Canada wide benthic scope for growth: Preliminary classification

V. Kostylev, C. Hannah, V. Soukhovtsev, C. Dickson

Ocean and Ecosystem Sciences Division
Maritimes Region
Fisheries and Oceans Canada

Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
Canada B2Y 4A2

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V. Kostylev[1], C. Hannah, V. Soukhovtsev, C. Dickson[1]

Ocean and Ecosystem Sciences Division
Fisheries and Oceans Canada
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
Canada, B2Y 4A2

[1] Natural Resources Canada
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
Canada, B2Y 4A2

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Abstract

The habitat template approach to benthic habitat mapping was applied to the continental shelves of Canada following methodology developed by Kostylev and Hannah (2007). The creation of the preliminary map of benthic scope for growth model for Canada's offshore waters is described. The model uses the data on seabed bathymetry, near bottom and surface water temperatures, salinity and water density, oxygen saturation, surface chlorophyll and near bottom nutrients, to produce the georeferenced scope for growth estimate at 5'x5' resolution. ArcGIS toolbox was created in Model Builder and Python to generate a normalized scope for growth raster file using the different input data layers. At a global scale the patterns of variability in the benthic scope for growth were reasonably well aligned with the current understanding of productivity of the benthic environment and seem to follow longitudinal and onshore-offshore gradients. South-western Scotian shelf and the Gulf of Maine, the narrow shelf off British Columbia and the shelf South of Greenland appeared to have the higher scope for growth while bathyal part of the Pacific region, the Arctic seas and the deep central part of the Baffin Bay displayed low scope for growth. The relatively higher estimates of scope for growth in the deep North Atlantic compared to similar water depths in the North Pacific were likely the result of the lower overall observed near-bottom oxygen saturation in the North Pacific. Of particular interest along Atlantic coast was the band of higher scope for growth along the shelf slope starting around the Grand Banks of Newfoundland and hugging the slope all the way up to the southern Greenland. Channels along Labrador coast were distinctly highlighted as regions of higher scope for growth. Flemish Cap and Orphans Knoll stood out compared to the surrounding as areas of higher productivity. Scope for growth variability along the Pacific coast was characterized by the sharp gradient between shelf and deep waters, with quick decrease beyond 200 m water depth. The data used in the Scope for Growth calculation have been archived with the Data Management Group of DFO-Science at the Bedford Institute of Oceanography).

Résumé

Suivant la méthodologie développée par Kostylev et Hannah (2007) l'approche de modèle de l'habitat à la cartographie des habitats benthiques a été appliquée sur les plateaux continentaux du Canada. Ici est décrite la création de la carte préliminaire du modèle de production benthique pour les eaux extracôtières du Canada. Le modèle utilise les données sur la bathymétrie des fonds marins, et des températures d'eau de surface et du fond, la salinité et la densité de l'eau, la saturation en oxygène, la chlorophylle de surface et nutriments de fond, pour produire l’estimation géoréférencée de la production a la résolution de 5'x5'. Pour générer un champ normalisé pour le fichier raster de croissance en utilisant les différentes couches de données d'entrée nous avon créée une boîte à outils en ArcGIS Model Builder et Python. Nous avons trouvé à l'échelle mondiale les modèles de variabilité dans le cadre benthique pour la productivité correspondent bien à la compréhension actuelle de la productivité du milieu benthique et semblent suivre les pentes longitudinales et côtières. Plateau Néo-Ecossais sud-ouest et le golfe du Maine, l'étroit plateau de la Colombie -Britannique et le plateau sud du Groenland sembles avoir la portée de croissance plus élevée tandis que la partie bathyale de la région du Pacifique, les mers arctiques et la partie centrale profonde de la Baffin Bay semblent affichent un faible potentiel de croissance. Les estimations relativement élevées de production dans les profondeurs de l'Atlantique du Nord par rapport à des profondeurs d'eau similaires dans le Pacifique du Nord étaient probablement le résultat d’une faible saturation en oxygène observée près du fond du Pacifique du Nord. Un intérêt particulier un Atlantique présente la bande de portée de croissance plus élevée le long de la pente du plateau qui part d'environ des Grands Bancs de Terre-Neuve et qui vas jusqu'au sud du Groenland. Les canaux le long de la côte du Labrador ont été nettement mis en évidence comme les régions de portée de croissance plus élevées. Les Bonnet Flamand et Orphans Knoll se démarquent par rapport à l’entourage comme des zones de plus grande productivité . La variabilité de la production le long de la côte du Pacifique a été caractérisée par le fort gradient entre le plateau et les eaux profondes, avec une diminution rapide au-delà de 200 m de profondeur. Les données utilisées pour le calcul de la croissance ont été archivées avec le Groupe de gestion des données de MPO-Sciences à l'Institut océanographique de Bedford).

1. Introduction

In this report we apply the habitat template approach to benthic habitat mapping to the continental shelves of Canada. The habitat template concepts, originally developed by Southwood (1977, 1988), were adapted by NRCan and DFO (Kostylev et al. 2005, Kostylev and Hannah 2007) to mapping the marine benthic environment in general, and to the Scotian Shelf in particular (DFO 2005) Recent applications include use as data layers in a systematic approach to Marine Protected Area network planning (Horsman et al. 2011) and to help interpret spatial patterns of the diversity of marine fish (Fisher et al. 2011).

Our approach is based on ecological theory that relates species life history traits to the properties of the environment. Many authors have argued that characteristics of habitats impose selective forces through a variety of biotic and abiotic factors; these factors affect the fitness of individual organisms by modifying their growth rate, survival, fecundity, etc. (Southwood, 1977, 1988; Grime, 1977, 1979; Margalef et al., 1979; Huston, 1994; Reynolds, 1999). The two major selective forces are physical disturbance and adversity of the environment. This disturbance–adversity continuum has been used to predict traits of species occurring in different quadrants of the habitat template, emergent properties of ecological communities, such as species competition and biodiversity (Southwood, 1988; Huston, 1994), and has been used in the classification of terrestrial habitats (Grime, 1977, 1979). We use the habitat template as a framework for transforming maps of the physical environment into a map of benthic habitat types; these habitats support species populations that have different life history traits, and species assemblages having characteristic sensitivity to human impacts. Instead of the term 'adversity' (Southwood 1988), which may be easily confused with 'disturbance', we use the term 'scope for growth' which is reciprocal to 'adversity'. Kostylev and Hannah (2007) provide more detailed description and discussion of this approach.

In this report we focus on developing the 'scope for growth' axis of the habitat template which considers availability of food and presence of environmental stressors that pose a cost for physiological functioning of organisms and limit somatic growth and reproduction. Kostylev and Hannah (2007) proposed that the scope for growth axis is an estimate of energy available for growth and reproduction of a species after accounting for energy spent adapting to the environment. Our definition of scope for growth is based on four factors: food availability (which combines stratification and surface chlorophyll as a measure of benthic–pelagic coupling), annual bottom temperature (as an indicator of metabolic rates), temperature variability (as an indicator of both thermal stress and temporal uncertainty for reproduction), and oxygen saturation (as a measure of metabolic stress). Indices, based on these factors, are additive, following fuzzy logic theory (Zadeh, 1965), which allows characterization of the environment on a continuous scale between 'benign' (high scope for growth) and 'adverse' (low scope for growth). The resulting "scope for growth" provides an evaluation of the benthic environment in terms of the amount of energy available to animals for growth and reproduction, and is meant to correlate with the production term in ecophysiological energy equation for ectotherms.

Simultaneously it does not constitute an explicit model of ecological and physiological processes in benthic communities.

2. Methodology and Data sources

All of the data fields have been processed from various sources in MatLab and gridded in ArcGIS as raster grids with 5' x 5' pixel size (the analysis grid) to achieve a good representation of the gradients that exist in each data layer. This does not mean that the data layers or the final map have a spatial accuracy of 5' (9.1 km in the N-S direction) because of disparity of scales and spatial resolutions in the original datasets, rather the analysis grid provides an underlying structure that resolves the gradients and will accommodate future improvements in horizontal resolution of the data layers.

Bathymetry and extent

The extent of the area of the analysis is shown in Figure 1. The bathymetry dataset included an extended ETOPO2[1] data (US Dept. Commerce 2006) updated with new data compiled from different sources by NRCan (John Shaw, pers. comm.). Several grid files for the parts of the total area with sea bottom depths were generated with 5' x 5' (1/12 x 1/12 degrees) resolution. The mapping of the bathymetry data to the analysis grid was done using optimal estimation.

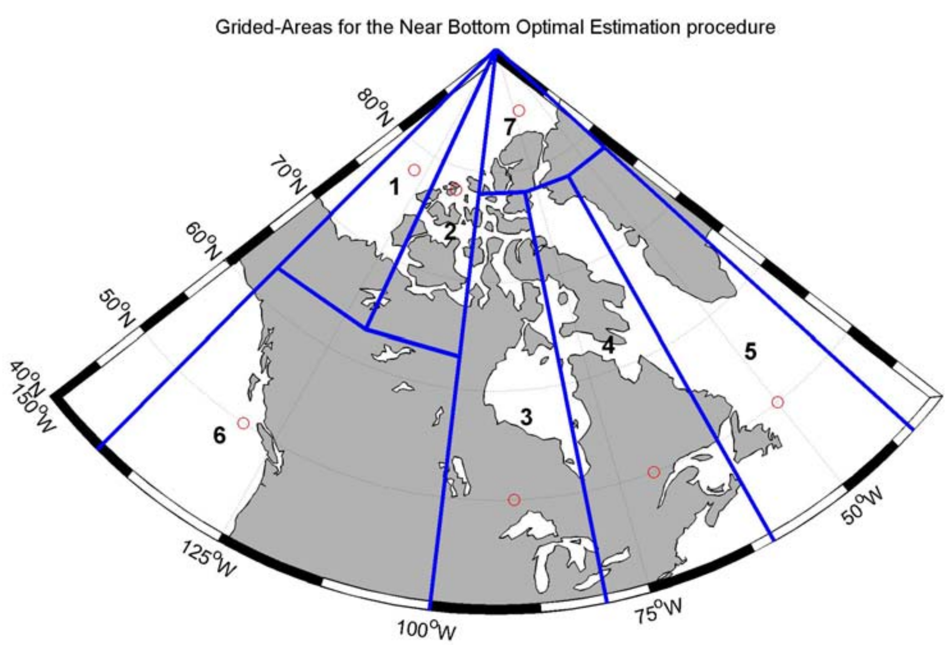

Figure 1. Seven areas used in the Near Bottom Optimal Estimation procedure with reference points indicated (red circles).

