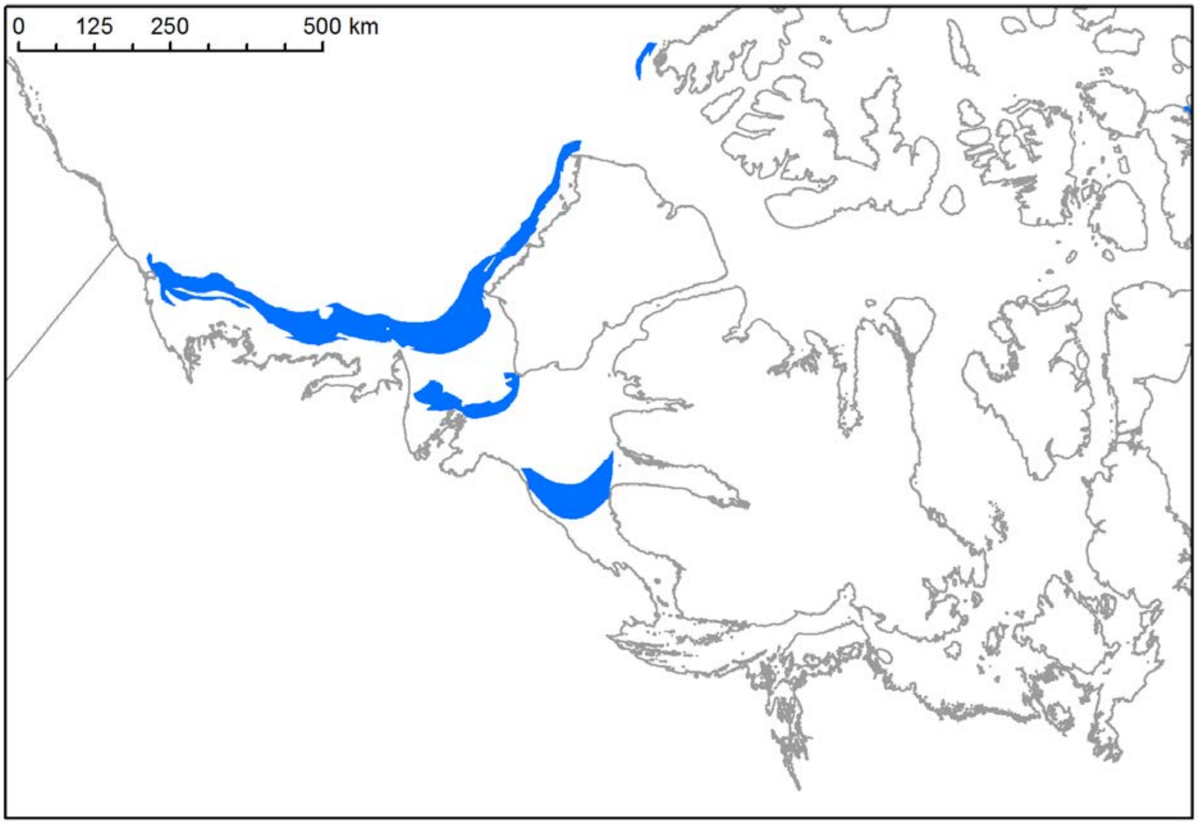
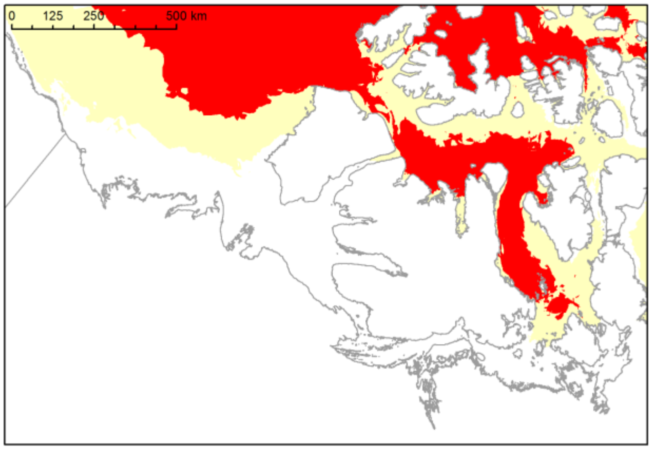


Figure 6. Areas identified as major polynyas and leads of the Western Arctic Bioregion

Similar but on the opposite extreme to the rationale used to support the use of ice data to delineate open water areas, areas of prolonged ice cover through the entire annual cycle also present important habitat relevant in the classification of eco-units. Areas of prolonged summer ice cover are a function of ice movement after breakup. These accumulation points will likely continue to exist within the delineated areas for prolonged periods in the future relative to the majority of the ice in the western arctic area, which is undergoing an aerial decline over time (Vihma 2014). Arctic ecosystem dynamics and habitat are dictated to a large extent by sea-ice presence from freeze-up to ice break-up, but areas that have persistent ice throughout the year due to climate, currents, winds and other ice dynamics are especially controlled by sea-ice dynamics. To delineate areas with persistent sea-ice cover, data from the Canadian Ice Service (CIS 2011) were used as the basis for GIS mapping. Ice frequency data were examined during late fall, just prior to freeze-up to detect the presence of ice remaining from the previous winter (and/or multi-year ice) as a representation of areas with persistent ice throughout summer. September showed a clear pattern of persistent ice (i.e., high frequency of ice presence during the general time of lowest ice concentrations) in areas prior to general increasing frequencies (i.e., new ice forming) in November associated with the onset of freeze-up (Figure 7). The beginning of September (Figure 7 plate b) showed a clear average ice minimum (Figure 8). The >90% ice frequency category exhibited clearly defined boundaries for expected patterns associated with mobile ice. Delineate areas of 50% and 90% ice presence at the time of seasonal ice minima (seen on plate b of figure 7) were extracted and simplified to be used as a data input layer to the classification system (Figure 8). The 50% and 90% ice minima show areas that had ice present in more than 50% and 90% of the years (1982-2012) at the time of minimum sea-ice coverage (i.e., just prior to new ice growth in the fall).

a)



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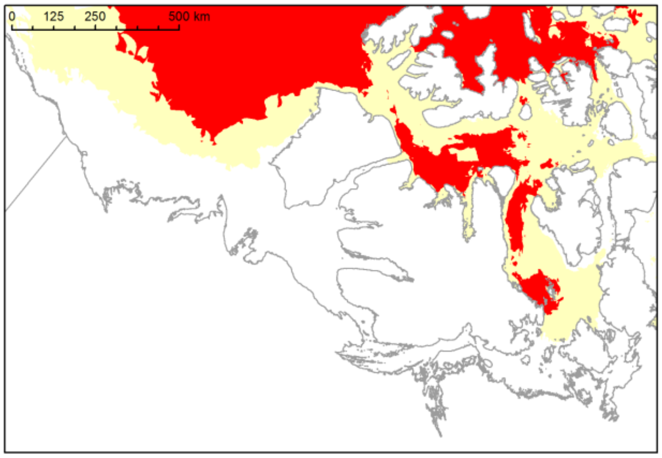

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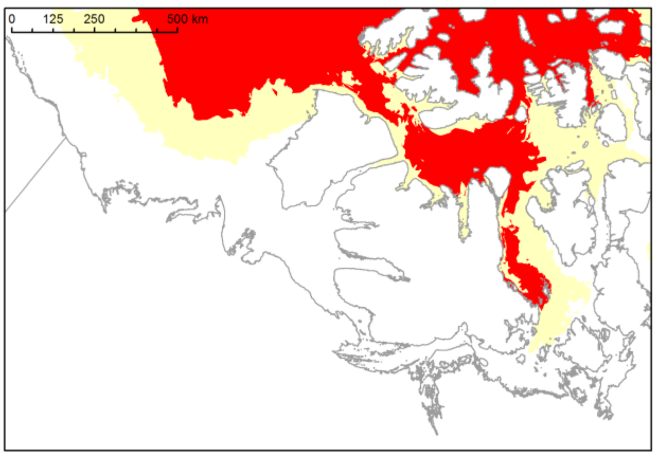

Figure 7. Annual fall ice minimums >50% (yellow) and >90% (red) frequencies on (a) August 20, (b) September 3, and (c) September 17 based on a 30-year average (CIS 2011). On the date shown, there is ice (>1 tenth) in the yellow area more than 50% of the time and more than 90% of the time in the red area. Areas without colour have ice less than 50% of the time on the dates shown.

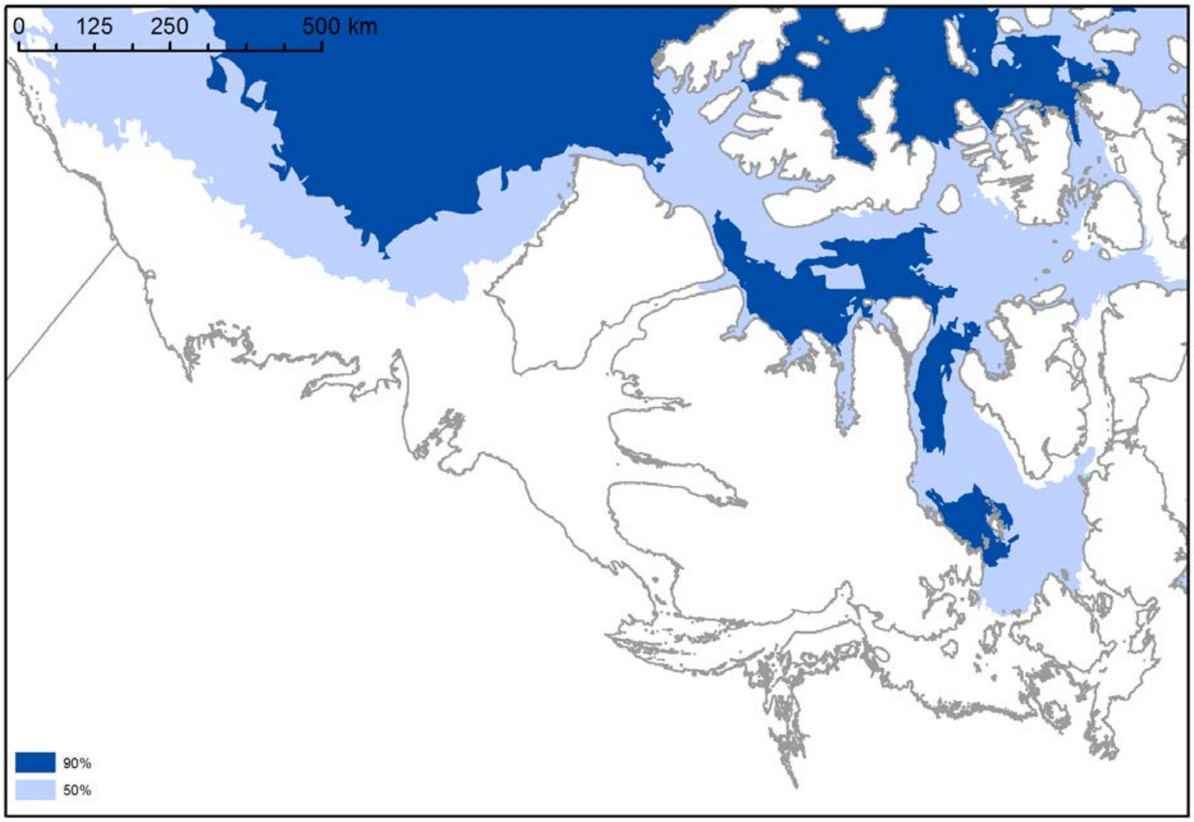

Figure 8. September 50% and 90% sea-ice frequencies based on the 30-year average minimum extent of ice (CIS 2011). September has the smallest area with the likelihood of encountering sea ice. This figure illustrates areas with high ice concentrations that seasonally persist throughout the year. Non-coloured areas had 0–50% sea-ice frequency.

The "Median of Old Ice Concentration" charts, representing the 30-year median concentration of old ice (sea ice which has survived the summer melt to October 1, plus any second year ice or multi-year ice) for each chart date, were used to depict the areas where old ice may play a large or dominant role in the ice regime of the area (Figure 9). These areas may reflect not only the physical parameters that cause the presence of old ice, but also give an indication of the different ecosystem and habitat dynamics in these areas. Data of this type are different from simply looking at ice presence or frequency on a specific date as it provides a critical separation of ice type. Ice type can be important to the physical and biological ecosystem components. For example old ice is largely or completely drained of brine (salt content), thus future melt of this ice results in fresh water added to the ocean surface layer and this fresh water changes the habitat for under-ice flora and fauna (e.g., by excluding species that are not fresh water tolerant).

