Predicting DOC and DON concentrations in watersheds draining into Beaufort Sea Lagoons, AK

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Introduction

Streams and rivers deliver critical quantities of terrestrial organic carbon and dissolved nutrients to nearshore marine ecosystems. Terrestrial influences are particularly important to the Arctic Ocean, which is only ~1% percent of the ocean volume, but receives more than 10% of global river discharge (Holmes et al. 2012). Coastal watersheds influencing the Alaskan Arctic Ocean are underlain by continuous permafrost with a highly organic soil layer at the surface. While there is little to no river and stream flow during the winter, large volumes of water containing high concentrations of organic carbon and nitrogen discharge into the ocean during spring and, to a lesser extent, summer months.

Freshwater carbon and nitrogen fluxes are particularly important on the Beaufort Sea coastline, where there is a high degree of hydrologic connectivity between land and sea. The coast of the Alaskan Beaufort Sea is characterized by many barrier islands that form shallow lagoons and estuaries. Freshwater discharge into these estuaries supply critical quantities of carbon and nitrogen in the form of dissolved organic matter (DOC), dissolved organic nitrogen (DON), and nitrate (NO_3^-). Spring sea ice and barrier islands restrict estuary-open ocean circulation, helping retain these river-borne materials in lagoons (McClelland et al. 2012). Indeed, studies of stable isotopes demonstrate that this land-derived organic carbon is accumulated into marine food webs (Harris et al. 2018). A schematic diagram of this ecosystem food web is shown in Figure 1. Despite the extreme seasonality of the arctic, these nutrient-rich conditions drive lagoon productivity, supporting diverse benthic fauna, migratory bird species, and important fisheries that local Inupiat communities depend on for subsistence (Dunton et al. 2012).

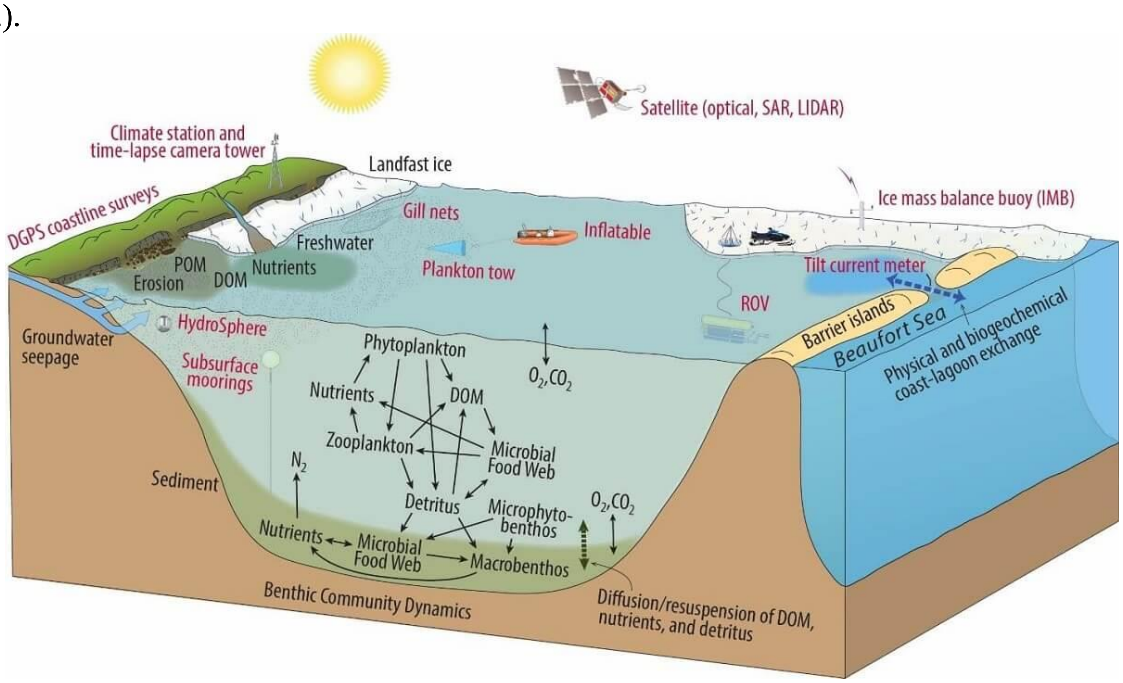

Figure 1. Schematic describing the research components of the Beaufort Sea Lagoons Long Term Ecological Research Project. From the BLE LTER Project Proposal, ble.lternet.edu.