[1] http://www.ngdc.noaa.gov/mgg/fliers/06mgg01.html

Seabed temperature data

The creation of the near bottom temperature fields illustrates the procedure used for most of the fields. Most of the details are given here. The mapping of the different datasets to the analysis grid was done using optimal estimation (OE). As described below, the OE procedure was done by dividing the whole area was divided into 7 smaller areas which are defined in Table 1 and Figure 1.

Table 1: The 7 areas used for the optimal estimation procedure. The REFERENCE POINT is shown in Figure 1.

Area Number	LON	LAT	REFERENCE POINT
1	142-120W	63-90N	78N,130W
2	120-100W	63-90N	78N, 110W
3	100- 80W	40-78N	50N, 90W
4	80 - 60W	40-78N	50N, 70W
5	60 - 40W	40-78N	50N, 50W
6	142-100W	40-63N	50N, 130W
7	100 - 40W	78-90N	85N, 70W

Two data sources were used to produce Temperature climatology: Climatology of the North Atlantic[2] (CNA), areas 3, 4, 5) and World Ocean Atlas (WOA) 2005[3] (Locarni et al. 2005)[4]. From CNA data set (provided by I. Yashayaev, Bedford Institute of Oceanography) with resolution 20’ x 20’ (1/3 x 1/3 degrees), and 14 standard levels of ocean depths (0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500), monthly near bottom temperatures for areas 3, 4, and 5 for the points with sea bottom depths within 550 m were calculated/estimated. This data set also included Hudson Bay and central part of Canadian Arctic Archipelago that was better represented by June - November raw data. To decrease computation time only data within 200 m of the bottom depths were included. The near bottom temperature data for 3 areas were combined into 12 monthly ASCII files.

WOA05 monthly and seasonal climatology data sets with resolution 1 x 1 degree, for standard levels from 0 to 5500 m were used to estimate near bottom sea water temperature. The following depths 0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500 m are associated with levels from 1 to 24 of the monthly data set. The seasonal data are extended to 33 levels. The first 24 levels are similar to the monthly ones. Level 25 corresponds to 1750 m, and other levels are distributed from 2000 to 5500 m following in 500 m. To create monthly input data files for the total area with bottom depths up to 5000 m the WOA05 monthly data were combined/appended with/by seasonal deep climatology data (for example,

[2] http://www.mar.dfo-mpo.gc.ca/science/ocean/woce/climatology/naclimatology.htm
[3] http://www.nodc.noaa.gov/OC5/WOA05/woa05data.html
[4] Since this work completion (in 2009) a newer version of WOA (2013) became available.

winter data were combined with Jan, Feb, and Mar monthly data sets). It means that the seasonal data for depths only more than 1500 m were added to each monthly data set of the season. To decrease computation time only data within 200 m distance from the bottom were included for the shelf grid points (less than 200 m) and within 600 m range for other points. The near bottom temperature data for 7 areas were combined to 12 monthly ASCII files.

The 2 datasets were combined in the following manner: For *June – November* the data records from the CNA data set with bottom depths less than 550 m were used for each month. From the WOA05 data set one part (output from OE for areas 1, 2, 6, and 7) was used completely. For areas 3, 4, and 5 only OE data for depths more than 550 m were appended. Rectangular merging area MA1 bounded by 85-80W, 51-78N (Figure 2,) was used to combine the two OE data sets. As a result, WOA05 data are presented completely West of the area and Climatology of the North Atlantic data East of it, with combination of both data sets used within MA1.

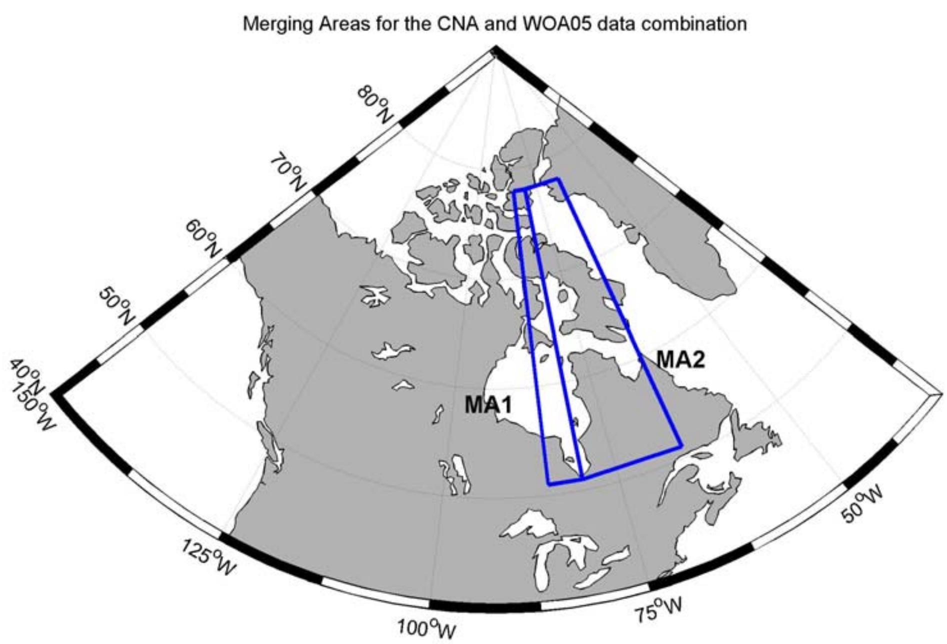

Figure 2. Merging areas used after Near Bottom OE procedure for June-November (MA1), and for December- May (MA2).

For *December – May* data were combined in the following manner: From CNA OE output for areas 4 and 5 data for bottom depths less than 550 were used for each month. From the WOA05 data set one part (output from OE for areas 1, 2, 3, 6, and 7) was used completely. For areas 4 and 5 WOA05 OE data for depths more than 550 m were appended. Rectangular merging area MA2 (Fig 2, 80-65W, 51-78N) was used to combine two OE data sets. The merging procedure similar to one used for June-November, was applied.

Monthly data sets were stored in the 3D array with the size 12 x 366746 x 5 (fields: month * record-number * set_of_variables).This array could be considered as 12 tables of the size (366,746 * 5), each one with 5 columns: LAT, LON, DEPTH, near bottom temperature, error of estimation. First 3 columns in each table were the same for different months. Another file represented Annual Means and magnitude of the Annual cycle of the near bottom temperature. The columns titles of the (366,746 x 8) table were LAT, LON, DEPTH, mean temperature, standard deviation, minimum of monthly temperatures, maximum of monthly temperatures, and number of monthly temperature values averaged. Resulting map of seabed temperature is shown on Figure 3. Annual variability of bottom temperature is the range between maximum and minimum monthly values for each grid cell (Figure 4).

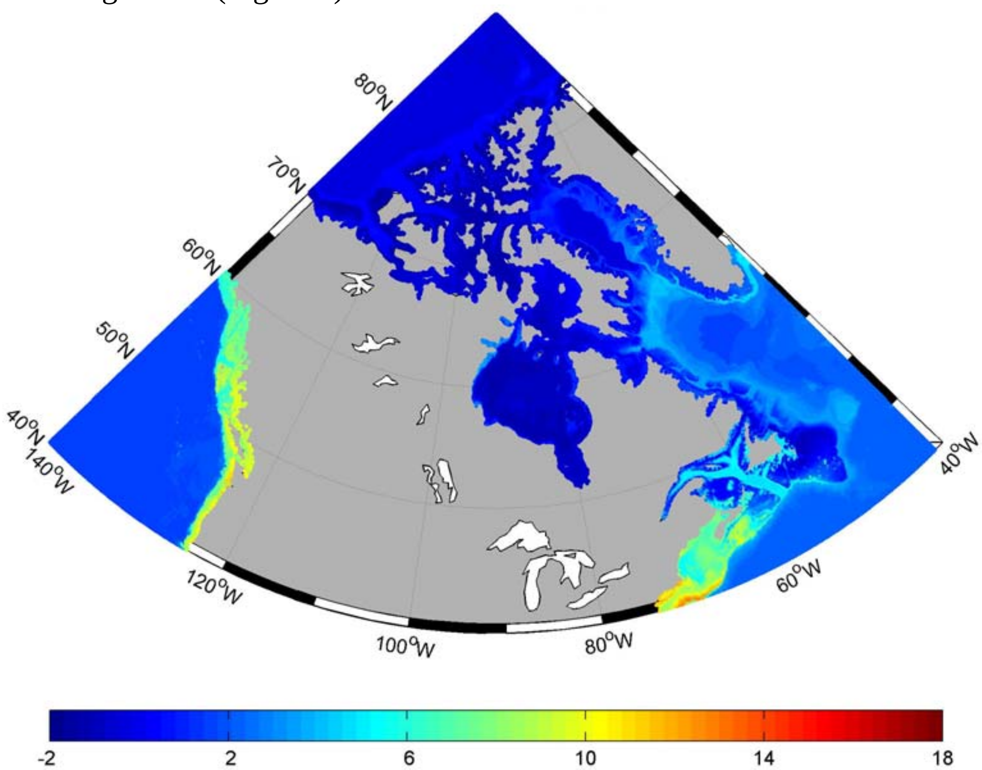

Figure 3.   Near bottom annual means of temperature (combination of WOA05 and Climatology of North Atlantic).