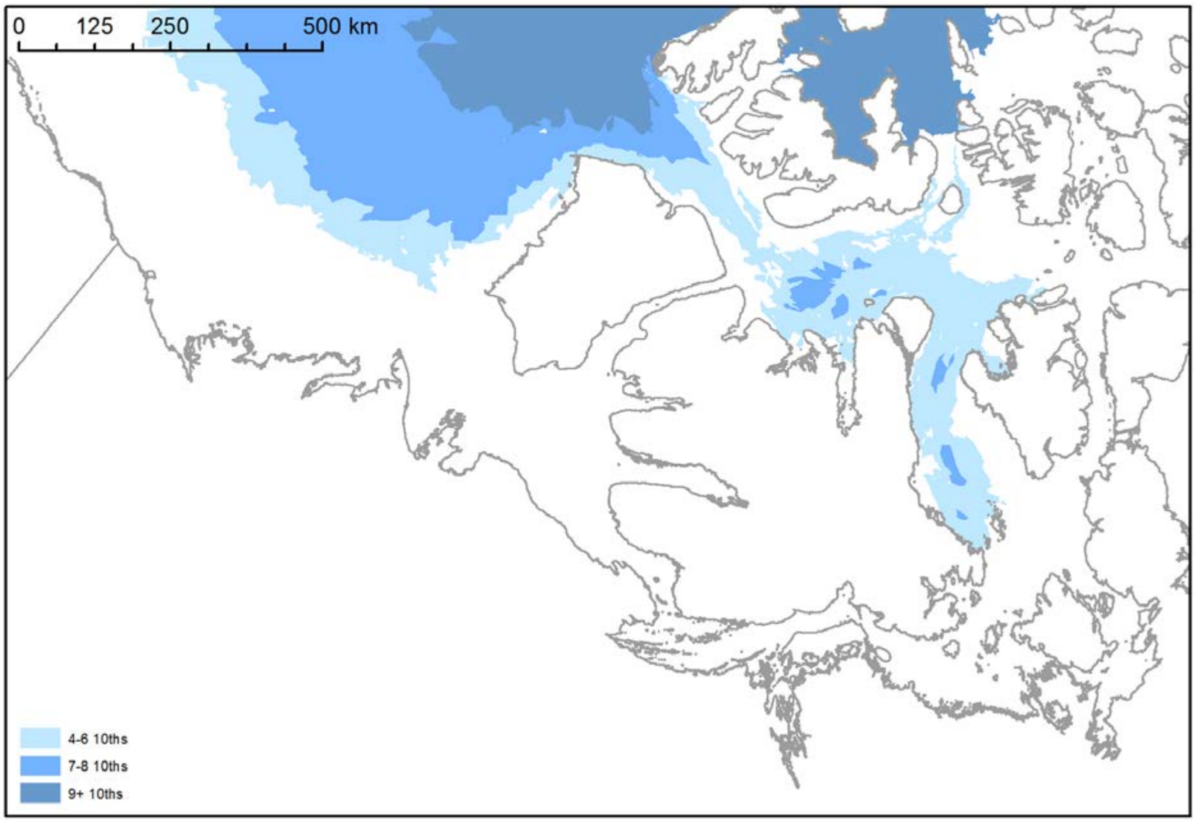

Figure 9. Median areal concentration of old ice (sea ice which has survived at least one summer's melt) from CIS (2011). Concentrations are shown in categories of tenths. Non-coloured areas indicate ice concentrations < 4 tenths.

Break-up (Figure 10) and freeze-up (Figure 11) dates are unaltered products from the CIS Ice Atlas, constructed using charts of the Median of Ice Concentration, to depict the extent of ice during freeze-up and break-up. The extent of ice on the date indicated thus represents the bi-weekly time step when ice concentration became greater than 5/10ths (freeze-up) or became less than 5/10ths (break-up). Freeze-up and break-up is seen as a useful dataset for eco-unit delineation because these parameters reflect several important driving forces (e.g., weather and climate including wind, ocean currents and circulation) while at the same time they give an indication of habitat conditions that impact ecosystem biological components.

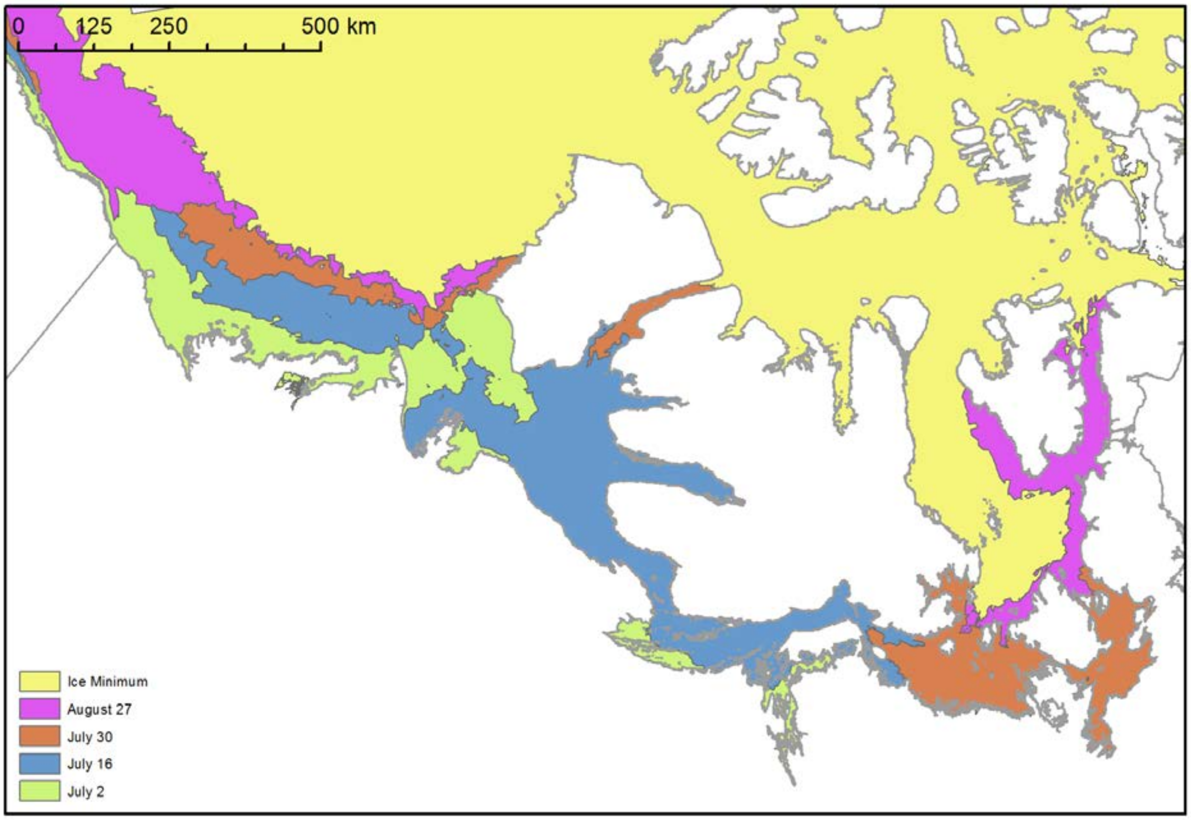

Figure 10. Average sea-ice break-up by date (30-year average CIS ice climatology database, CIS 2011). For example, the purple area reached 50% ice concentration by August 27 while the yellow area never reached 50% ice concentration.

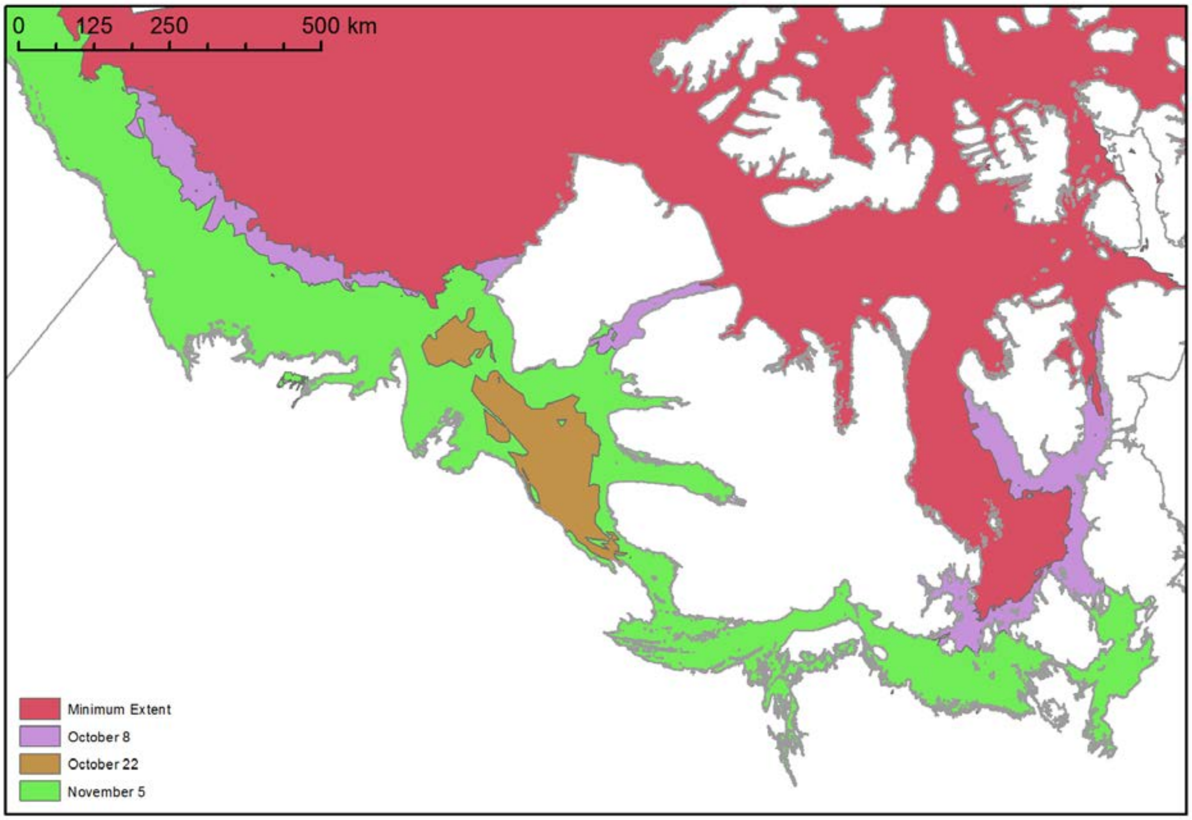

Figure 11. Average sea-ice freeze-up by date from the 30-year CIS ice climatology database (CIS 2011). For example, the green area reached 50% ice concentration by November 5 while the maroon area never went below 50% ice concentration for this analysis.

The Median of Ice Concentration dataset from CIS (2011) was used to examine where and when landfast ice (10/10ths ice) is at its maximum extent. April 1 was the date when the maximum extent of 10/10ths ice occurred (Figure 12).

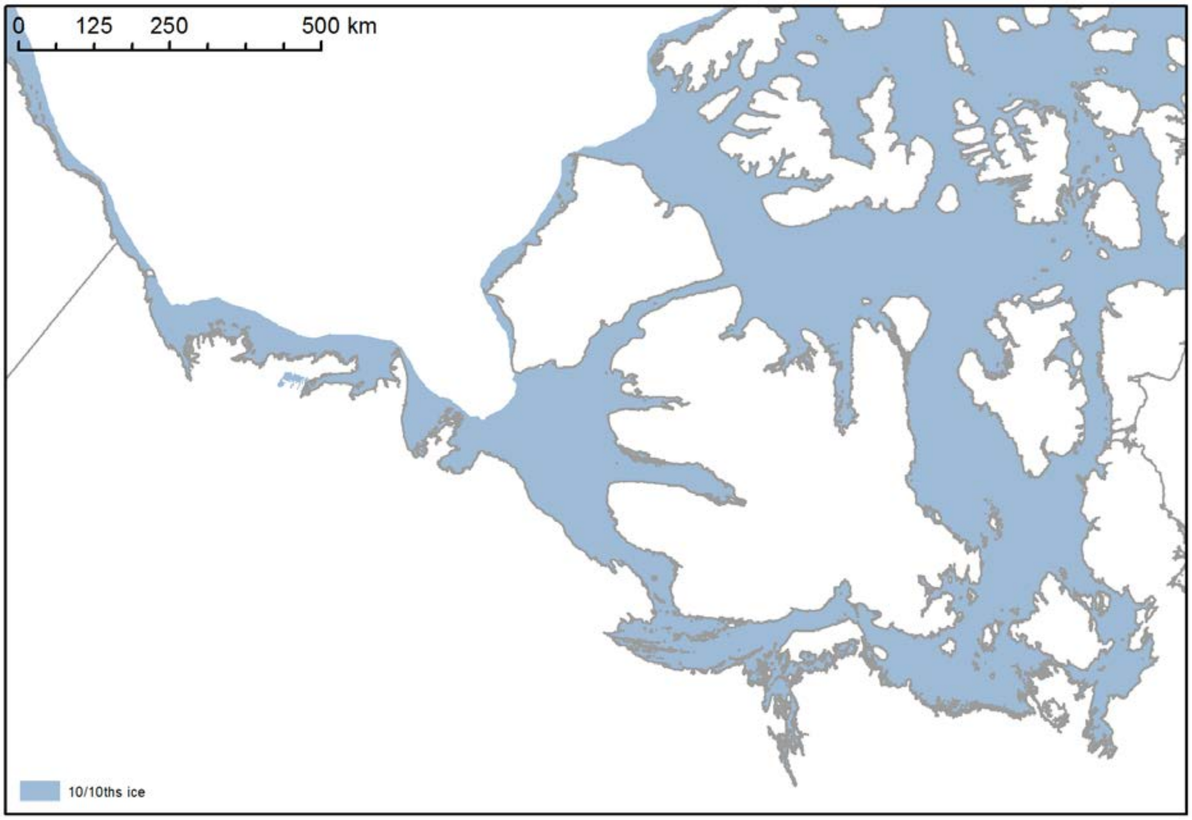

Figure 12. Average maximum extent of landfast (10/10ths) sea ice (CIS 2011).

In addition to looking at the maximum extent of landfast ice, the seasonal retreat of this landfast ice-edge was examined. The ice-edge feature is an important one ecologically (Alexander and Niebauer 1981) and for local hunters using the secure landfast ice to access the productive open-water areas adjacent to the landfast ice. In the spring as light returns to the north, under-ice habitats and open-water areas become productive, this drives:

1) productivity cycles,
2) seasonal increases in abundances of biota (population growth), and
3) return of species to the area.