Due to the remote and extensive nature of the arctic, it is important to develop models to help estimate export of carbon and nitrogen from rivers, streams, and groundwater. Connolly et.

al. developed models to describe the relationship between watershed slope and fluvial nutrient concentrations. These relationships are conserved across the Arctic region and across catchment sizes, making them useful for estimating DOC and DON concentrations where no water chemistry data exists (Connolly et al.). While the large Alaskan rivers such as the Yukon and the Colville are well studied, there are many smaller catchments that discharge into the Beaufort Sea with no associated water chemistry data. Simple models that rely on publicly-assessible data are useful tools to estimate water chemistry in these many smaller, unstudied catchments.

Knowledge of river discharge and biogeochemistry is crucial to understand estuarine productivity and food web structure. Predicting stream biogeochemistry is particularly important in an era of rapid arctic warming, where arctic freshwater hydrologic cycling is expected to accelerate and river discharge is expected to increase (McClelland et al. 2006). This, when paired with permafrost thaw and increased erosion rates, will likely alter nearshore biogeochemistry and estuarine trophic dynamics. Accurate assessments of current conditions are needed in order to monitor changes and predict future changes.

Objective

In this project, I use high resolution digital elevation model data from the ArcticDEM project to delineate catchments with visible surface water inputs to four major lagoons on the Beaufort Sea Coastline: Elson Lagoon, Simpson Lagoon, Kaktovik Lagoon and Jago Lagoon. Aerial imagery and approximate locations for these lagoons are shown in Figure 2.

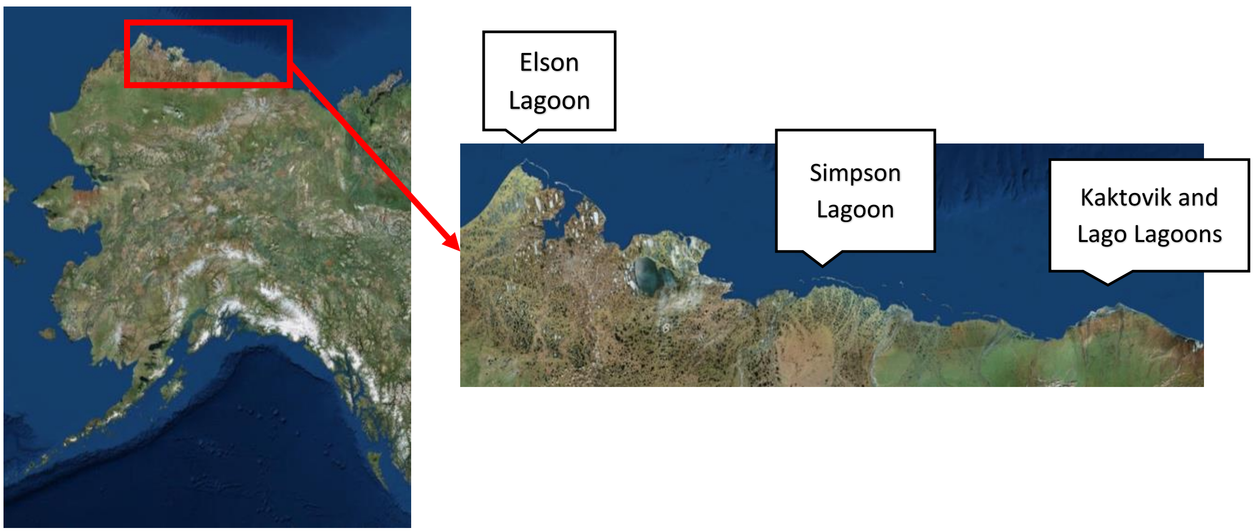

Figure 2. Aerial imagery of the four lagoons studied by the Beaufort Sea Lagoons Long Term Ecological Research.

I chose these four lagoons because they are the primary research sites for the Beaufort Sea Lagoons LTER project. After watershed catchments are defined, catchment area and average catchment slope can be calculated. Values for average catchment slope can be applied to the models developed by Connolly et al. to estimate the concentrations of DOC and DON entering each lagoon. From this analysis, I can examine the variability of catchment size and DOC and DON concentrations between lagoons and make inferences about relative influence of low-order streams to export carbon and nitrogen to lagoons. These analyses will aid our understanding of land-ocean connectivity in the arctic, and help establish a baseline for monitoring climate change impacts on lagoon biogeochemical cycling.