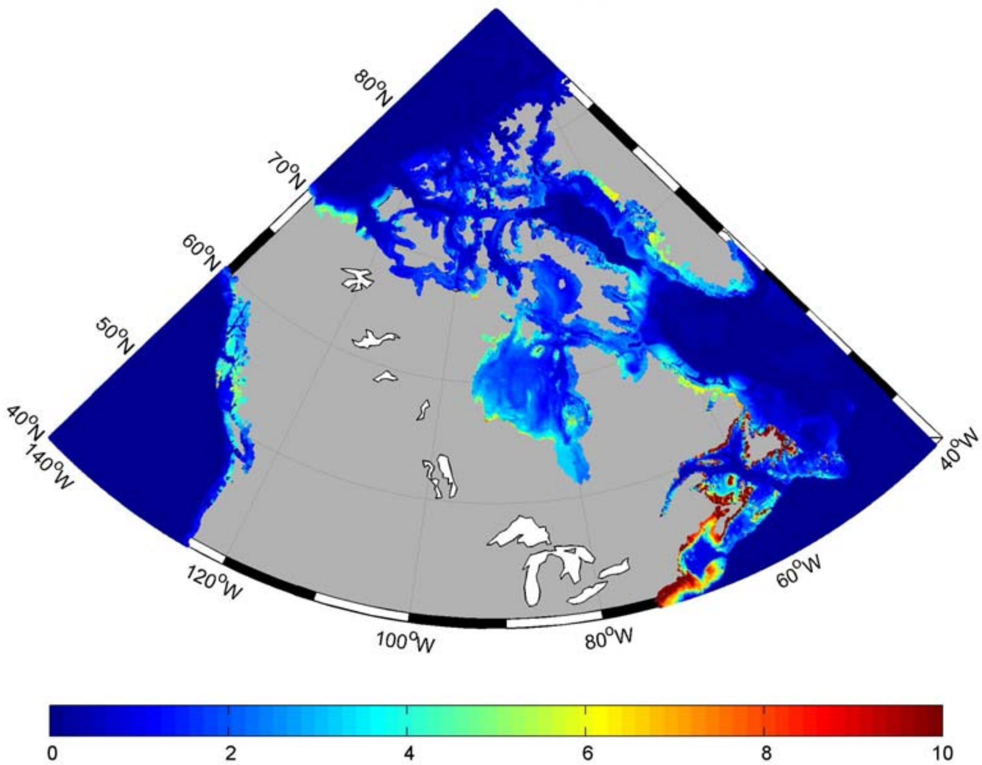

Figure 4. Annual variability of the near bottom temperature, (Tmax – Tmin), (combination of WOA05 and Climatology of North Atlantic).

Summer season upper ocean temperature, salinity and density

Three data sets were used to get the summer near surface (0 and 30 m) temperature and salinity climatology: Canadian Arctic Archipelago data set[5] (CAA; Kliem and Greenberg 2003) (with the latitudes higher than 63N), climatology data set of the North Atlantic (CNA) for July, August and September (latitudes less than 78N; eastern Canadian sea waters), and WOA05 climatology for July, August and September (for the Pacific Canadian sea waters). Each data set for temperature and salinity fields was processed separately first. The 5' x 5' grid (same as in the bottom temperature OE calculations) was used for interpolation. The T and S for 0 m and 30 m calculated in MatLab and the three data sets merged to obtain the final data set.

For CNA data set - July, Aug, Sep data were extracted. A subset of data from a 0.5 X 0.5 degrees box around each grid point was processed with *griddata* function (option- 'linear') in MatLab (interpolation to one point). If no result was generated, the size of the bounding box was changed to 1.5 X 1.5 degrees around each point. If there is still no result, the 'nearest' option of the griddata function was used. After that NaN was used if no result occurred. The mean from July, August and September outputs (after interpolation to 5'X5' grid) was saved to the ASCII file with format LON, LAT,

[5] N.Kliem, D.Greenberg, Atmosphere-ocean , 41(4), 2003, pp.279-289

temperature_0m, temperature_30m, salinity_0m, salinity_30m, distance_to_closest_data_point.

For the Canadian Arctic Archipelago (CAA) the gridded fields of potential temperature and salinity were constructed by Kliem and Greenberg (2003). The gridding was performed in an iterative procedure where the horizontal correlation scales depend on the data coverage as well as on the flow field. August-September were best represented in the CAA data, as these are the months with the lowest ice concentration and thus present the best possibilities for ship-based observations. There was smaller contribution from the March-April on-ice surveys. The output T and S data for 0 and 30 m depths were interpolated to the grid of 5’x5’. The procedure similar to the processing applied to the North Atlantic data set was used here. The processed data where saved to the ASCII file.

From the WOA05 data set summer raw data for 32 levels (up to 5000 m) was created for the total area. Interpolation to 5’x5’ grid (similar to the one explained above) was applied to T and S to obtain 0 and 30 m depth values.

The data from the 3 data sets were combined to one table. Three merging rectangular areas were used to combine the CNA and CAA data (Figure 5. MA31: 100-80W, 76-78N; MA32: 100-80W, 63-76N; MA33: 80-60W, 76-78N). Transformation from the CAA to the CNA data set within each merging area was done as follows: Area M31: CAA data are presented completely at the left upper corner of the area and CNA data - at the right lower corner. Combination of both data sets is used at the intermediate points. Area M32: CAA data was presented completely at the left side of the area and CNA data at the right side. Combination of both data sets was used at the intermediate points. Area M33: CAA data was presented completely at the upper side of the area and CNA data - at the lower side. Combination of both data sets was used at the intermediate points. The WOA05 data set was used only for the Pacific Canadian waters. The final combined data were saved to the ASCII file.

Stratification

Near surface combined data for temperature and salinity were used to calculate sigma-t (density of seawater at a given temperature) and difference of sigma-t for the depths 30 m and 0 m (Figure 6).

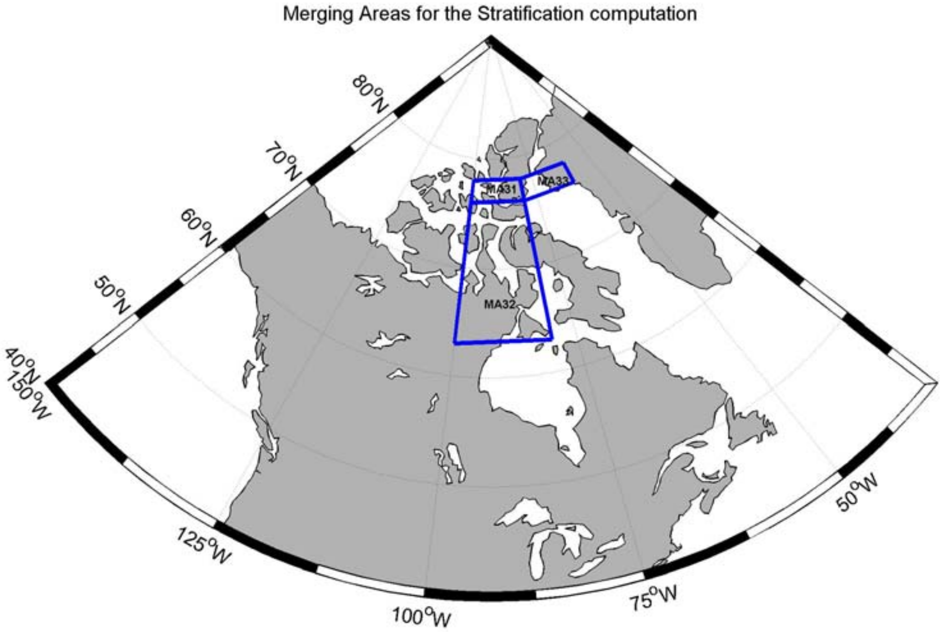

Figure 5. Merging areas used for the Summer Near Surface sigma-t Data and Model fields (MA31,32,33).

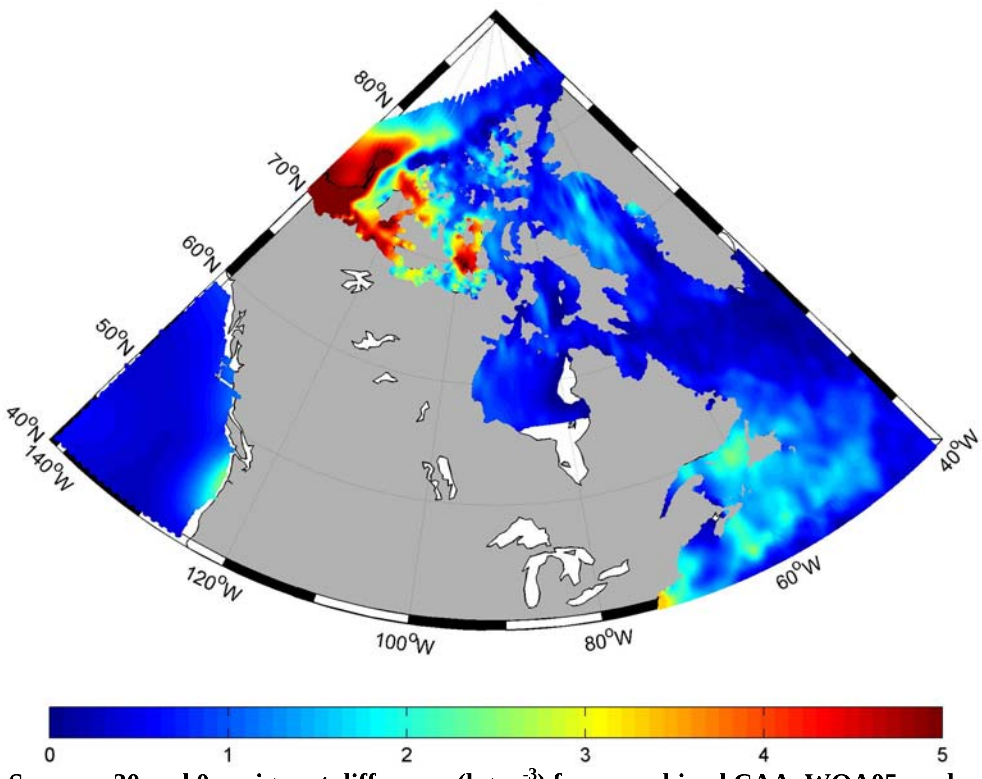

Figure 6. Summer 30 and 0 m sigma-t difference (kg m^{-3}) from combined CAA, WOA05, and Climatology of North Atlantic data sets.

Oxygen saturation

Monthly data for Percent Oxygen saturation were processed from WOA05 data set (Garcia et al. 2006) in a similar fashion to the processing of temperature fields from WOA dataset described above. Monthly 5’x5’ gridded values and an output summary data for the annual mean, max and min values were saved to ASCII files. Results are shown in Figure 7.

Salinity

Monthly data for water salinity were processed from WOA05 data set (Antonov et al. 2006) the way similar to the above. Monthly 5’x5’ gridded values and an output summary data for the annual mean, max and min values of salinity were saved to ASCII files. Average bottom salinity is shown on Figure 8, variability in salinity in Figure 9.