All these then establish the pattern and processes associated with the trophic structure. The differential timing of landfast ice break-up based on local conditions and climate causes the presence and timing of the ice-edge feature to differ within a regional scale. To better understand this process, ice break-up dates (from CIS data described above – see 'Freeze-up and Break-up Dates') were used to track the retreat of the fast ice-edge from its maximum extent (April) through the spring and summer period (Figure 13). 10/10ths ice used to define landfast-ice was examined on dates coinciding with breakup dates for that area. The associated extent of 10/10ths ice for each area (as delineated by breakup date) thus gives an approximate location of the ice-edge.

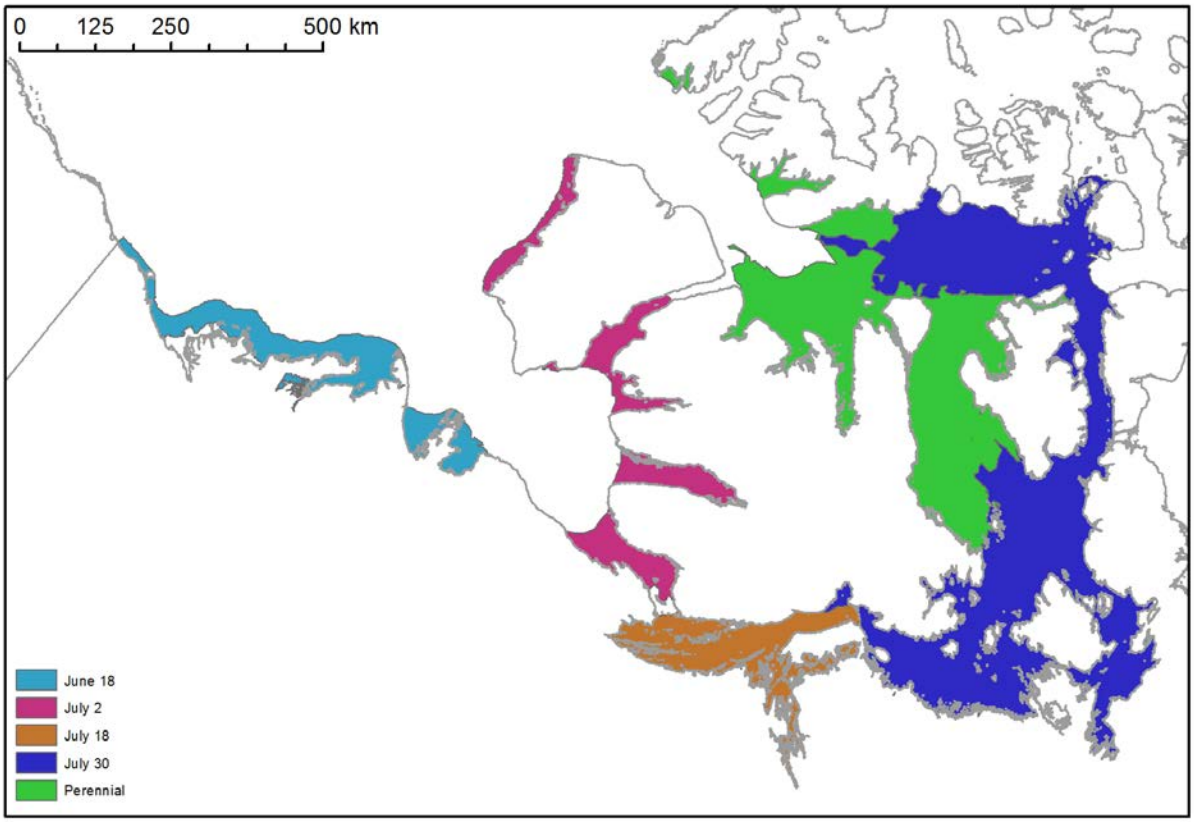

Figure 13. Landfast ice-edge retreat (distribution of 10/10ths ice on dates shown indicates approximate location of landfast ice-edge) through the spring break-up period (CIS 2011).

Sea ice typically breaks up as a result of physical forces acting on it such as wind, tidal fluctuations and water currents as it begins to weaken during melt. This break-up typically separates an off-shore ice pack from land-fast ice and the transition between these two regimes is often called the spring ‘ice edge’.

Additionally, as snow and ice melt first from the land, fresh water inputs can accelerate sea-ice melt/break-up in an area offshore from river mouths. To evaluate the influence of river inputs on accelerated ice melt, areas with decreased frequency (areas within the 100% (pre-breakup fastice) with <100% ice frequency) of ice prior to break-up were plotted (Figure 14). Examining the patterns of spring ice reduction in areas along the coast with river outflows can give a relative idea of the different zones of river influence. Figure 14 shows areas close to rivers/shore that have a greater probability of becoming ice-free prior to the more general break-up of landfast ice in the area.

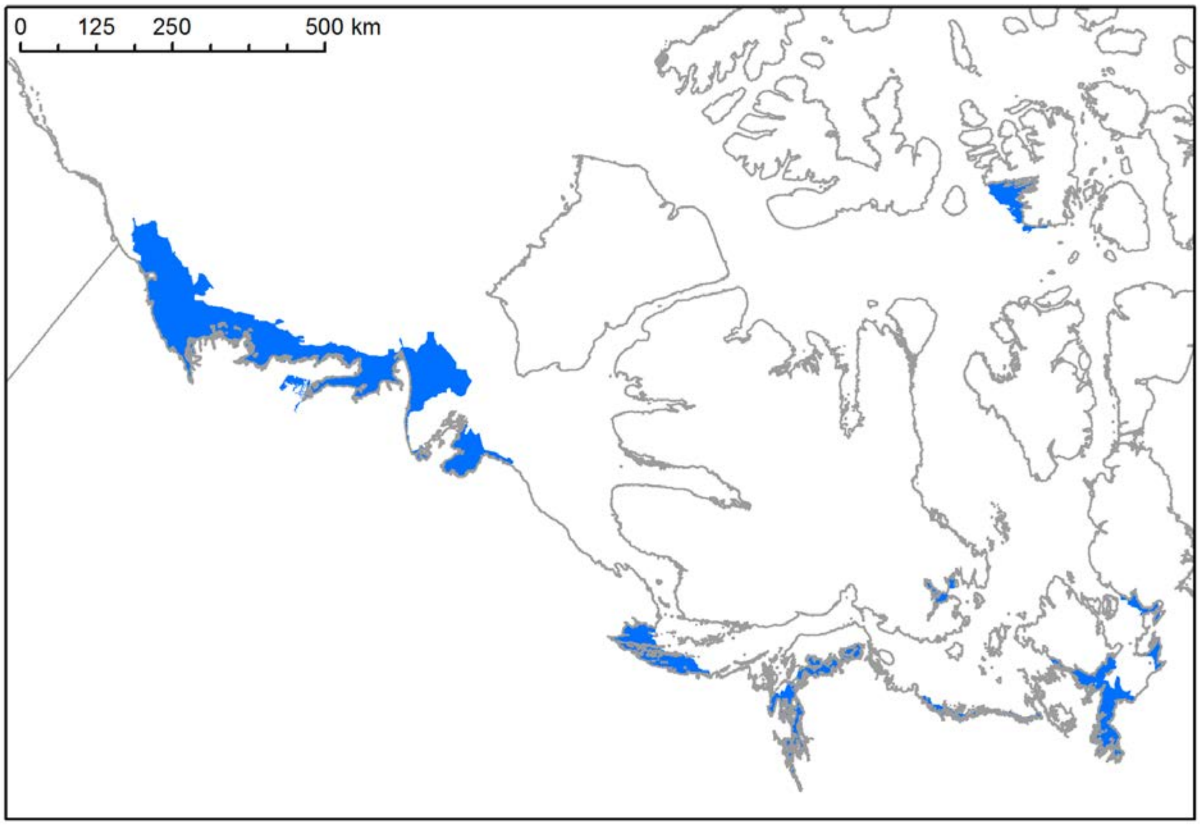

Figure 14. Areas of coastal sea-ice melt as a proxy for river influence on nearshore ice dynamics (CIS 2011). Derived from sea ice historical frequency data, where landfast ice is taken as ice attached to shore with 100% frequency, and melt at river mouths is seen as a shoreward reduction in sea ice frequency prior to fastice breakup.

In addition to the ice frequency analysis using (CIS 2011), the Canadian Ice Service divides the Arctic into Regions and Sub-regions (CIS 2007 unpubl. rep.) based on historical ice conditions and logistical requirements. Appendix 2 illustrates the relevant CIS ice sub-regions in the WAB.

Sills and Water Masses

In delineating marine areas, consideration as to the origin and composition of the water masses is essential (Table 1). As in other marine systems, the waters of the western Arctic are part of a complex system of water inputs, outputs and internal movements. Localized inputs from rivers and ice melt combine with older source waters from the Pacific and Atlantic oceans. All of these interactions are made more complex by gradients in temperature, salinity (thereby density), by the physical constraints of the seabed morphology and physical forcings (e.g., Coriolis force). For the purpose of eco-unit delineation at the bioregion scale, these complexities were distilled to identify areas that could be defined by the locations of physiographic barriers (i.e., sills) that cause the waters on either side to differ in some respect (i.e., sill causes at least one layer or component of the water column to differ on either side). For example, a shallow depth sill may only allow surface water to exchange, whereas a deeper sill may allow exchange of surface and some type of subsurface flow.

The location of sills was taken from Melling (2000) and mapped (Figure 15), delineating adjacent areas that may have differing water mass/source properties while recognizing this is a simplified two dimensional representation of three dimensional processes.

Table 1. A simplified picture of the vertical stack of water masses within the Canada Basin (H. Melling, DFO, pers. comm.).

Name	Depth	Attributes
River Inflow Water	0-5 m	Very low salinity, low or high temperature depending on season, proximity to river mouths
Arctic Surface Water	0-50 m	Low salinity, low or high temperature depending on season, mix of river and Pacific inflow waters plus ice melt-water
Pacific Summer Inflow Water	50-80 m	Salinity 30-32, temperature up to 0°C
Pacific Winter Inflow Water	80-250 m	Salinity 32-33.5, temperature < -1°C, rich in dissolved nutrients
Atlantic Inflow Water via Fram Strait	250-900 m	Salinity 33.5-34.95, temperature up to 1°C
Arctic Inflow Water via the Barents Sea	900-1500 m	Salinity <34.9, temperature <0°C

Using the water mass characteristics in Table 1 along with sill locations and depths can provide a generalized picture of water column properties in the western arctic bioregion (H. Melling, DFO, pers. com.). Sills shallower than 50 m (i.e., Dolphin and Union, and Victoria straits) only allow Arctic surface waters to pass, so the area between two shallow sills is made up of Arctic surface waters and river outflow waters. In this case, even though there may be deeper areas between shallow sills, the water source/type is controlled by the depth of the sills. The sills isolating the basins in Amundsen Gulf and M'Clure Strait (350-400 m) allow the entry of surface and Pacific waters but block most of the Atlantic waters. Sills at the south ends of M'Clintock Channel and Franklin Strait (135 m, 105 m, respectively) allow some Pacific waters into Larsen Sound. The sill at the north end of M'Clintock Channel (305 m) prevents the movement of Atlantic water and the sill at the northeast corner of the bioregion (Barrow Strait - 125 m), allows entry of Pacific summer waters and Arctic surface waters.

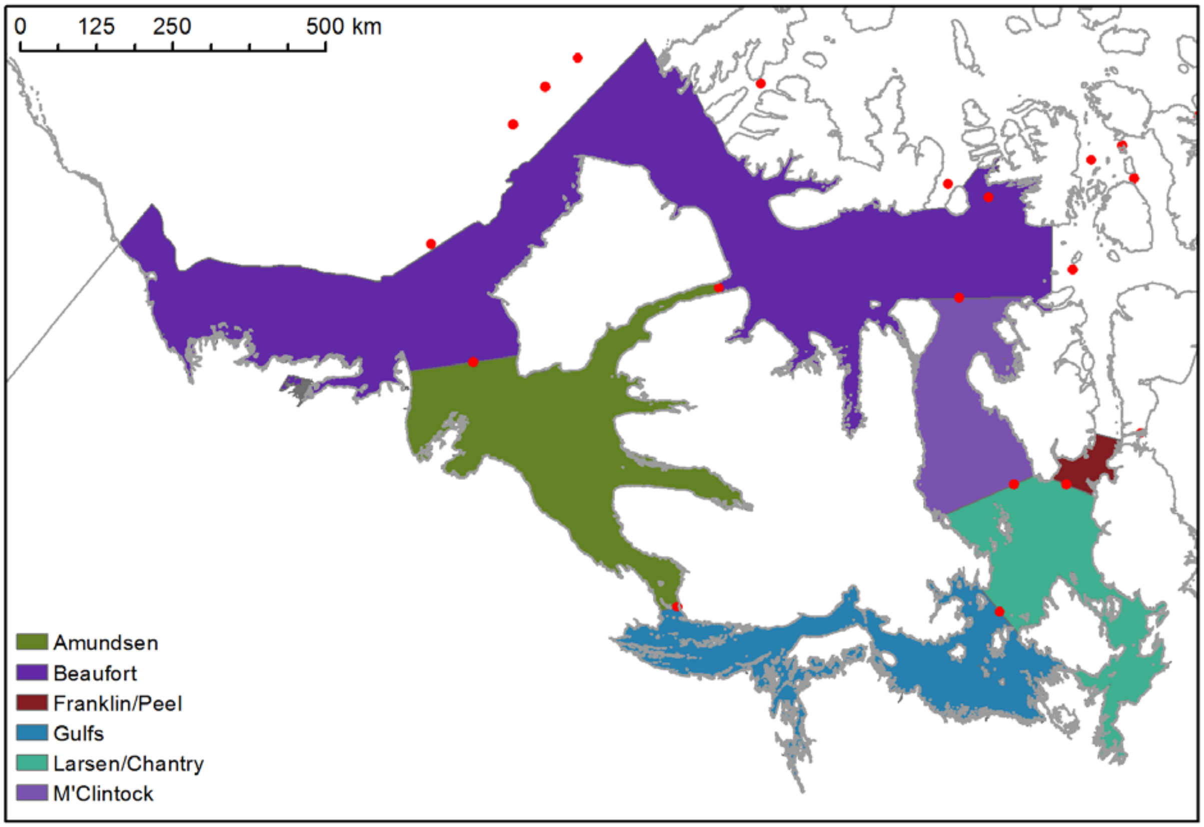

Figure 15. Location of sills (from Melling 2000) and a simplified depiction of differing water masses/sources.