Methods

All geospatial analyses in this project were completed in ArcGIS Pro with a Spatial Analyst License (www.ersi.com). Digital elevation model (DEM) data for this project was obtained through the ArcticDEM project at the University of Minnesota (www.pgc.umn.edu/data/arcticdem/). Mosaiced DEM files at a 10m resolution were downloaded for the regions surrounding Elson, Kaktovik, and Lago Lagoons. Due to the large extent of the Colville River, 100m resolution DEM data was used for the region surrounding Simpson Lagoon. For each region, the tiles were stitched together using the Mosaic Rasters raster function. An Alaska state boundary shape file from the Alaska Department of Natural Resources and obtained through the Geographic Information Network of Alaska (GINA) was used to using the Extract By Mask tool to exclude ocean waters from DEM analysis. Data was projected to the WGS 1984 geographic coordinate system and the Stereographic North Pole projected coordinate system.

Although there is no National Hydrography Dataset Plus (NHDPlus) data available for the state of Alaska, there is National Hydrography Dataset (NHD) data available through GINA. Two NHD shapefiles were used in initial analysis: Northern Alaska Hydrographic Area Features (non-lake) polygon shapefiles and flowline shapefiles. During an initial attempt to delineate watersheds, I used the Feature to Line tool to convert the Hydrographic Area Features polygon shapefile to stream lines so dangling vertices from the flowlines could be used as "seed" points to delineate catchments. However, missing links in flowline data warranted this method ineffective. I attempted this delineation method a second time using the NHD flowlines. While I could complete the delineation, it resulted in dense network of streams that were not visible from aerial imagery. NHD polygon features only included larger streams and rivers, whereas NHD flowlines included many stream networks that did not appear in aerial imagery, which can be seen in Figure 4. For this reason, I decided not to use either dataset in my watershed delineations.

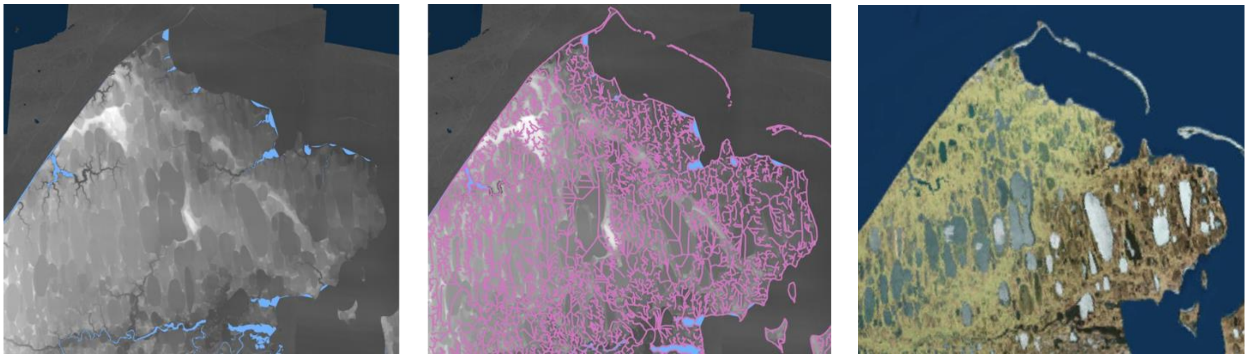

Figure 4. Example images of a region near Elson Lagoon. Left and middle images are DEM data overlain with NHD Hydrographic Area Feature polygons (left) and NHD flowlines (middle). The image on the right is aerial imagery provided by ESRI through ArcGIS Pro.