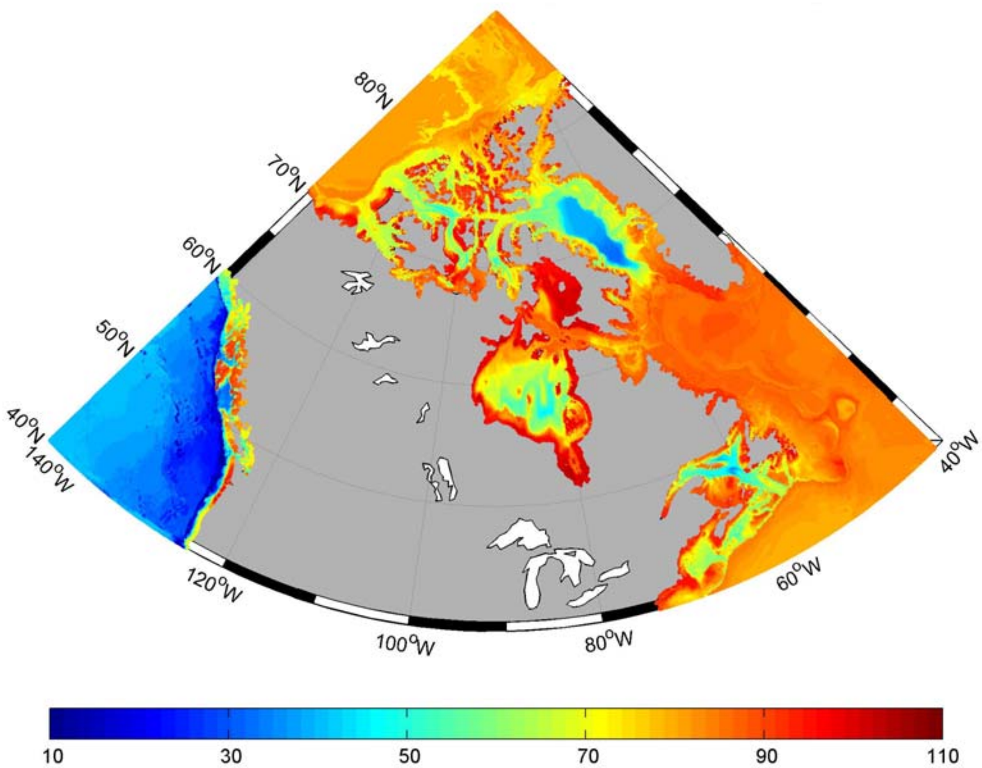

Figure 7. WOA05 near bottom MINIMUM percent Oxygen saturation.

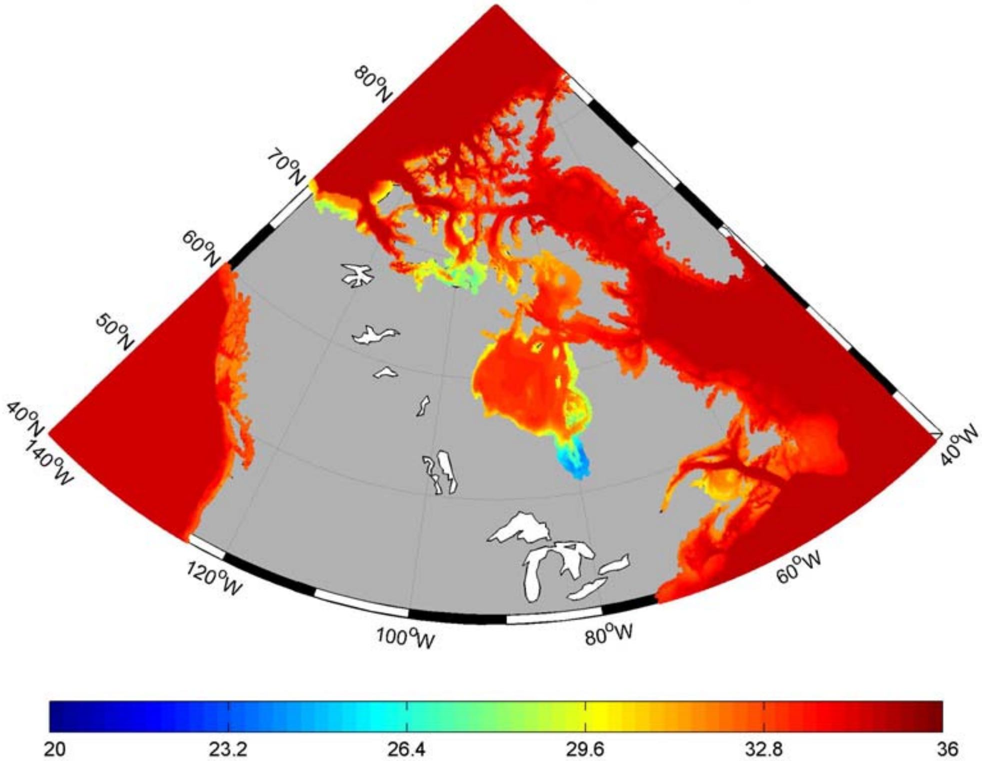

Figure 8. WOA05 near bottom annual mean salinity.

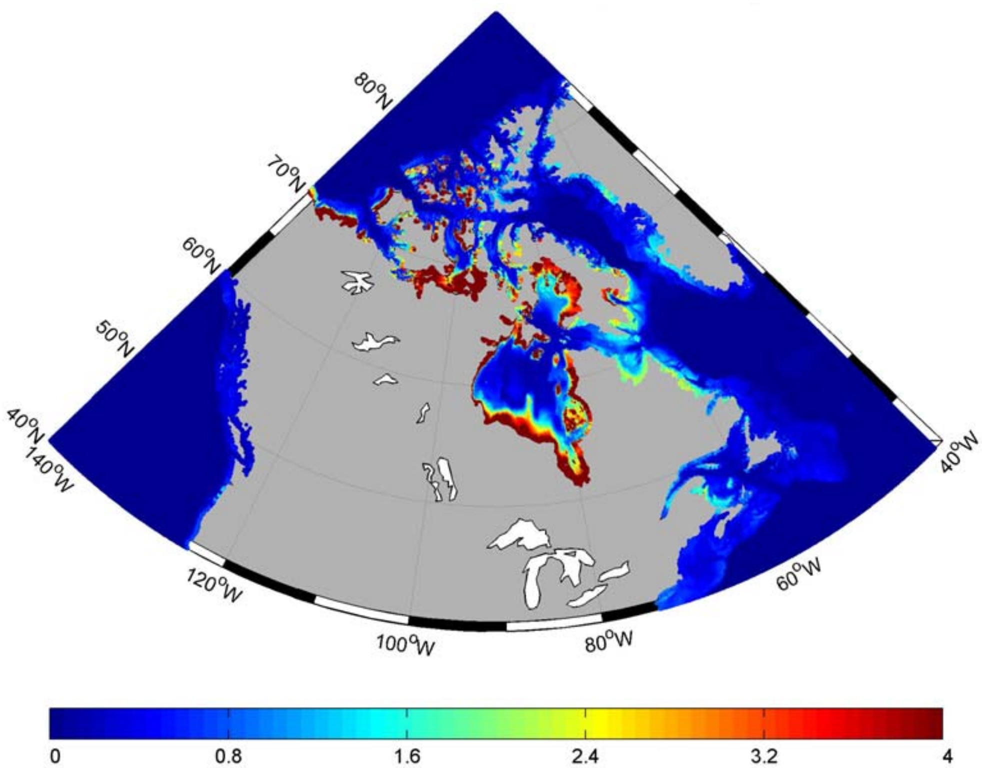

Figure 9. WOA05 near bottom annual variability of salinity.

Surface Chlorophyll

The monthly surface chlorophyll concentration data were obtained from SeaWIFS Climatology (1997 – 2007) at 9 km (5 minutes) resolution, with global coverage (90S-90N, 180W-180E). Data covering Canadian oceans were extracted for 40-90N, 140-40W. Each monthly climatology data file was processed by SeaDAS[6] software, with ASCII output data file for the area of interest containing 5 variables (CHL (mg/m^3), LAT, LON, Pixel, Line] and with 1201*601 = 721801 records. Bad data or NO DATA were defined as value = 64.5740. For Canadian offshore only values of chlorophyll concentration < 22 mg/m^3 were considered valid and retained for the analysis, which left about 100,000-200,000 records (depending on month) of clean CHL data for further processing. Two resulting plots from clean data sets for average March and September chlorophyll concentration (approximately corresponding to spring and fall maxima) are shown below.

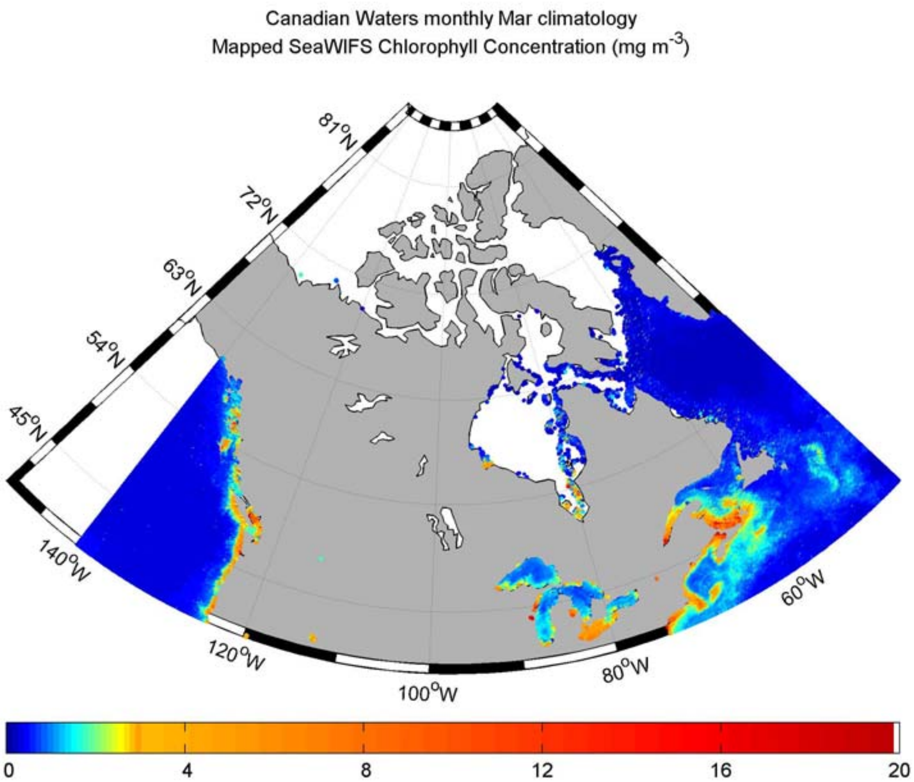

Figure 10. SeaWIFS climatology - CHL (mg/m^3) for March. Color map is altered to emphasize low concentrations.