RESULTS AND DISCUSSION

AREAS ASSOCIATED WITH THE MACKENZIE RIVER

1) Mackenzie Estuary (including the Tuktoyaktuk Peninsula, Husky Lakes and Liverpool Bay)
2) Mackenzie Inner-shelf
3) Mackenzie Outer-shelf

The Mackenzie estuary is a gradient based on the mixing zone of river and ocean waters and this zone can change significantly with season and annual variability (McClelland et al. 2011). To be conservative in our estimate of the eco-unit delineated by the influence of waters of the Mackenzie River and for consistency we used the area described in the Beluga Management Plan (2002) as the Mackenzie Estuary and Tuktoyaktuk Peninsula for the Mackenzie Estuary eco-unit (Figure 16).

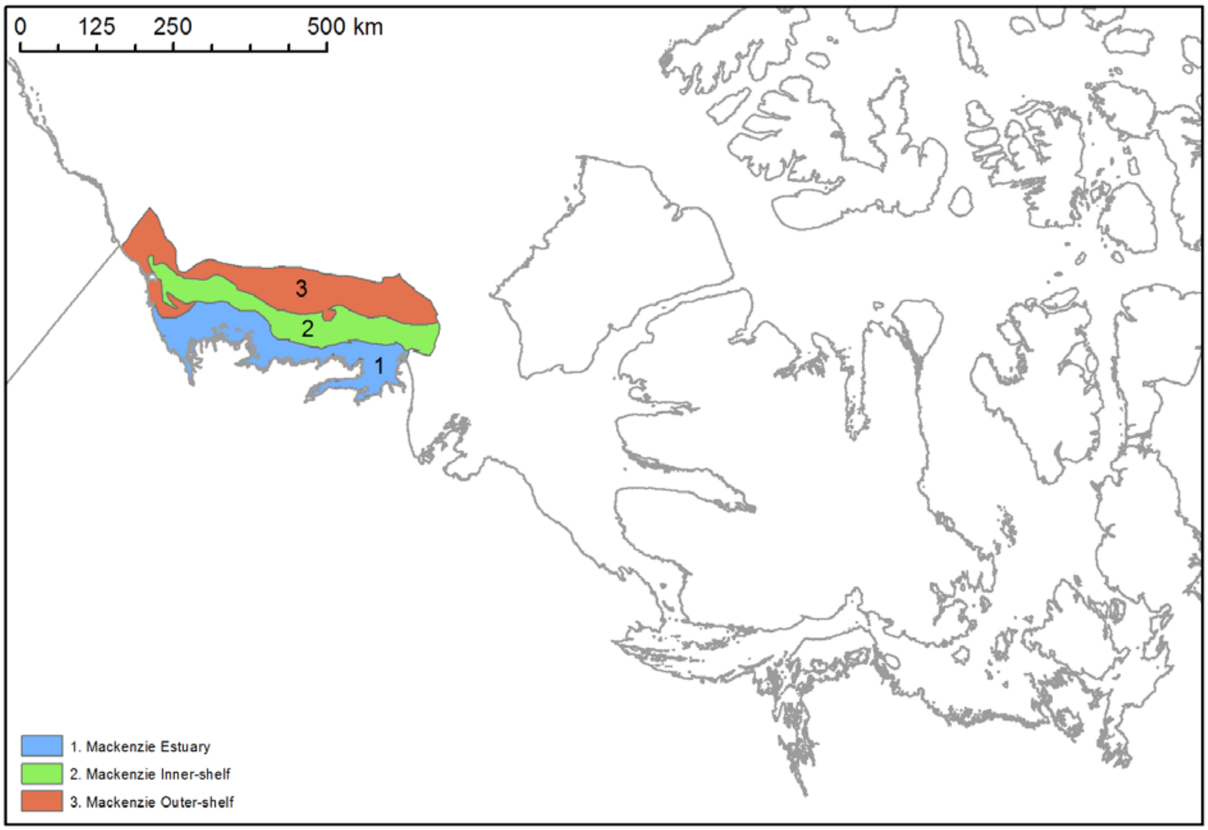

Figure 16. Three eco-units associated with varying influence of the Mackenzie River.

The effect of the Mackenzie River discharge waters on adjoining ecosystems is significant (Carmack and Macdonald 2002, Richerol et al. 2008). Beyond the estuary itself, the plume of the Mackenzie River can be used to delineate this extended area that is influenced significantly by mixing of fresh river waters and sediment with marine waters. However, the extent and shape of the plume changes in accordance with multiple factors including the volume of river discharge waters, wind dynamics and ocean currents, and the presence (or absence) of ice. Due to its dynamic nature the plume itself is not easily used as a primary eco-unit delineator.

Within the area influenced by the Mackenzie River plume is the spring flaw lead (see Figure 6). These two factors are why a Mackenzie Inner-shelf eco-unit is delineated. Since the exact boundaries of the plume are difficult to delineate, this eco-unit is delineated based on the average extent of the spring flaw lead that overlies the shelf (eastern edge is delineated by the edge of the shelf, i.e., 200 m depth).

North of the Mackenzie Estuary and Mackenzie Inner-shelf eco-units, the physiography of the ocean floor continues to be relatively flat with water depths <200 m to the shelf break (steep slope) and from there into the Arctic Basin. The outer edge of the Beaufort Shelf is also the boundary of the Western Arctic Bioregion generally following the 200 m isobath. The areas of deeper waters within Canada’s Exclusive Economic Zone are not considered here as they are within the Arctic Basin Bioregion. Thus the Mackenzie Outer-shelf eco-unit is largely delineated by the boundaries of Mackenzie Inner-shelf eco-unit to the south, the boundary of the WAB to the north and west and by the bathymetry (shallow water and slope edge) to the east (Figure 16). The Mackenzie Outer-shelf eco-unit would still have some limited and seasonal influence of the Mackenzie River, however, the fall-to-spring ice regime of this area is dominated more by the mobile ice of the Beaufort Sea pack-ice as it is offshore of the extent of both the fast-ice area and the flaw-lead/polynya system.

AREAS OF AMUNDSEN GULF

1) Amundsen Gulf Polynyas
2) Amundsen Gulf Bays
3) Amundsen Gulf Pelagic

Two isolated areas south/southwest of Banks Island were deemed to be representative of what is commonly referred to as the Cape Bathurst Polynya/flaw lead complex (Arrigo and van Dijken 2004, Galley et al. 2008, CIS 2011). Although this ice feature is re-occurring annually, the exact location, timing and extent of the feature is unpredictable due to the many factors that influence its development (e.g., ice structure and strength, wind direction and speed, ocean currents and temperatures). Based on historical occurrence three areas are delineated, however, on any given year the polynya is unlikely to form at all three locations. Forces driving the formation and location of the polynya in a given year will dictate which of these likely areas will contain the polynya. The more northern of the two areas is associated with the flaw lead that extends west, following off-shore along the mainland coast and extending north-northeast off-shore along the coast of Banks Island (see Figure 6). The extensions are included in separate eco-units due to other associated features. There is a third area of reduced spring ice frequency at the mouth of Dolphin and Union Strait, between the mainland and Victoria Island, which is apparent from the same spring sea-ice frequency data (CIS 2011). All three areas are included in the Amundsen Gulf Polynyas eco-unit as they were all delineated by the same data source and have no particular secondary data source that would justify treatment as separate eco-units. It is noted, however, that because the areas are spatially independent from one another, use of the Amundsen Gulf Polynyas eco-unit within a resource management/planning perspective should be done with special consideration taken in respect to the three isolated areas.

Four large bays adjacent to Amundsen Gulf were delineated as a separate eco-unit (Amundsen Gulf Bays) based on their physical characteristics (i.e., sheltered coastal physiography as well as river influences), water depths and sea-ice regime (spring ice-edge used to delineate mouth of bays/eco-unit extent) (Figure 17).

Areas within Amundsen Gulf not captured by the Amundsen Gulf Polynyas or Amundsen Gulf Bays eco-units are considered the Amundsen Gulf Pelagic eco-unit (Figure 17). The western boarder of the Amundsen Gulf Pelagic eco-unit is the boundary of the bioregion and not an ecosystem boundary. They align well with Roff et al. (2003), and Wilkinson et al. (2009) and are classified here due to the deeper waters (>200 m), and ice regime (ice type and duration). It is important to note that the three areas that make up this eco-unit are not separate in any physical or biological sense. In fact, for most of the year these areas have no delineating feature to separate them from one another or from the areas of the Amundsen Gulf Polynyas eco-unit. It was however, important in this classification scheme to capture the prominence of polynyas, and as a consequence the Amundsen Gulf Pelagic eco-unit is divided into three areas.

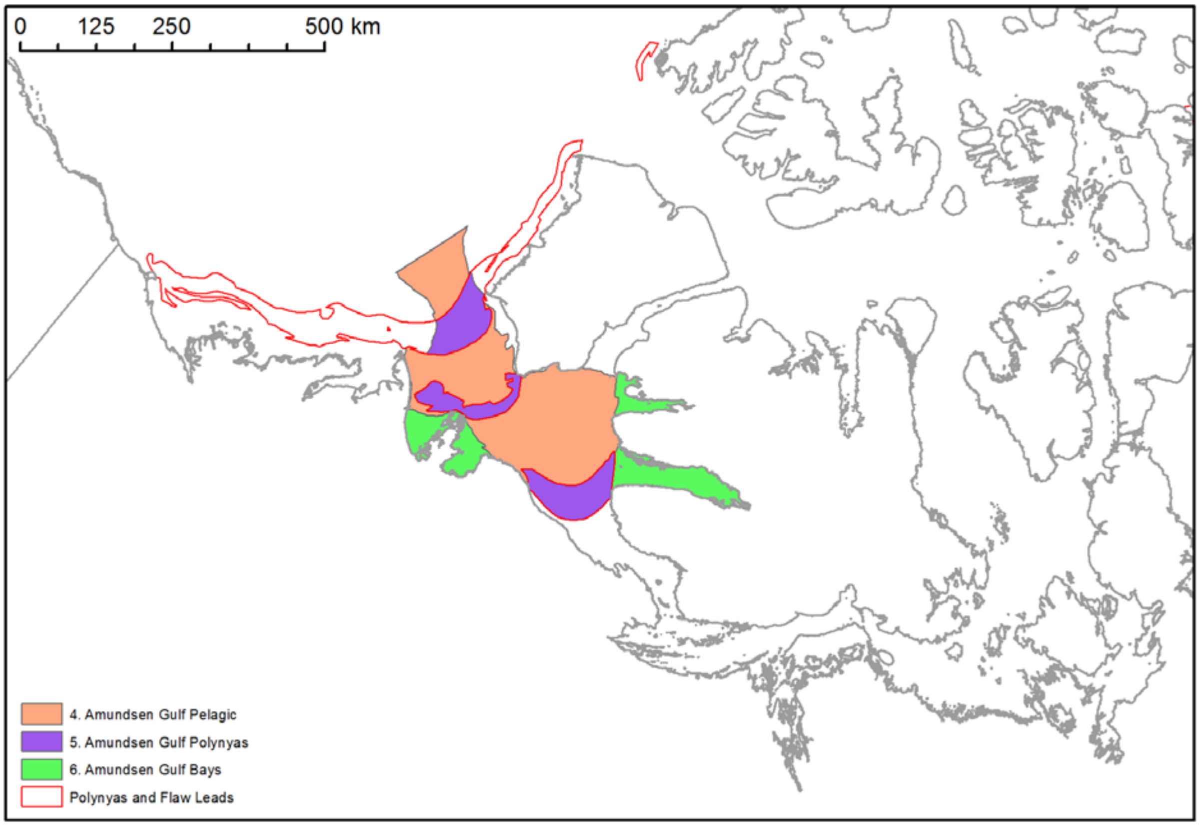

Figure 17. Three eco-units of the Amundsen Gulf area. Red lines overlay the polynyas. The ice edge data from April 30 (average 1981-2010) were used to delineate the Amundsen Bays eco-unit.