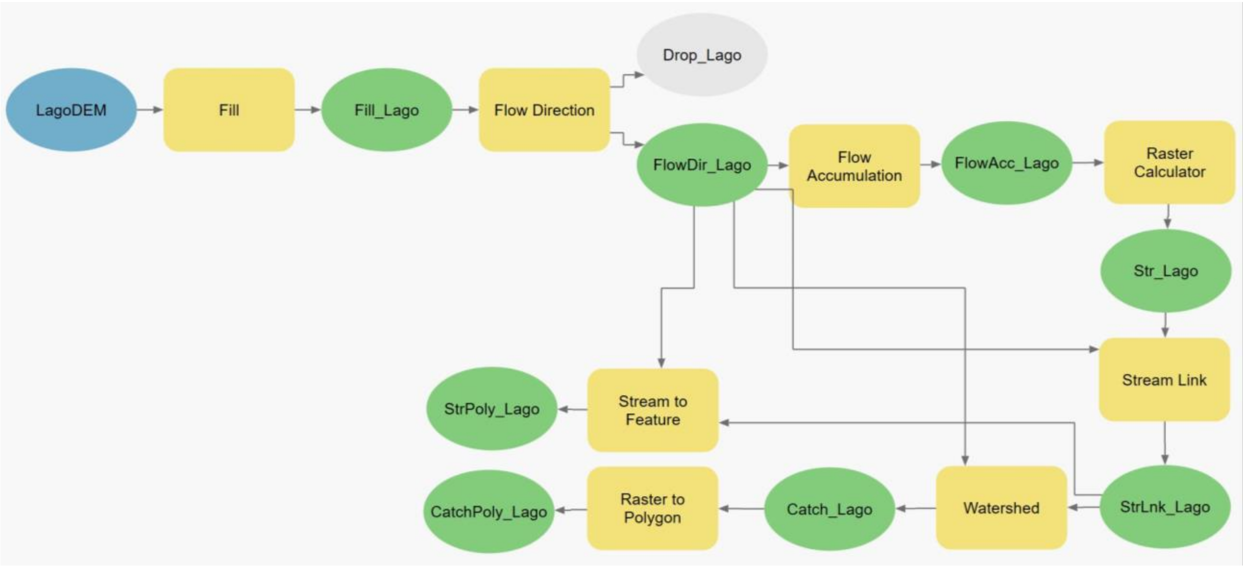

Figure 5. Example ModelBuilder model used to delineate watersheds draining into Lago Lagoon.

To delineate the watersheds that drain into each lagoon, I used the Hydrology tools in the Spatial Analyst toolbox. The workflow I used is outlined in Figure 5, using Lago Lagoon as an example. To determine at what flow accumulation to define a stream, I compared aerial imagery to flow accumulation raster values. I chose a flow accumulation value to use in the raster calculator that consistently had surface water across the whole region. This method produced stream flowlines that were more accurate than either NHD dataset. After stream shapefile flowlines and subcatchment boundaries associated with each stream link were produced, I manually selected each stream network that had output into the lagoon of interest. Then, using Select Layer by Location, I selected each subcatchment that intersected with these stream networks. Dissolving these subcatchment boundaries created a shapefile that described the entire region that contributed surface water flow to the lagoon of interest.

When I delineated stream networks and associated watershed basins for all surface waters flowing into Elson, Simpson, Kaktovik and Lago Lagoons, I was able to calculate the drainage basin area and average catchment percent slope. Percent slope values were applied to the Connolly et al. concentration-slope models.

Results and Discussion

The contributing drainage areas to each of these lagoons ranged in orders of magnitude, from 282.2 km^2 of stream catchments that flow into Kaktovik Lagoon (Figure 6) to to the 70,000 km^2 Colville River basin which drains into Simpson Lagoon (Figure 7).

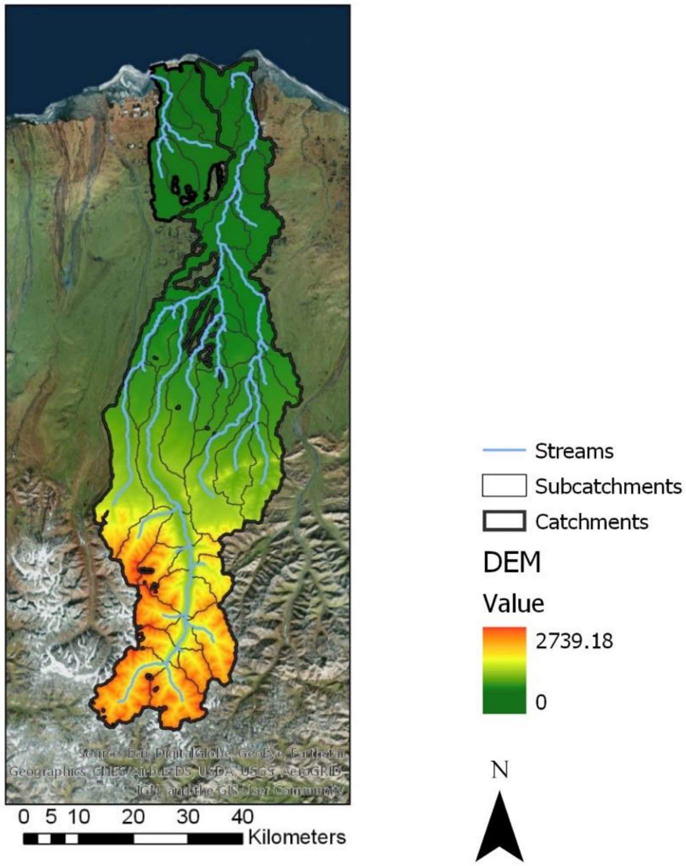

Figure 6. Contributing drainage areas stream and river flow into Kaktovik Lagoon (left) and Lago Lagoon (right). DEM data in meters.