[6] http://seadas.gsfc.nasa.gov/

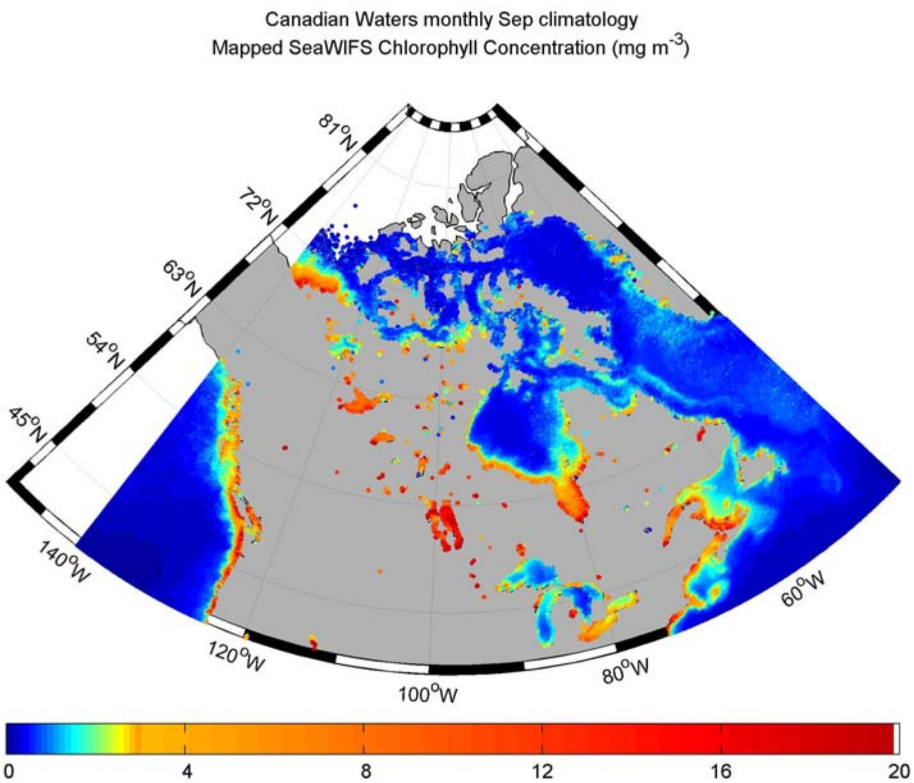

Figure 11. SeaWIFS climatology - CHL for September. Color map is altered to emphasize low concentrations.

Near bottom nutrients

Data of nitrates, silicates and phosphates were also processed but not currently used in the construction of the scope for growth model. The WOA05 Monthly data on nutrients were given only for the first 14 depth levels (up to 500 m). Monthly data for nutrients were processed the way similar to the processing of bottom temperature described in this report. Monthly 5' x 5' gridded values and an output summary data for the annual mean, max and min values were saved to ASCII files (Figure 12 – Figure 17).

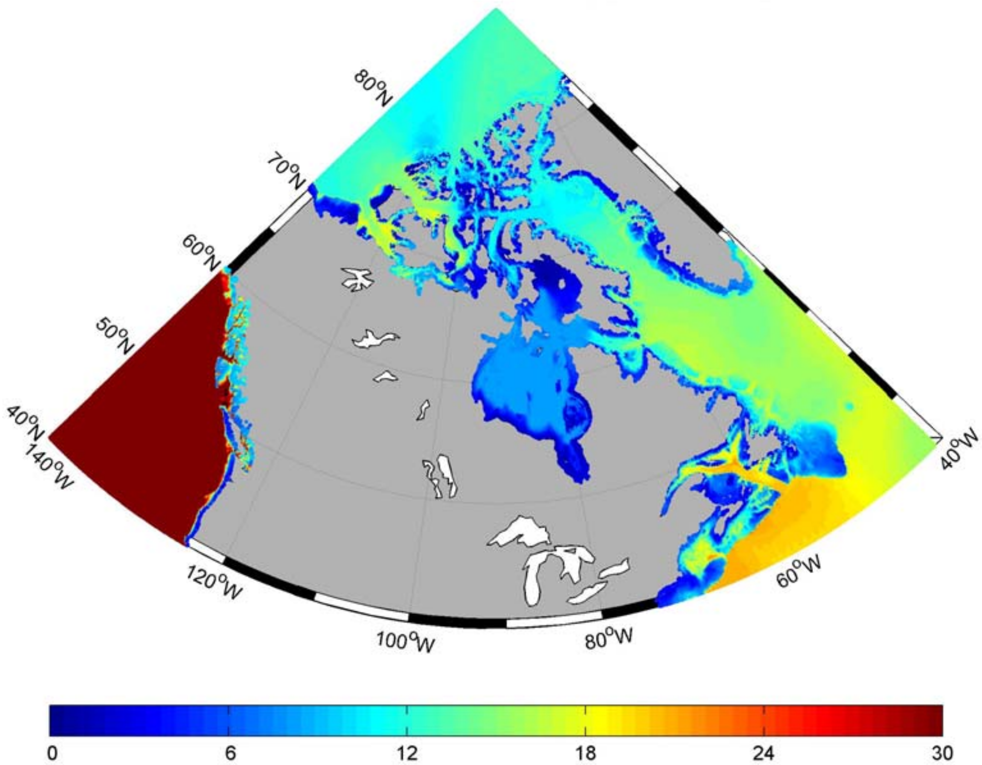

Figure 12. WOA05 near bottom annual mean Nitrate (mcMol).

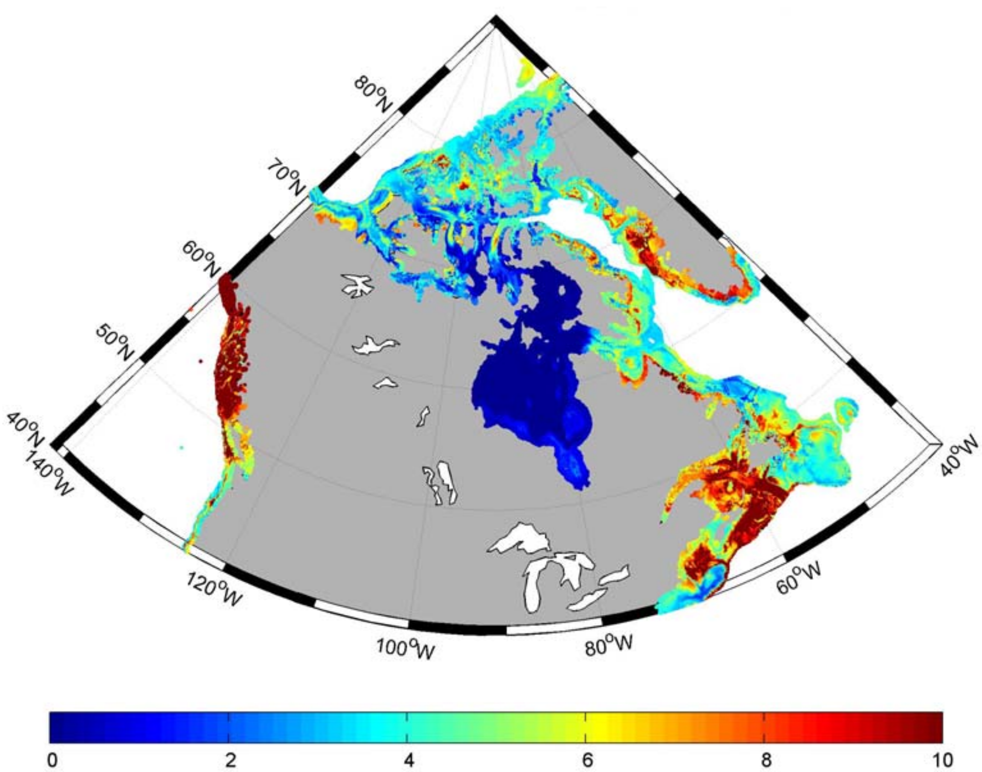

Figure 13. WOA05 near bottom annual variability of Nitrate (mcMol). Bottom depths less than 550 m.

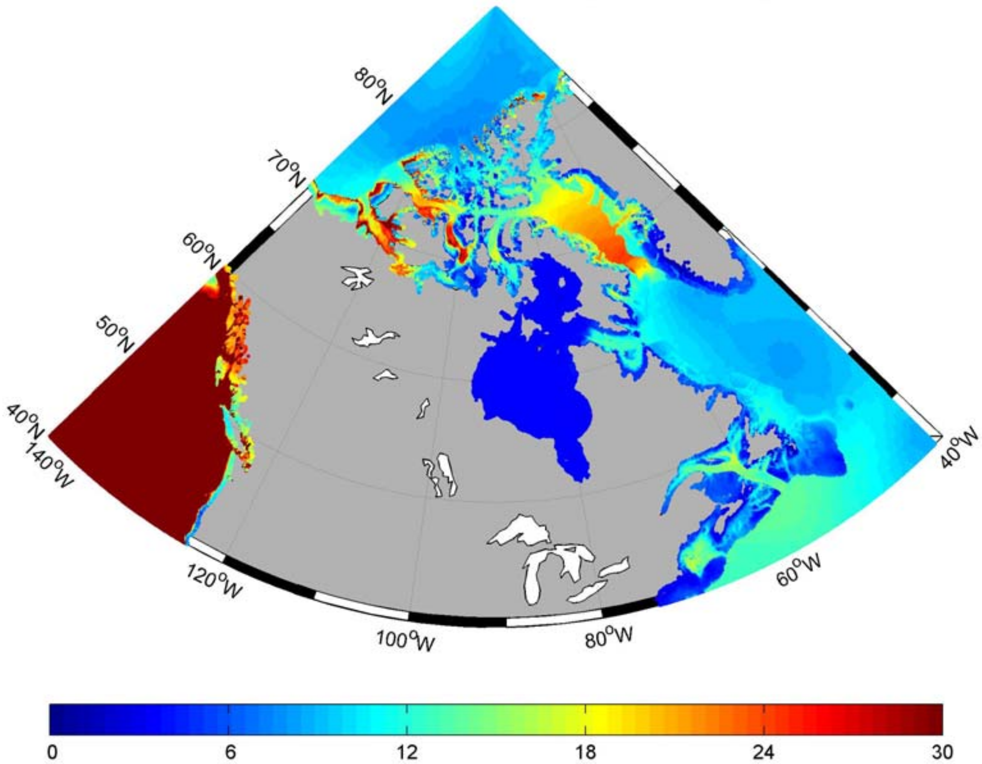

Figure 14. WOA05 near bottom annual mean Silicate (mcMol).