ICE-DOMINATED AREAS

1) Beaufort Sea Pack-ice
2) North Victoria Island Shelf
3) Melville Banks Shelf
4) Western Parry Deep Channel
5) M'Clintock Channel Complex

Two significant, spatially separate areas were identified from analysis of the September ice frequency data (Figure 18) and corroborated by CIS old-ice concentration data. Area 1 is the Beaufort Sea Pack-ice eco-unit, and Area 2 is the North Victoria Island Shelf eco-unit. Area 1 corresponds in character to CIS sub-region cwa01_04 although this sub-region does not extend into M'Clure Strait as depicted by the ice frequency analysis. The western boarder of the

Beaufort Sea Pack-ice eco-unit is the boundary of the bioregion and not an ecosystem boundary.

The North Victoria Shelf eco-unit on the south side of Viscount Melville Sound appears similar to the Melville coastal area in Roff et al. (2003) and Wilkinson et al. (2009) systems. Roff et al. (2003) does separate a deeper basin in the centre of Viscount Melville Sound extending down into Hadley Bay, and also a euphotic coastal area around Stefansson Island. Here we incorporate the areas identified in the summer/fall ice minimum analysis (Figure 18). This area has a tendency for ice to build up (via wind and water currents moving ice into this area) and remain in this area throughout summer until the onset of freeze-up. Therefore delineation inputs for this eco-unit are bathymetry (and derived seabed morphology, i.e., basin and ridge – see Figure 19) and sea-ice regime (i.e., accumulation of mobile ice throughout the summer months).

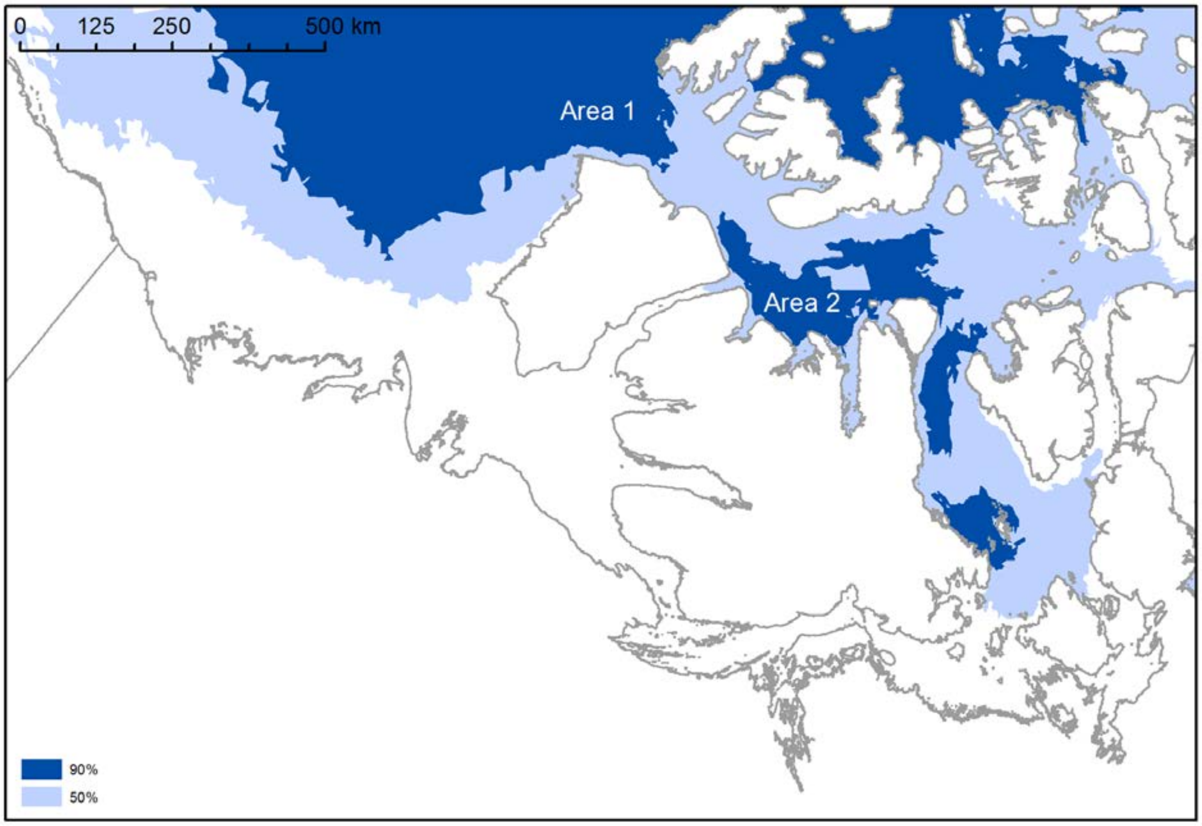

Figure 18 Beaufort Sea Pack ice, areas 1 and 2. Summer ice minimum, 90% (dark blue) and 50% (light blue) ice frequencies. Analysis from data supplied by CIS 2011.

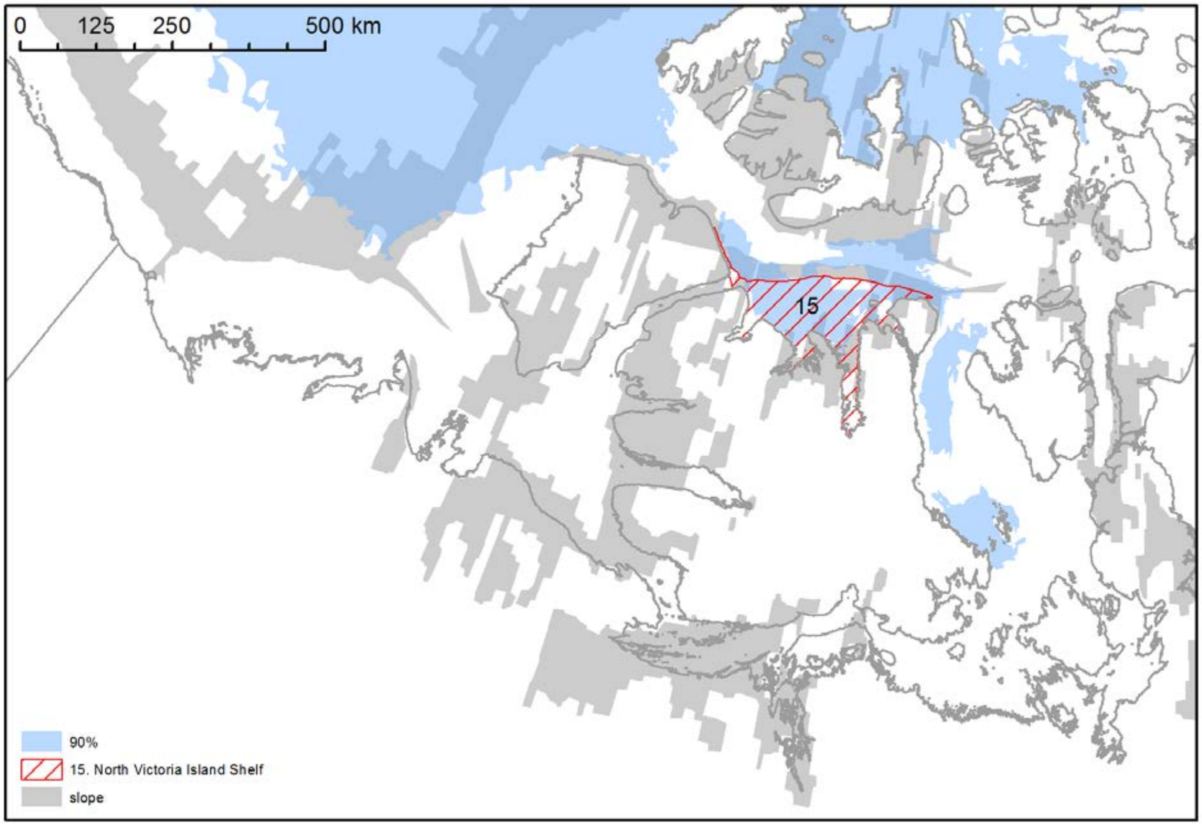

Figure 19. North Victoria Island Shelf eco-unit (hatching) overlain with summer ice >90% (blue) and seabed morphology/slope (gray).

The coastline of the islands along the northern boundary of the WAB consists of little or no shallow euphotic zone as the land and coastal seabed are steeply sloped. Coastal areas delineated by Roff et al. (2003) and Wilkinson et al. (2009) consist of narrow deeper shelves classified as being Neritic[1] (Wilkinson et al. 2009) and Dysphotic[2] (Roff et al. 2003). Unlike the main channel this coastal area, named the Melville Banks Shelf eco-unit (Figure 20), is unlikely to contain multi-year ice and is not likely to remain ice covered throughout the year. Primary delineation inputs for the Melville Banks Shelf eco-unit are bathymetry and multi-year ice distribution. The coastal zone separates the shelf (<200 m) from the channel proper (Western Parry Channel and Viscount Melville Sound) with depths greater than 1000 m. The east boarder of the eco-unit is the boundary of the bioregion and not an ecosystem boundary.

Characterized here and by others based on the deep waters (i.e., bathymetry as a primary delineator) of M’Clure Strait and the presence of ice throughout the year, the Western Parry Deep Channel eco-unit is comprised of the remaining areas between the Beaufort Sea Pack-ice to the west, the Melville Banks Shelf eco-unit to the north, and the North Victoria Island Shelf eco-unit to the south and the M’Clintock Channel Complex eco-unit to the south-east (Figure 20).

M’Clintock Channel was delineated into a single eco-unit called the M’Clintock Channel Complex. This eco-unit matches well with the CIS sub-region cwa06_00 (Appendix 2). The

[1] Relating to the region of the sea over the continental shelf which is less than 200 meters deep
[2] Poorly lighted designating the dim tract between the photic and aphotic levels in a body of water

channel has been subdivided by depth into three classification units by Roff et al. (2003), and two by Wilkinson et al. (2009). Two sills (north and south of the channel) separate M'Clintock Channel water mass from other water masses in the bioregion, however, due to the nature of the source data for the sills (originally only point locations not linear delineations) it was not used directly for delineation although it presents the strongest scientific case for this area as an eco-unit. Multiple sea-ice data inputs (old ice, minimum ice extent, freeze-up and break-up) as well as the sills data corroborate the boundary of the eco-unit.

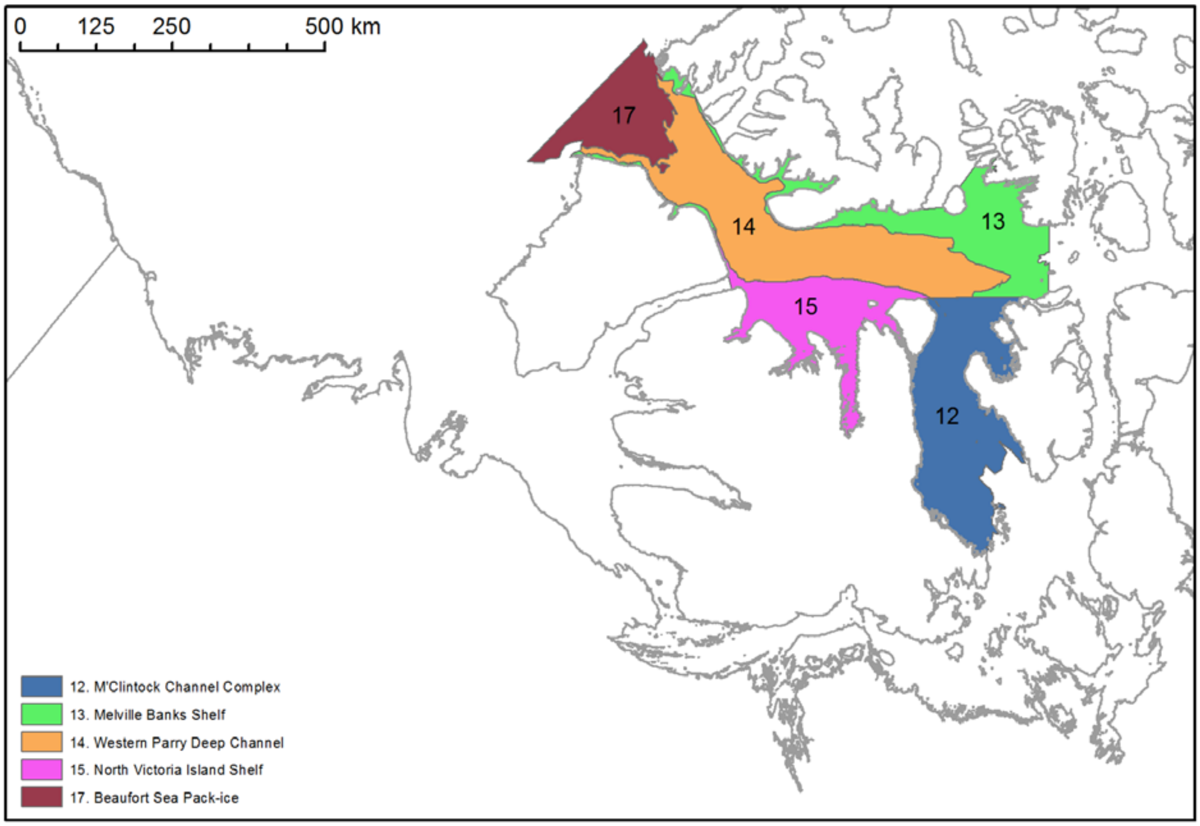

Figure 20. Five eco-units largely influenced by the dominance of ice throughout the year.