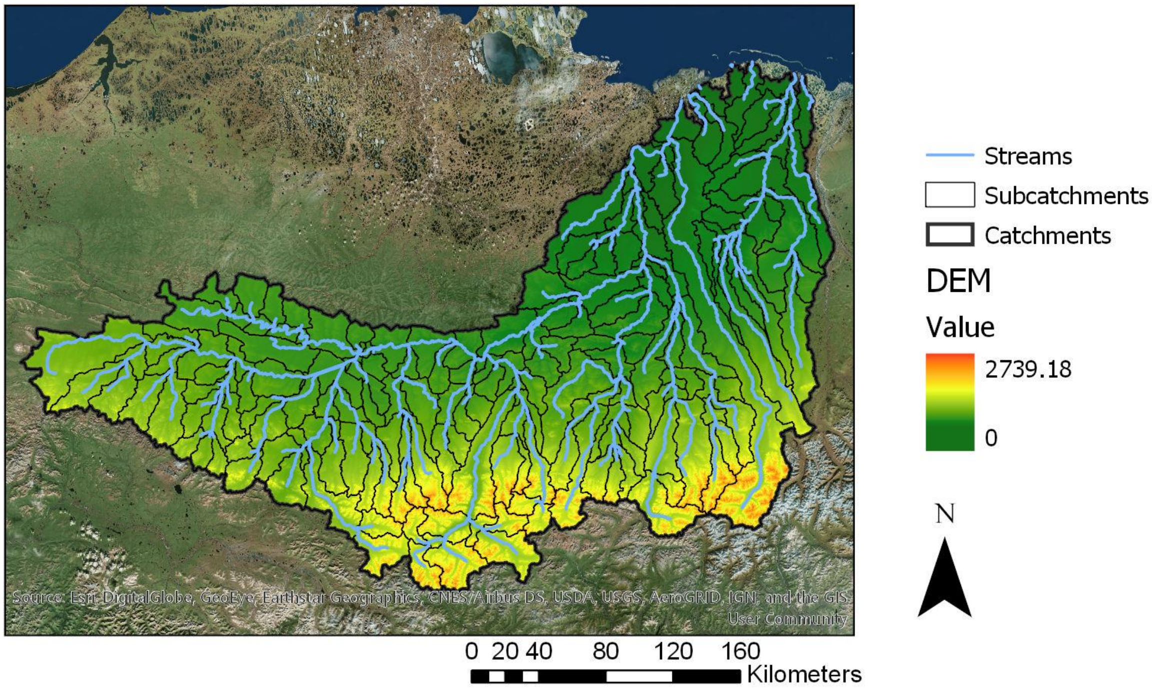

Figure 7. Contributing drainage area for stream and river flow into Simpson Lagoon. DEM data in meters.

Average catchment slope also has a large range, from 0.10% to 3.14%. Due to this wide range of slopes, there are considerable difference in the estimated average spring and summer freshwater DOC and DON concentrations for these drainage areas. Spring DOC concentrations are consistently higher than summer, but, within the same season, the drainage areas differ by concentrations up to 10 mg C L^{-1}. Spring expected DON concentrations range from around 0.3 to 0.6 mg N L^{-1} depending on the slope of the drainage area. Summer DON concentrations are about 10% higher, but with a similar range in values. This data summary is displayed in Figure 8.

Lagoon	Contributing drainage area (km^2)	Slope (%)	Spring DOC (mg C L^{-1})	Spring DON (mg N L^{-1})	Summer DOC (mg C L^{-1})	Summer DON (mg N L^{-1})
Elson	427.6	0.106	23.09	0.62	18.52	0.77
Simpson	70,809.7	1.236	14.24	0.40	11.39	0.47
Kaktovik	282.2	0.183	21.11	0.57	16.92	0.70
Lago	2,339.9	3.142	10.88	0.32	8.68	0.36

Figure 8. Contributing drainage area, average catchment slope, and estimated spring and summer DOC and DON concentrations for Elson, Simpson, Kaktovik, and Lago Lagoons.