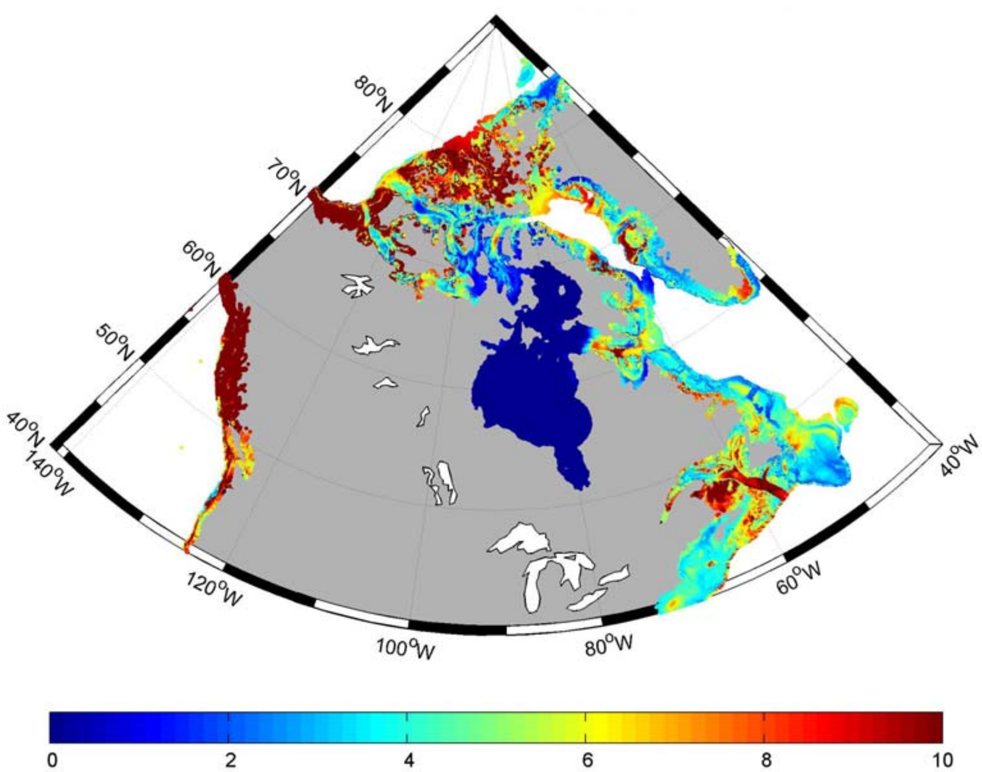

Figure 15. WOA05 near bottom annual variability of Silicate (mcMol). Bottom depths less than 550 m.

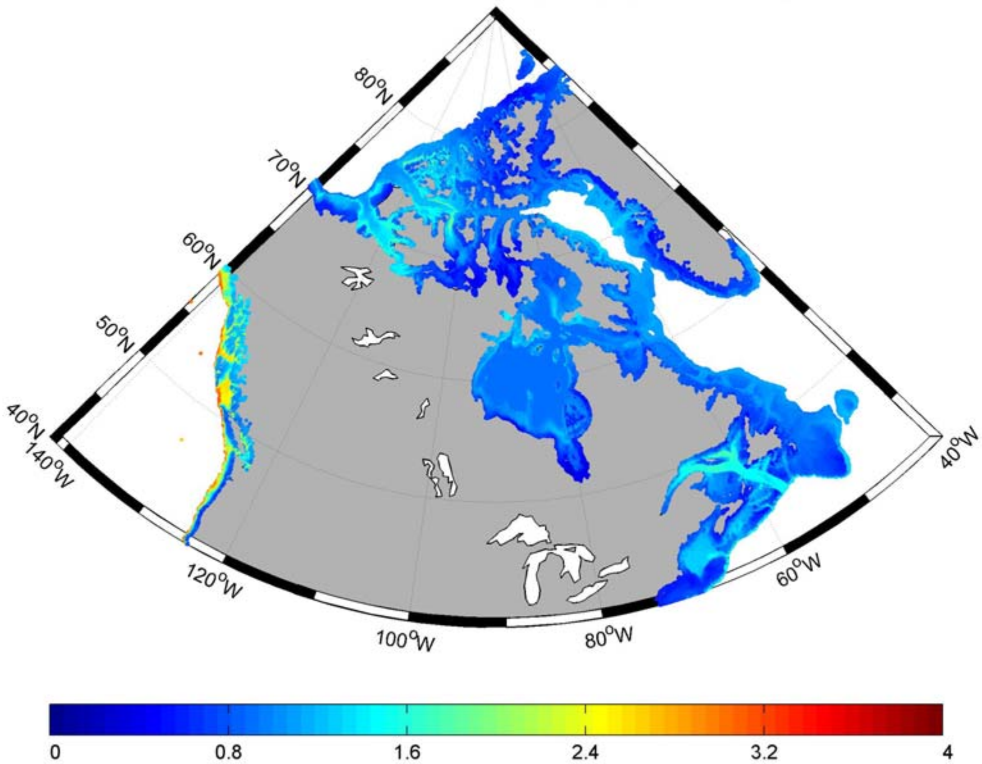

Figure 16. WOA05 near bottom annual mean Phosphate (mcMol). Bottom depths less than 550 m.

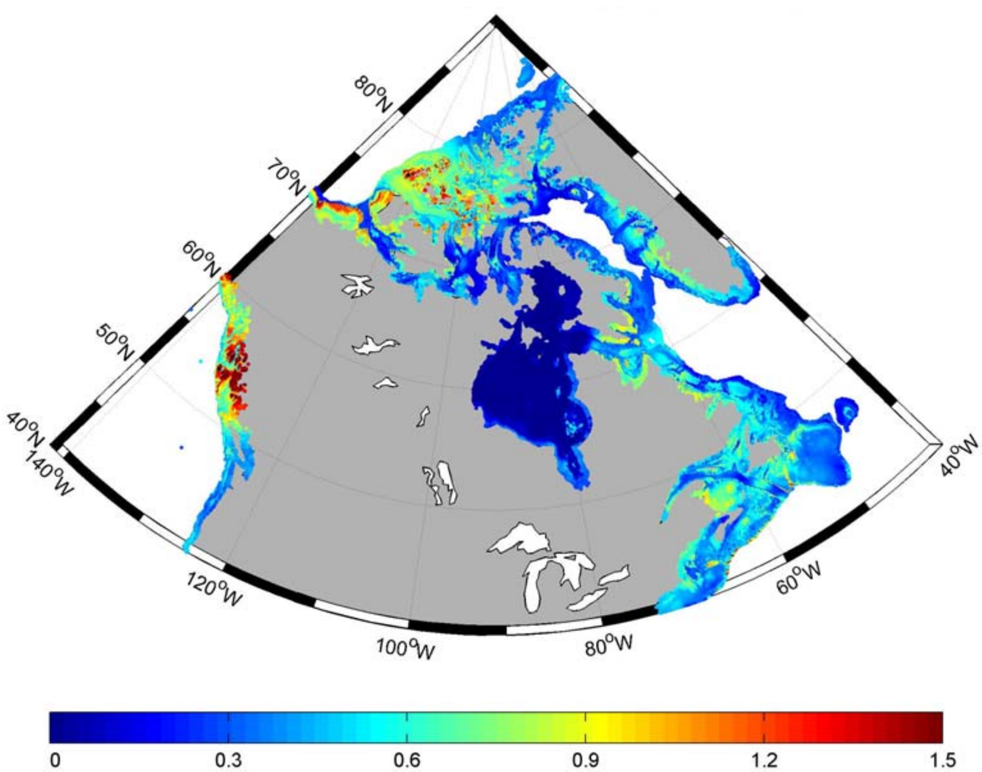

Figure 17. WOA05 near bottom annual variability of Phosphate (mcMol). Bottom depths less than 550 m.

Modeling the scope for growth in ArcGIS

ArcGIS toolbox was created in Model Builder and Python to generate a normalized scope for growth raster file using several different input data layers.

The food availability layer (Fa) was calculated as

$$Fa = \log(CB) – S,$$

where CB is the ratio of Chlorophyll-a concentration (C) to water depth (B) and S is the stratification index. The log(CB) and S were each rescaled to range from 0 to 1 before Fa was calculated. Fa was also rescaled to the range 0 to 1 before input to the scope for growth calculation.

The scope for growth (Sg) was defined as

$$Sg = (Fa + Tm – Ta + O),$$

where Tm is the mean bottom temperature index, Ta is the annual temperature variability index, and O is the oxygen saturation index.

Calculation of final normalized Scope for Growth is done using the following procedure:

1. Calculate CB:

$$CB = \log(ChlaMaximum / (DEM))$$

Where DEM is the Digital Elevation Model for bathymetry (must contain positive values)