SOUTHERN GULFS

1) Queen Maud Shallow Gulf
2) Coronation Deep Gulf

Queen Maud Shallow Gulf and Coronation Deep Gulf eco-units are sandwiched between the continental mainland and Victoria Island and have been classified as one unit by others (Meqag et al. 1994, Roff et al. 2003, Wilkinson et al. 2009) (Figure 21). While there are many similarities between these areas, Coronation Gulf and Queen Maud Gulf were separated based on differences in the timing of sea-ice breakup, and bathymetry/sea bed morphology, and because of the influence of several rivers in both areas (see Figure 14). None of the delineation sources alone were strong enough to support the delineation of these gulfs into two eco-units, however, the corroborating evidence of all three results in two eco-units that are spatially distinct.

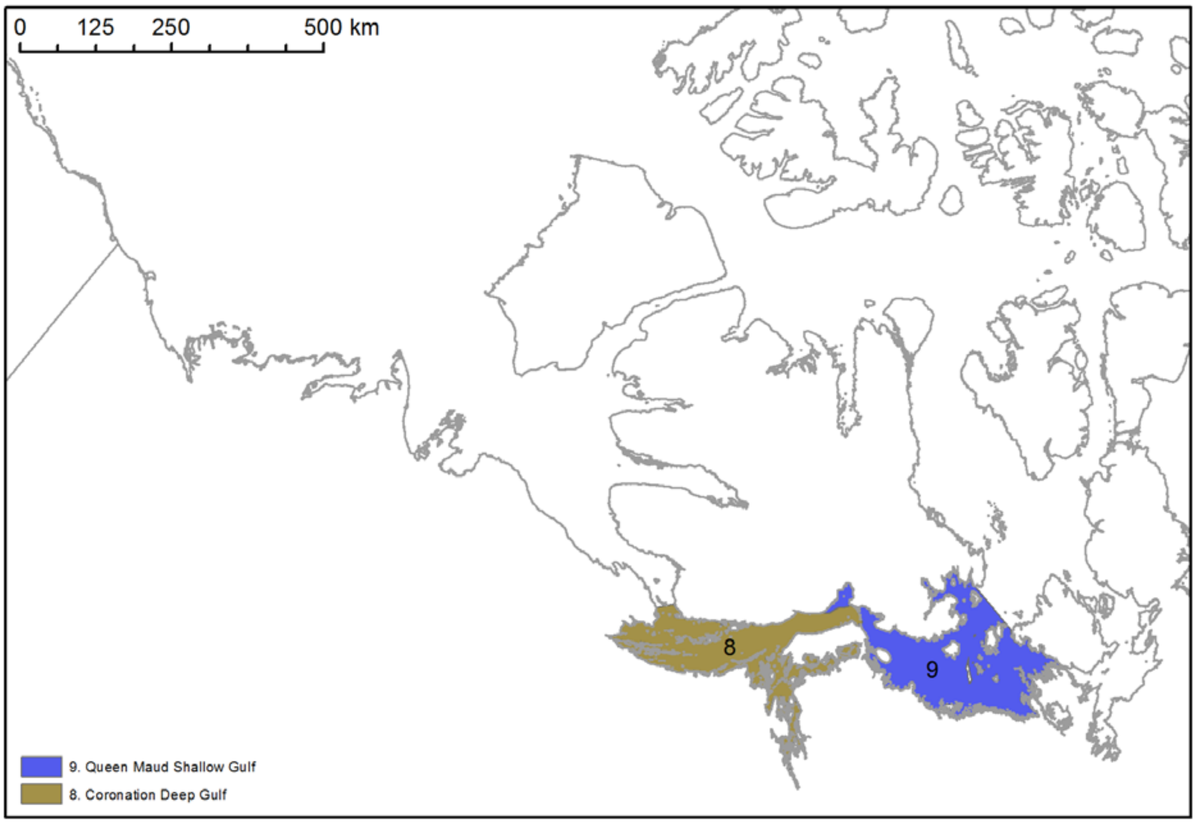

Figure 21. Queen Maud Shallow Gulf and Coronation Deep Gulf Eco-units.

EASTERN AREAS OF THE BIOREGION

1) Larsen Sound Complex
2) Franklin Strait

A sill separates the Franklin Strait eco-unit from adjacent areas of the bioregion and thus functions as the primary delineating input for this area (Figure 22). In addition, this area has a different annual ice regime than the majority of the surrounding areas. It tends not to accumulate mobile ice after primary break-up and therefore remains largely ice free for the summer. The Franklin Strait eco-unit matches well with the Peel Sound sea-ice sub-region (Appendix 2). The northern end of the eco-unit is the boundary of the bioregion and not an ecosystem boundary.

Larsen Sound Complex is delineated on all sides by the location of sills. It is at a critical intersection adjoining three other eco-units (Queen Maud Shallow Gulf, M'Clintock Channel Complex, and Franklin Strait). Thus, portions of the eco-unit closely align in characteristics with adjoining eco-units. Without the presence of sills to delineate this area as a separate eco-unit, portions of this area would likely have been incorporated with adjoining eco-units, perhaps resulting in the elimination of this eco-unit. Nevertheless, this eco-unit is scale appropriate and justified given the strong delineating nature of the identified sills (see Figure 15).

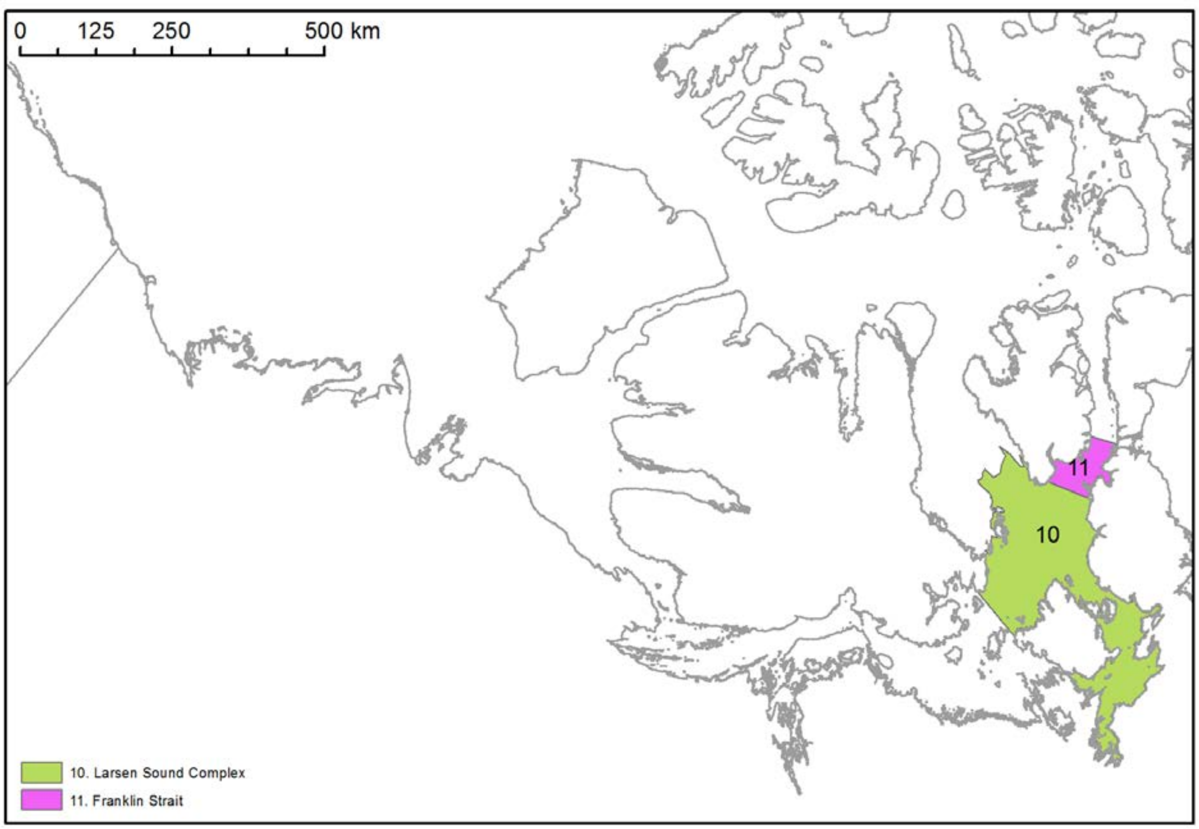

Figure 22. Franklin Strait and Larsen Sound Complex eco-units.

BANKS ISLAND WESTERLY GRADIENT

The Banks Island Westerly Gradient eco-unit is located along the west coast of Banks Island. Presence of a flaw lead (part of the Bathurst Polynya complex discussed earlier) drives the nature of the delineation here, however, the area of the flaw lead is small and the biological use of this lead by birds and mammals is associated with the adjoining land-fast ice and beyond that with the coast of Banks Island. For this reason this eco-unit was delineated to include the full complex of the slope west of Banks Island (Figure 23). It is stressed however, that in specialized cases like this, later use of this eco-unit should consider the nature and direction of the gradient captured in the eco-unit. This eco-unit falls within the Banks sea-ice sub-region (cwa01_03) described as often being free of ice in the summer. However, it often can also have significant summer ice if and when ice is pushed up against the coast by wind and currents (CIS 2007 unpubl. rep.). The western boarder of the eco-unit is the boundary of the bioregion and not an ecosystem boundary. Wilkinson et al. (2009) categorized this area as the ‘Central Arctic Shelf’. Roff et al. (2003) divided the area into three based on presence of ice and water depth/euphotic zone.

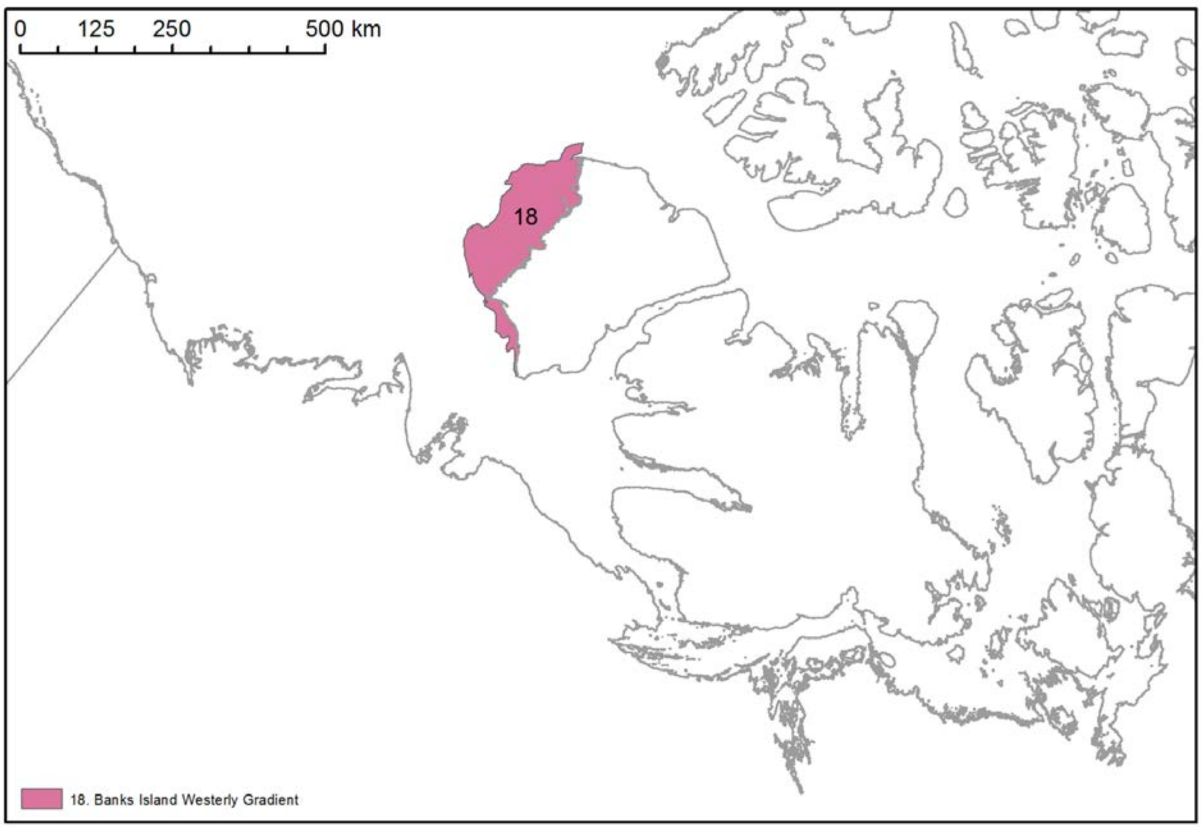

Figure 23. Banks Island Westerly Gradient Eco-unit.

STRAITS

1) Dolphin and Union Strait
2) Prince of Wales Strait

A sill at the southern end of Dolphin and Union Strait is the initial delineation input for this eco-unit (Figure 24). The Northern boundary of the eco-unit is defined by the earlier delineated polynyas eco-unit. This eco-unit has many characteristics that are similar to the Large Amundsen Gulf Bays eco-unit, however, due to this area being a strait with higher currents and water through-flow, it has been kept as a separate eco-unit.

Prince of Wales Strait is similar to Dolphin and Union Strait in that one end is delineated clearly by a sill. The southern boundary of the eco-unit opens to Amundsen Gulf (Amundsen Gulf Pelagic eco-unit) as do the areas included in the Amundsen Gulf Bays eco-unit. However, this area has a later ice break-up date and therefore this input in conjunction with the through-flow nature of this strait (in contrast to Amundsen Gulf Bays) results in this area being classified as a separate eco-unit.