These results demonstrate that freshwater chemistry varies greatly across the north slope region of Alaska. While some lagoons, like Simpson Lagoon, have large rivers exporting nutrients to them, other lagoons, such as Elson Lagoon (Figure 9), only receive freshwater from small order streams. Not all lagoons are near large rivers, highlighting the need study the many small order streams in the region. While this paper does not attempt to estimate the volume of freshwater discharge entering these lagoons, the large variation in watershed size indicates a range of hydrologic connectivity between terrestrial and lagoon ecosystems. Based on the data in Figure 8, alongside DEM data from across the region, smaller watersheds near the coast tend to have lower average slopes. Larger watersheds expand into the Brooks Range, increasing the average slope of the drainage area. This tendency for larger watersheds to have sleeper slopes may moderate the concentrations of DOC and DON, such that fluxes of carbon may be similar to smaller watersheds with lower slope. Due to the location and orientation of the Brooks Range, there is also a longitudinal gradient the average slope of watersheds, with slope increasing east to west.

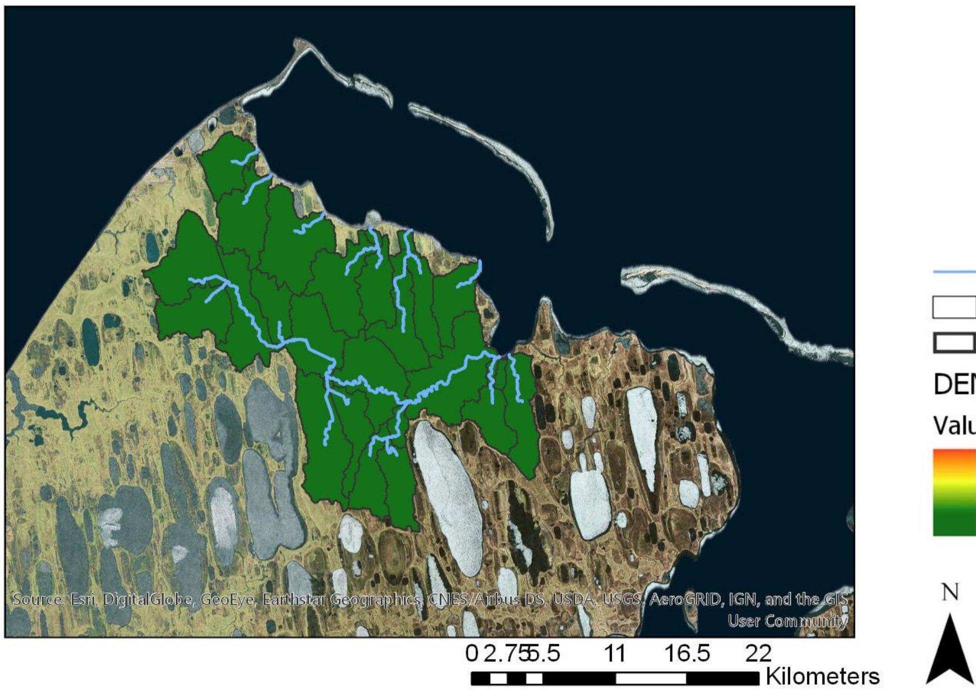

Figure 9. Contributing drainage area for streamflow into Elson Lagoon. DEM data in meters.

These watershed delineations and estimates of DOC and DON export can benefit analyses of lagoon productivity. However, there are limitations to soley using these methods. To asess the fluxes of DOC and DON to these lagoons, reasonable estimates of stream and discharge are needed. Models of circulation between estuaries and open ocean is also important, since estuary-ocean connectivity will affect the retention of freshwater carbon and nitrogen. Looking at satellite imagery, it is clear that certain lagoons, for example Elson Lagoon, are more closed off. Even with less freshwater export, concentrations of DOC and DON retained in the lagoons may be higher than more open lagoons such as Simpson Lagoon. Additionally, it is often difficult to determine which streams and rivers to include in these analyses. Rivers that are adjacent to lagoons may influence the lagoon, depending on current patterns. As these lagoons are studied by the Beaufort Sea Lagoons LTER project, a better understanding of hydrology and lagoon circulation will aid analysis of carbon and nitrogen export to lagoons. However, this project demonstrates how a combination of modeling and GIS analyses can provide estimates for water quality parameters where no field data exists.

References

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