2. Normalize CB:

$$cb' = (CB – CB(min))/(CB(max) – CB(min))$$

3. Normalize Stratification:

$$s' = (DD – DD(min))/(DD(max) – DD(min))$$

where DD is the difference between 0 and 30m water density

4. Calculate Food availability index:

$$Fa = \log(CB) – S$$

5. Calculate Scope for Growth:

$$Sg = (Fa + Tm – Ta + O)$$

6. Normalize Scope for Growth:

$$sg' = (SG - SG(min))/(SG(max) - SG(min))$$

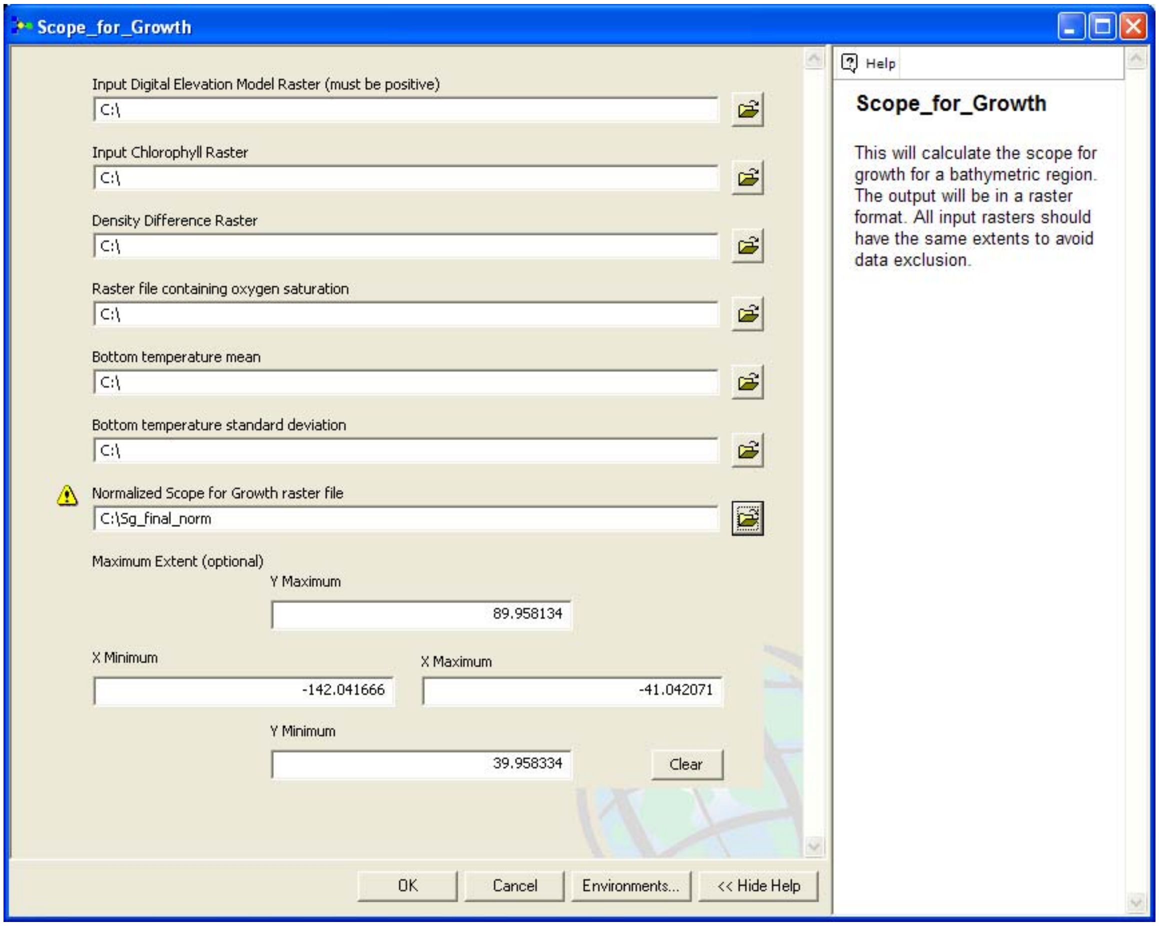

Figure 18. User input window for Scope for Growth toolbox.

This version of the Scope for Growth calculation has been encapsulated in an ArcGIS toolbox by the authors (Colin Dickson, NRCan, Bedford Institute of Oceanography, Dartmouth, NS). The user input window is shown in Figure 18.

The data files used in the Scope for Growth calculation have been archived with the Data Management Group of DFO-Science at the Bedford Institute of Oceanography). The Scope for Growth calculation has been captured in an ArcGIS toolkit and a web browser tool is available from Patrick Upson (DFO, Bedford Institute of Oceanography, Dartmouth, NS).

3. Discussion

The preliminary Canada-wide benthic scope for growth map is shown in Figure 19. Atlantic, Arctic, Hudson Bay and Pacific subsets are also shown below separately in Figures 20 - 22, but the calculation of the Scope for growth was done for the whole Canadian offshore as a single item because of sensitivity of the approach to value ranges of input variables.

On a global scale the observed patterns of variability in the scope for growth are align reasonably well with our current understanding of productivity in the benthic environment and seem to follow longitudinal and onshore-offshore gradients. South-western Scotian shelf and the Gulf of Maine, the narrow shelf off British Columbia and the shelf South of Greenland appear to exhibit the higher scope for growth while the bathyal part of the Pacific region, Arctic seas and deep central part of the Baffin Bay display low scope for growth. The relatively higher estimates of scope for growth in the deep North Atlantic compared with similar depths in the North Pacific likely result from the lower values of observed near-bottom oxygen saturation in the North Pacific (compare with Figure 7).

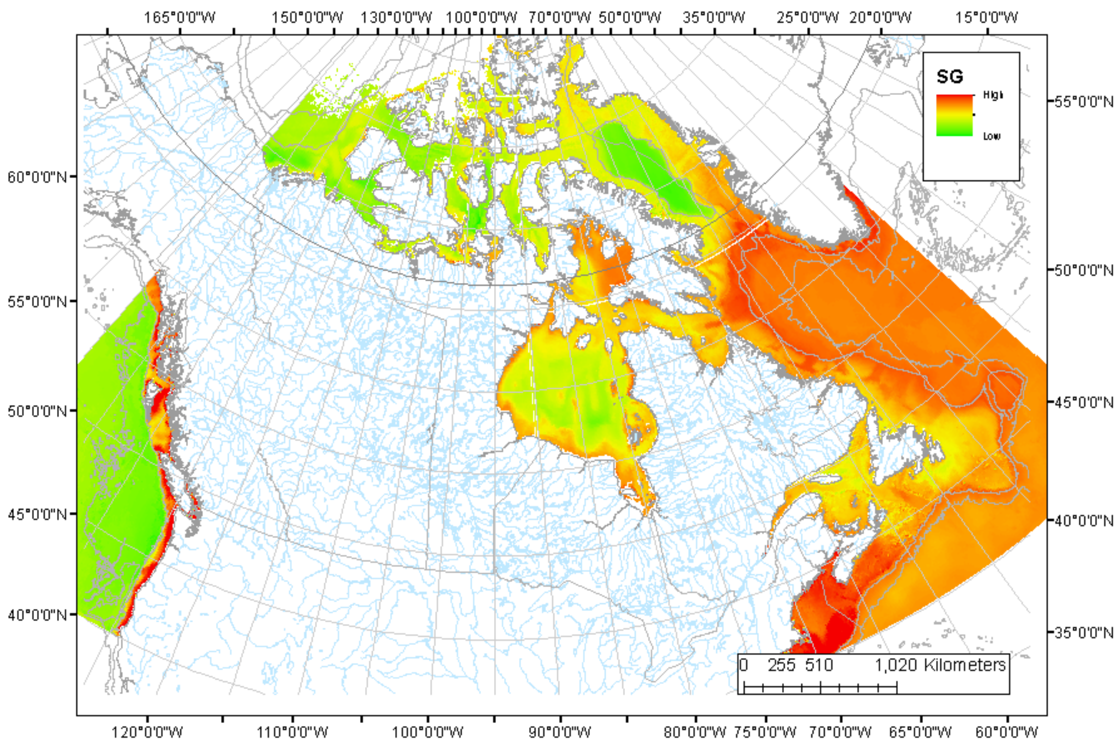

Figure 19. Overview of normalized (0 – 1) scope for growth for benthic environment

Of particular interest along Atlantic (Figure 20) coast is the band of higher scope for growth along the shelf slope starting around the Grand Banks of Newfoundland and hugging the slope all the way up to southern Greenland. Channels along Labrador coast are distinctly highlighted as regions of higher scope for growth. Flemish Cap and Orphans Knoll stand out compared to the background as areas of higher scope for growth.

Hudson Bay is characterized by average to low scope for growth; with higher values along the coast (Figure 20). Specular noise (separate pixels with extreme high or low values) and gaps in data along the boundaries of joined oceanographic datasets are apparent in this figure. Foxe Basin in General shows unusually high scope for growth which is the effect of relatively high oxygen saturation.

Regional views show presence of erroneous results along the coastline seen as specular noise along Labrador and Ungava Bay coast (Figure 20). This is a result of missing data in the underlying digital bathymetric model stemming from assimilation of data to 5x5 minutes resolution and erroneous values in nearshore temperature. Similar errors are visible along the coast of Hudson Bay and in the south of Foxe Basin. Scotian shelf patterns in scope for growth correspond well to the results of Kostylev and Hannah (2007) obtained using higher resolution data. This suggests that the modeling approach is locally consistent.

Scope for growth variability along the Pacific coast is characterized by the sharp gradient between shelf and deep waters, with quick decrease beyond 200 m water depth (Figure 21). Basins on the shelf have lower scope for growth due to the decreased availability of food, lower temperatures and oxygen saturation. The model was not applied to the coastal fjords. The temperature fields for the Pacific continental shelf are very smooth because the underlying WOA has coarse resolution (1 degree). They should be replaced by fields such as those described in paragraph 7 of Foreman et al. (2008). Unfortunately they were not available when the analysis described in this report was done.

In the Arctic (Figure 22) in addition to Foxe Basin patches of relatively high scope for growth are shown in the straight between Kitikmeot and Prince William Island; between Cornwallis Bathurst and Devon islands, along the Western coast of Banks island and in the East of Mackenzie shelf. Most of these locations correspond to persistent polynyas (Hannah et al., 2009). Specular single pixels with high values along the coastline are erroneous, similarly to other regions.