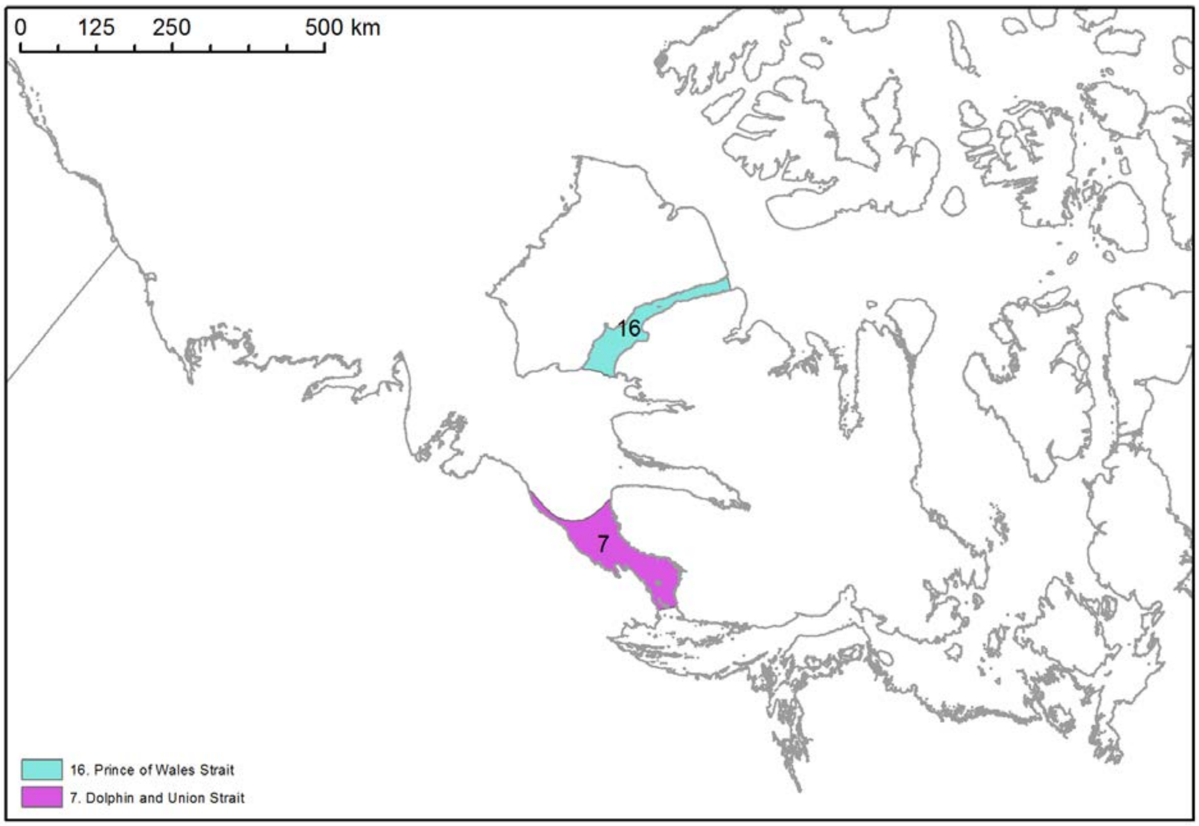

Figure 24. Dolphin and Union Strait, and Prince of Wales Strait Eco-units.

CONCLUSIONS

PROPOSED WESTERN ARCTIC BIOREGION ECO-UNITS

Combined results of the biogeographic classification system produced 18 eco-units in the WAB (Figure 25). Data sources used in different stages of eco-unit delineation are summarized in Table 2.

The classification approach used is intended to produce marine planning units of a specific scale sufficient to divide the WAB into manageable areas based on common data characteristics. For this scale of exercise and the overall size of the WAB, 18 eco-units was deemed to be close to the maximum number for this level of ecosystem mapping and given the type and scale of input data available and used. From an ecosystem perspective, delineation of areas with fixed boundaries (especially in an marine environment) conflicts with the complexities of ecosystem dynamics in space, time and with depth. Therefore, the eco-units presented here should be viewed as and used as such, with care taken to use additional information and data appropriate to each specific question that might be asked in the future, as well, to consider the boundaries between eco-units as ‘fuzzy-boundaries’ that are dependent on the specifics of the question being asked (i.e., seasonality, species focus, scale and dimensionality). This being said, the proposed eco-units were created using the scientific data readily available for spatial planning and GIS analysis, and the results are consistent with respect to the appropriate number, location and scale of ecosystem types and driving forces in the Western Arctic Bioregion, as per previous classifications (e.g., Roff et al. 2003). The delineation of areas by others showed significant similarities between one another as would be expected based on many common inputs, such as bathymetry (Roff et al. 2003; Wilkinson et al. 2009; Meqag et al. 1994).

Some information that could be relevant to the process of determining eco-units was not available for this process. For example, physical features of ecological importance such as upwelling areas were not directly integrated into the classification scheme although they may be considered in other steps in the process of MPA Network development (e.g., EBSAs).

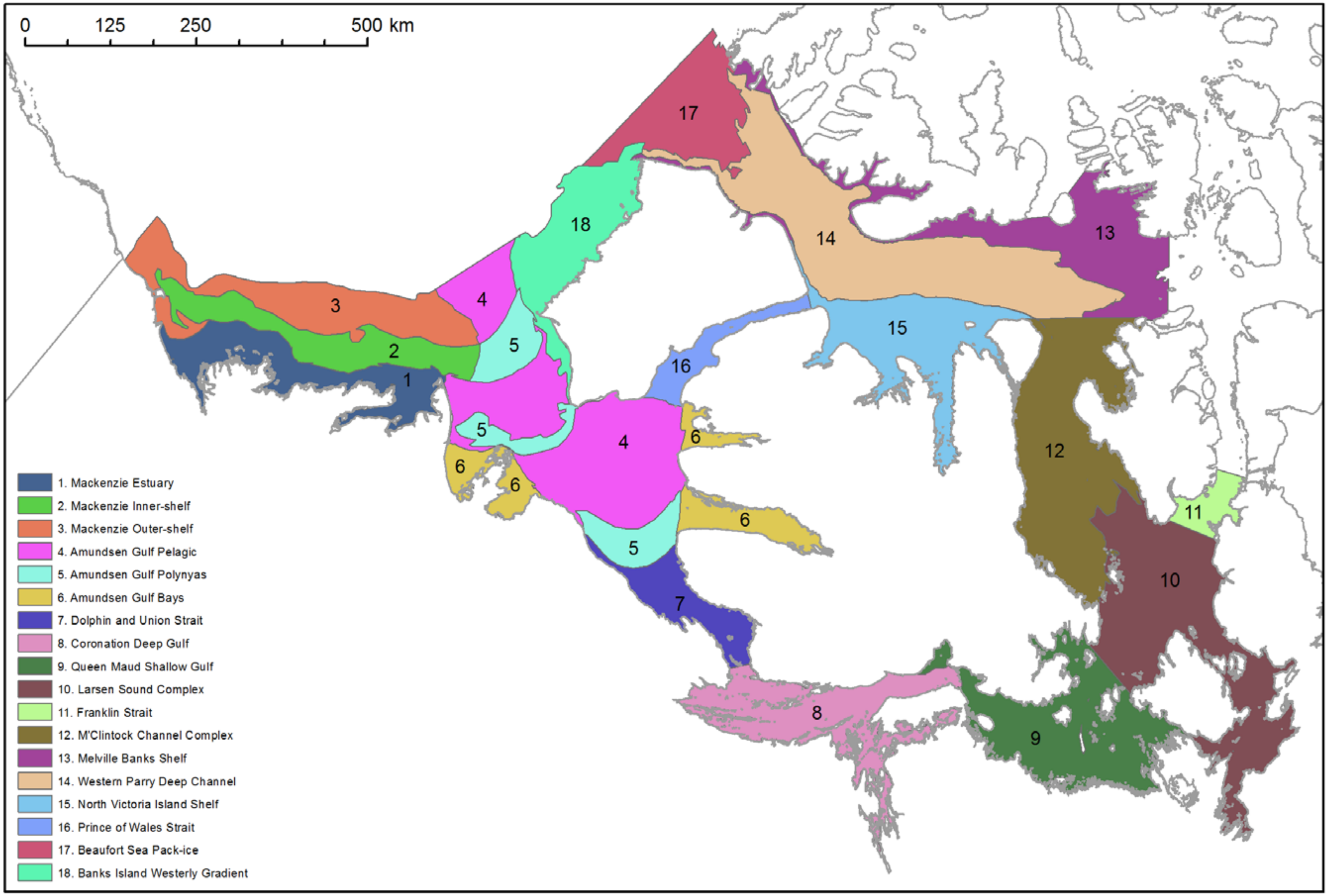

Figure 25. Proposed eco-units in Canada's Western Arctic Bioregion.

Table 2. List of proposed eco-units and the data sources used for their delineation.

ECO-UNIT NAME	PRIMARY SOURCE DELINEATION	OTHER SOURCES OF DELINEATION	CORROBORATING SOURCES
Amundsen Gulf Bays	Fast-ice edge	Ice Frequency Analysis - (removal of areas)	Roff et al. 2003, Wilkinson et al. 2009
Amundsen Gulf Pelagic	Bathymetry	Ice Frequency Analysis - (removal of areas)	MEQAG et al. 1994, Roff et al. 2003, Wilkinson et al. 2009
Amundsen Gulf Polynyas	Ice Frequency Analysis	None	MEQAG et al. 1994, Arrigo and Dijken 2004, CIS 2007, Galley et al. 2008
Banks Island Westerly Gradient	Bathymetry	Ice Frequency. Analysis	CIS 2007, Wilkinson et al. 2009
Beaufort Sea Pack-ice	Ice Frequency Analysis	None	None
Mackenzie Outer-shelf	Bathymetry	Beluga Management Zones (FJMC 2001); Removal of areas (see Mackenzie Inner-shelf)	None Required
Coronation Deep Gulf	Ice Breakup Seabed Morphology	Bathymetry, Sills (western entrance)	MEQAG et al. 1994, Roff et al. 2003, Wilkinson et al. 2009
Dolphin and Union Strait	Ice Frequency Analysis	Sills	None
M'Clintock Channel Complex	Ice Frequency Analysis	Sills, Bathymetry	Roff et al. 2003, CIS 2007, Wilkinson et al. 2009
Mackenzie Inner-shelf	Ice Frequency Analysis	Bathymetry	Roff et al. 2003 , CIS 2007
North Victoria Island Shelf	Ice Frequency Analysis	Bathymetry, Seabed Morphology	Roff et al. 2003, Wilkinson et al. 2009
Mackenzie Estuary	FJMC (2001) Beluga Management Zones	Fastice Edge Analysis	None

ECO-UNIT NAME	PRIMARY SOURCE DELINEATION	OTHER SOURCES OF DELINEATION	CORROBORATING SOURCES
Larsen Sound Complex	Sills	Ice Frequency Analysis, Coastal Analysis (inclusion of flaw lead)	None
Melville Banks Shelf	Ice Analysis	None	Roff et al. 2003, Wilkinson et al. 2009
Franklin Strait	Sills	Bathymetry (lack of shallow coast)	Roff et al. 2003, Wilkinson et al. 2003, CIS 2007
Queen Maud Shallow Gulf	Ice Breakup	Sills, Seabed Morphology (lack of slope)	MEQAG et al. 1994, Roff et al. 2003, Wilkinson et al. 2009
Prince of Wales Strait	Sills/ Ice Analysis	Current (inferred from nature of waterbody)	None
Western Parry Deep Channel	Bathymetry	None	CIS 2007

Table 3. Eco-units in the Western Arctic Bioregion, their primary source and delineation characteristics based on the GIS analysis, not on general characteristics or observations. Percentages are area-based, as derived from GIS data layers (i.e., percentage of the eco-unit area containing the feature layer).