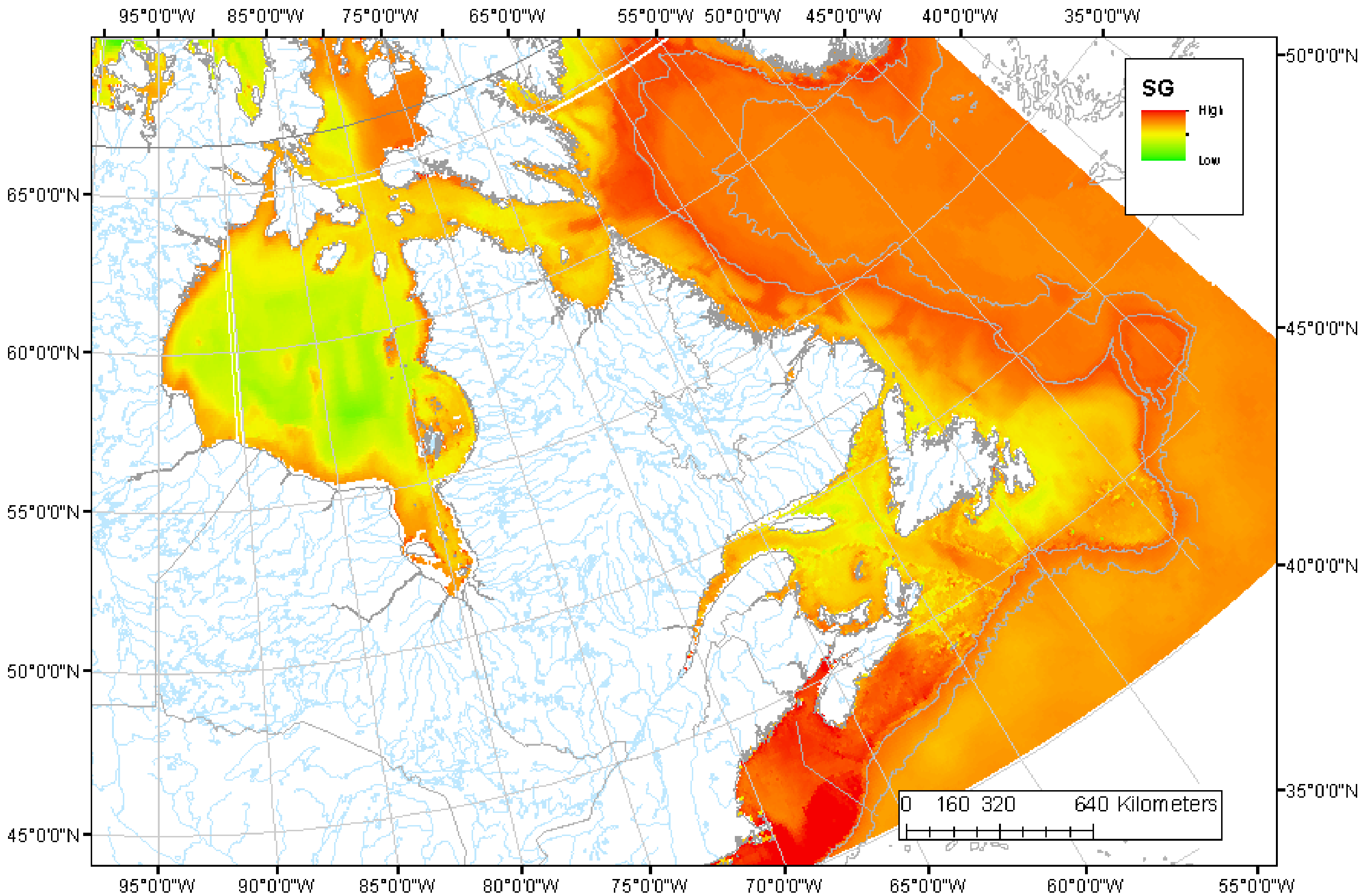

Figure 20. Normalized Scope for Growth, North Atlantic and Hudson Bay region.

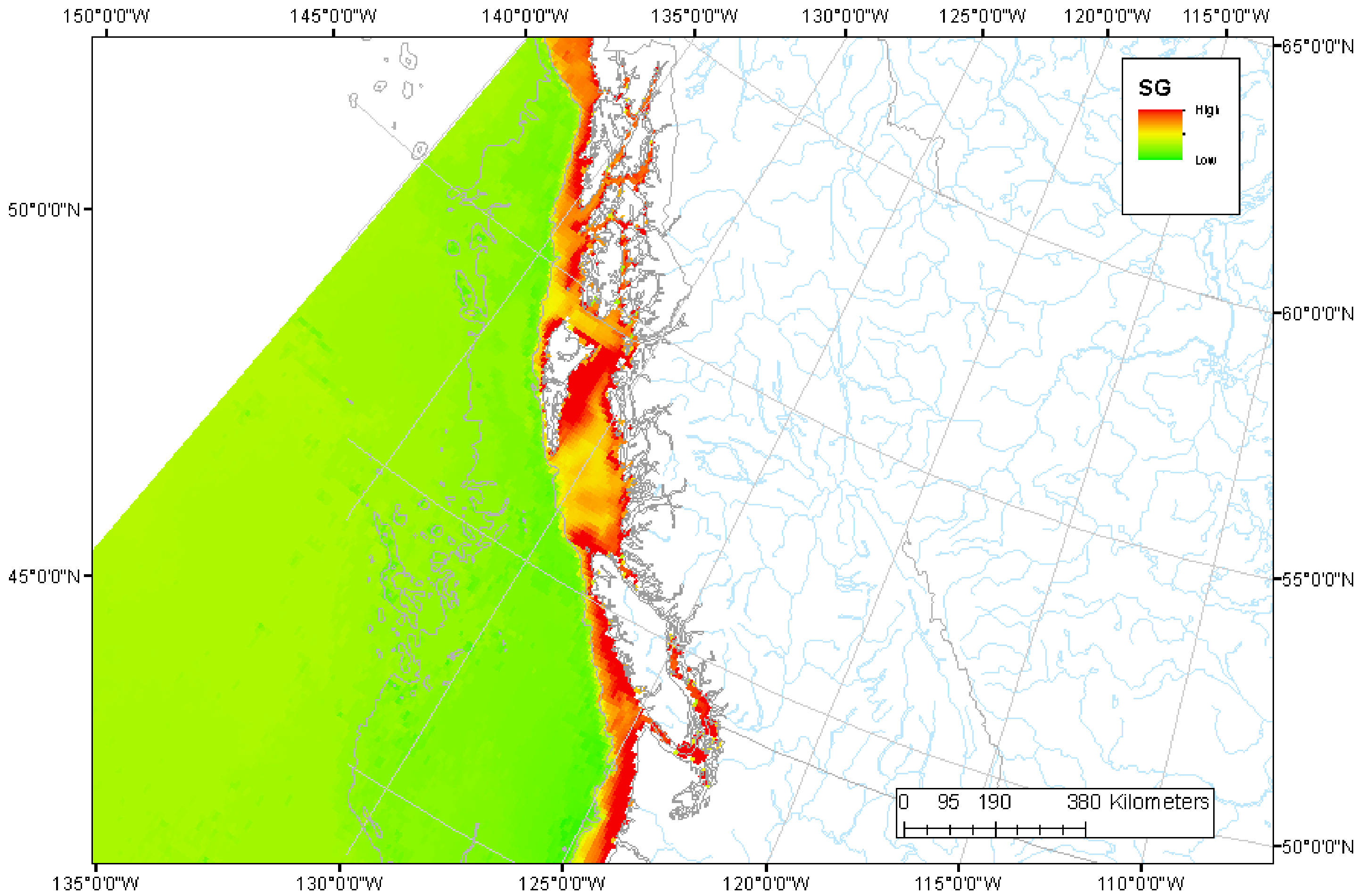

Figure 21. Normalized Scope for Growth, Pacific region.

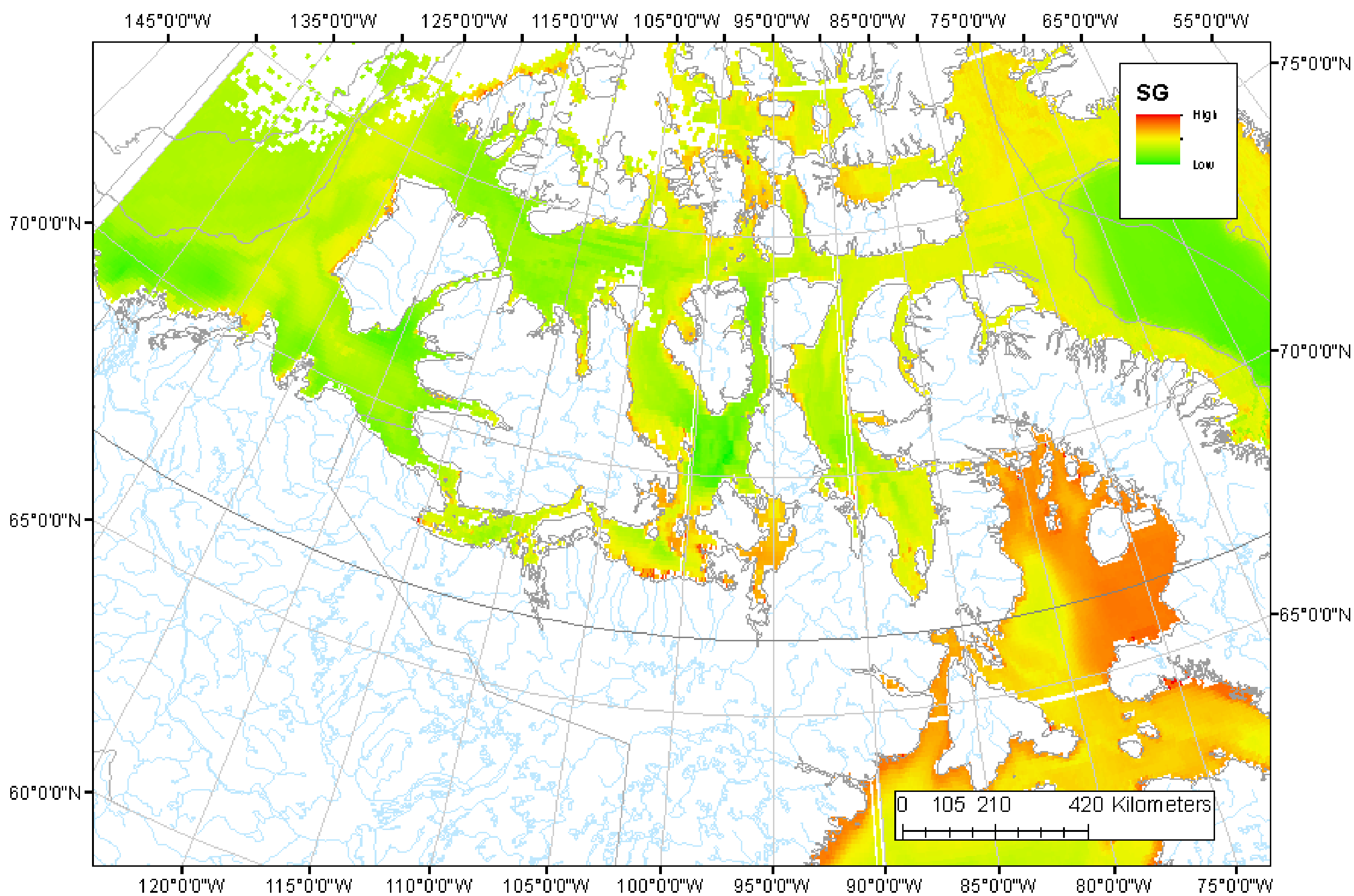

Figure 22. Normalized Scope for Growth, Arctic region.

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