	Eco-unit	Neighbours	Unique from neighbours	Characteristics
1	Mackenzie Estuary	Mackenzie Inner Shelf	Dominance of fastice Shallow depths (<20 m)	98% fastice, fastice edge mid-June, no old ice, shallow 20 m depth, early July breakup, Late October freeze-up, 87% River influence (Mackenzie), Beaufort water mass
2	Mackenzie Inner-shelf	Mackenzie Estuary Mackenzie Outer-shelf	Depths (79% 20-100 m) Presence of spring open water lead	9% fastice, fastice edge defines southern edge, no old ice, mixed shallow-moderate depths, mid-July breakup, Late October freeze-up, 24% River influence (Mackenzie), Beaufort water mass
3	Mackenzie Outer-shelf	Mackenzie Inner-shelf	Same as Mackenzie Inner Shelf except no spring open water lead	9% fastice, no significant ice edge, no old ice, 87% 100-200 m depths, mixed July breakup, 87% late October freeze-up, 21% River influence (Mackenzie), Beaufort water mass
4	Amundsen Gulf Polynyas	Amundsen Gulf Pelagic Amundsen Gulf Bays Mackenzie Inner -shelf	Depths separate from Mackenzie Inner Shelf and Amundsen Gulf Bays (80% 200-500 m - same as Amundsen Gulf Pelagic) Spring open water separate from Amundsen Gulf Pelagic and Amundsen Bays.	47% fastice, no fastice edge, no old ice, small chance of late season ice, 80% moderately deep (200-500 m), mid-July breakup, Late October freeze-up, 7% River influence (Mackenzie), mostly Amundsen water mass with 37% Beaufort water
5	Amundsen Gulf Pelagic	Amundsen Gulf Polynyas Amundsen Gulf Bays Mackenzie Outer-shelf	Depths separate from Amundsen Gulf Bays and Mackenzie Outer Shelf (76% 200-500 m) Lack of spring open water separates from Amundsen Gulf Polynyas	60% fastice, no fastice edge, no old ice, small chance of late season ice, 76% moderately deep (200-500 m), mid-July breakup, Late October freeze-up, 11% River influence (Mackenzie), mostly Amundsen water mass with 26% Beaufort water
6	Amundsen Gulf Bays	Amundsen Gulf Polynyas Amundsen Gulf Pelagic	Dominance of fastice and fastice edge Mixed depths (0-500 m) Protected coastal areas with river influences	98% fastice, fastice edge first half of July, no old ice, mixed shallow depths, mid-July breakup, Late October freeze-up, 19% River influence, Amundsen water mass

	Eco-unit	Neighbours	Unique from neighbours	Characteristics
7	Prince of Wales Strait	Amundsen Gulf Bays Amundsen Gulf Pelagic	Similar to Amundsen Gulf Bays, except channel has water throughput and undetected river influence	99% fastice, fastice edge mid-July, no old ice, with 10% chance of persistent ice, mixed shallow-moderate depth channel, mid-late July breakup, early-mid October freeze-up, undetected river influence, Influenced by Amundsen and Beaufort water masses
8	Dolphin and Union Strait	Amundsen Gulf Pelagic Amundsen Gulf Bays Coronation Deep Gulf Prince of Wales Strait	Almost identical in data to Prince of Wales Strait –differs in that the sill (primary delineator in both cases) is unique in terms of the water masses it influences.	100% fastice, fastice edge in until early July, no old ice, mixed depths, mid-July breakup, Late October/early Nov freeze-up, undetected river influence, Amundsen water mass
9	Coronation Deep Gulf	Dolphin and Union Strait Queen Maud Shallow Gulf	Differs from Dolphin and Union Strait in water mass and river influence Differs from Queen Maud Shallow Gulf in river influence, break-up and deeper waters	99% fastice, fastice-edge until mid-July, no old ice, mixed depths, 72% mid-July breakup, 99% Late October freeze-up, 30% River influence, Gulfs water mass
10	Queen Maud Shallow Gulf	Coronation Deep Gulf Larsen Sound Complex	Differs from Coronation Deep Gulf in river influence (less), break-up (later), shallower waters Differs from Larson Sound Complex in lack of persistent ice, ice free season, water mass	99% fastice, fastice edge until end of July, generally little or no old ice, mixed shallow depths, end of July breakup, Late October freeze-up, 5% River influence, Gulfs water mass
11	Larsen Sound Complex	Queen Maud Shallow Gulf Franklin Strait M'Clintock Channel Complex	Differs from Queen Maud Shallow Gulf in persistent ice presence, and ice free season (shorter) Water mass is unique to this eco-unit River influence separates from M'Clintock Channel Complex and Franklin Strait	99% fastice, fastice-edge until end of July, generally little or no old ice, but 57% chance of persistent ice at 50% concentration, mixed shallow-moderate depths, mixed late season breakup, mixed early freeze-up, 13% River influence, Larson/Chantrey water mass
12	Franklin Strait	Larsen Sound Complex M'Clintock Channel Complex	Water Mass is unique Early breakup for this area	99% fastice, fastice-edge until end of July, generally little or no old ice, chance (30% @ 50% concentration) persistent ice, mixed moderately deep, early July breakup, early October freeze-up, undetected river influence, Franklin/Peel sound water mass

	Eco-unit	Neighbours	Unique from neighbours	Characteristics
13	M'Clintock Channel Complex	Larsen Sound Complex Franklin Strait Western Parry Deep Channel	Unique water mass Dominance of late season and old ice separates from Larsen Sound Complex and Franklin Strait	100% fastice, no fastice-edge, 67% old ice, with 96% chance of persistent 50% and 90% ice concentrations, mixed depths (channel), no discernable breakup, no discernable freeze-up, undetected river influence, M'Clintock water mass
14	Western Parry Deep Channel	M'Clintock Channel Complex North Victoria Island Shelf Melville Banks Shelf Beaufort Sea Pack-ice	Deep channel with significant current Fastice in winter separates from Beaufort Sea Pack-ice Can contain spring open water areas and ice edge	100% fastice, possible fastice-edge in late July, 68% 4-8 10ths old ice, with 100% chance of persistent ice, moderate-deep water, no discernable breakup, no discernable freeze-up, undetected river influence, Beaufort water mass
15	North Victoria Island Shelf	Western Parry Deep Channel	Large bay type area separated from Western Parry Deep Channel by seabed ridge Mobile summer ice is trapped and packed onto the shelf	99% fastice, no fastice-edge, 61% 4-8 10ths old ice, with 99% chance of persistent ice, mixed shallow-deep water depths, no discernable breakup, no discernable freeze-up, undetected river influence, Beaufort water mass
16	Melville Banks Shelf	Western Parry Deep Channel	Mixed depths and coastal areas separates from Western Parry Deep Channel as well as influence of river type areas along coast	99% fastice, possible fastice-edge in late July, chance of old ice, with 90% chance of persistent 50% ice concentration, mixed moderate depths, no discernable break-up, no discernable freeze-up, 8% influence (possible river or other), Beaufort water mass
17	Beaufort Sea Pack-ice	Western Parry Deep Channel Banks Island Westerly Gradient Melville Island Shelf	Little fastice presence Dominance of pack ice and old ice	27% fastice, no obvious fastice-edge, significant old ice, 90% moderately deep, undetected river influence, Beaufort water mass
18	Banks Island Westerly Gradient	Beaufort Sea Pack-ice Amundsen Gulf Pelagic	Mixed depths associated with coastal shelf slope separate from Beaufort Sea Pack-ice as well as spring open water lead and ice edge Water mass fastice (less) and lack of river influence separate from Amundsen Gulf Pelagic	29% fastice, some ice edge first half of July, significant amounts of old ice, mixed depths (slope), area of persistent ice throughout season, undetected river influence, Beaufort water mass

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APPENDIX 1

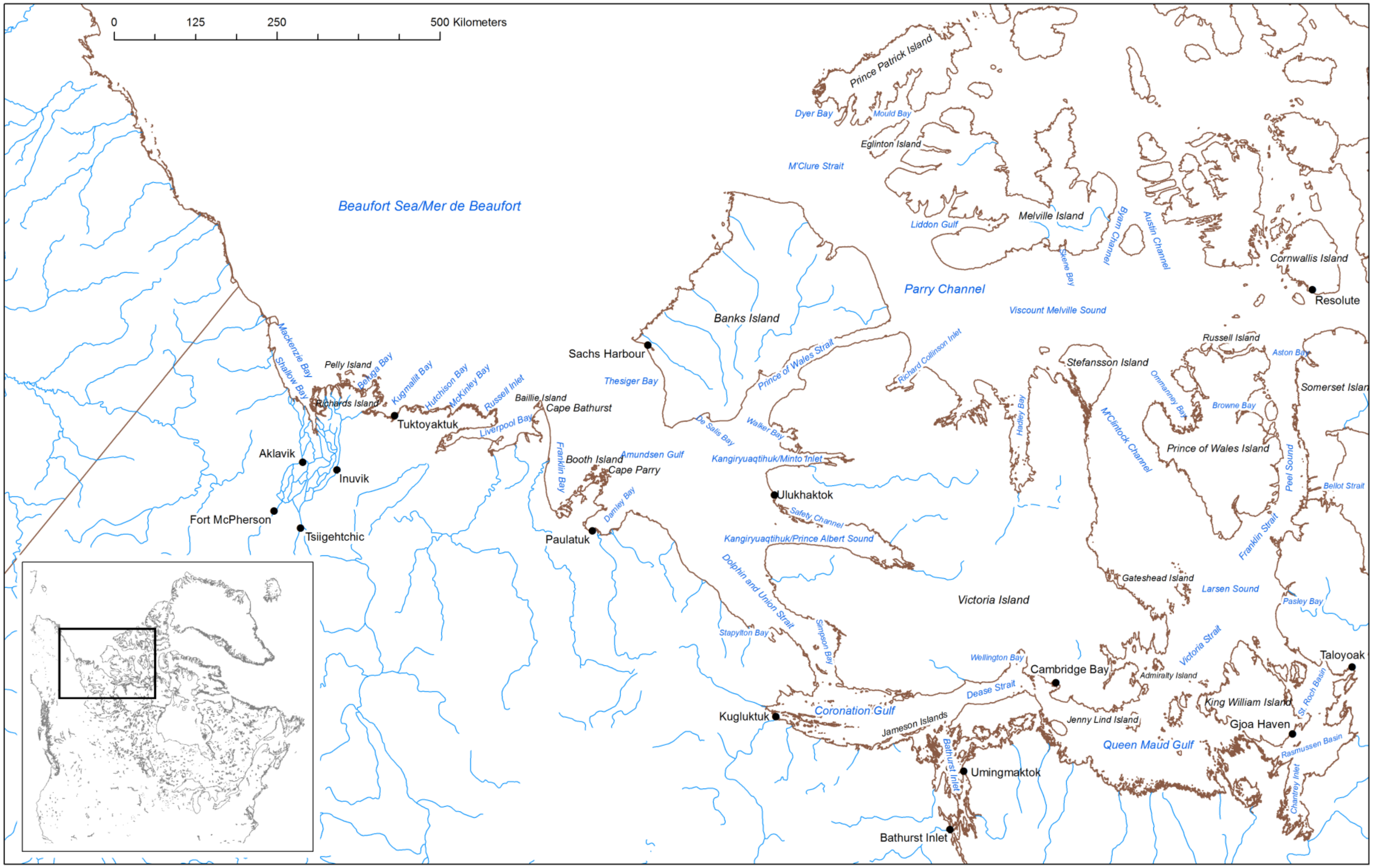

Figure A1. Place names in the Western Arctic Bioregion.

APPENDIX 2

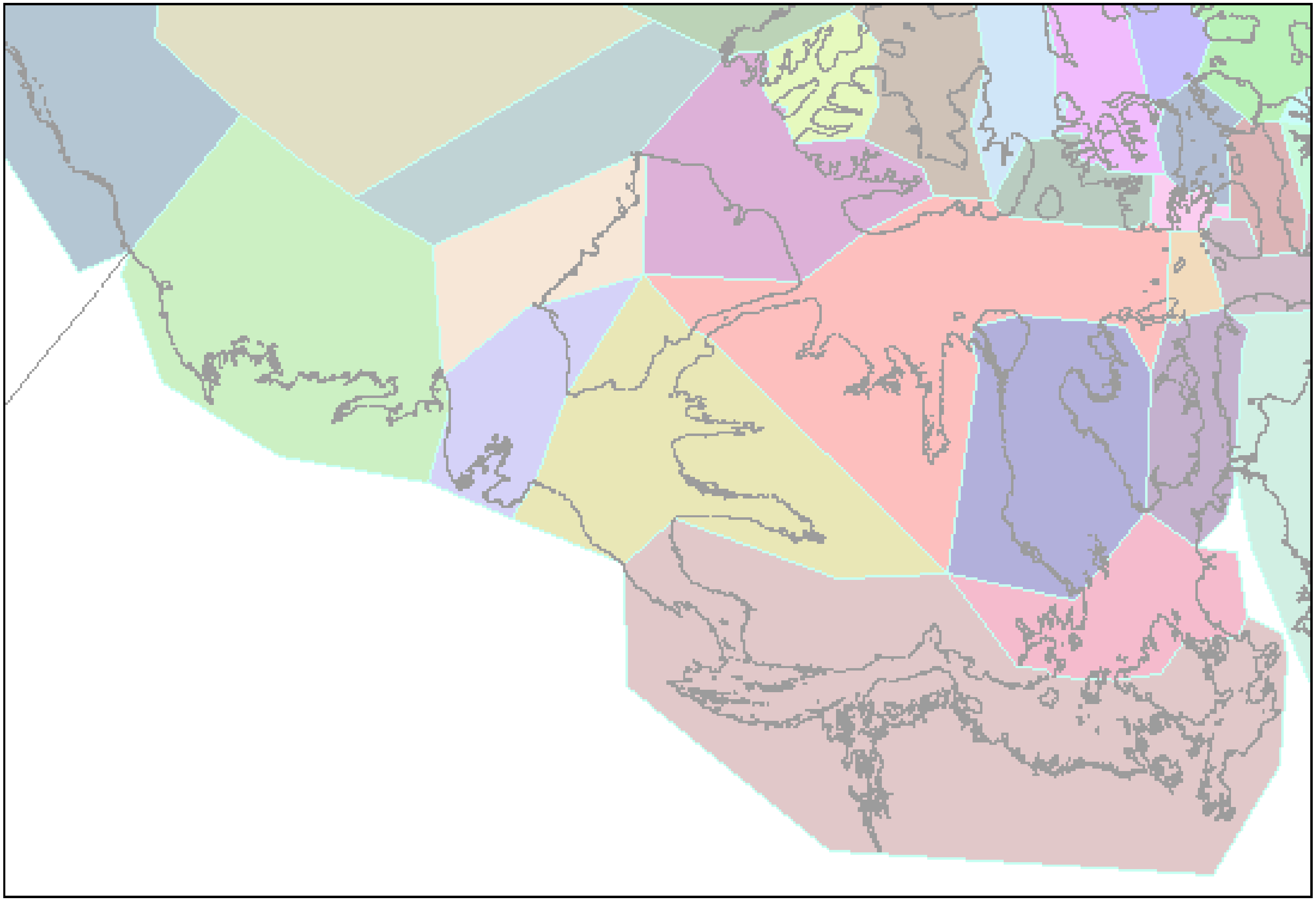

Figure A2. Canadian Ice Service sub-regions in the Western Arctic Bioregion (Unpublished report from CIS 2007).