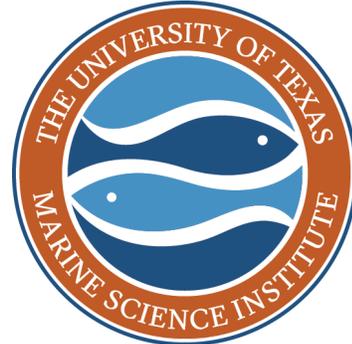


A Spatial Analysis of the Physicochemical Variables that Correspond to the Highest Benthic Organism Densities off the North Alaskan Coast



By: Daniel Fraser

The Problem

High abundances of organisms that live on the bottom of coastal environments (such as the benthic invertebrate in **Figure 1a**) are an important food source for all kinds of higher trophic level organisms including, but not limited to: fish, migratory birds (Wauchope *et al.* 2017), and whales (Moore and DeMaster 1997). Furthermore, the fish and whales that feed on these benthic organisms are in turn food for polar bears and humans (Gadsby and Steele 2004). While these benthic organisms are an important link in any coastal food web, their distributions can be unpredictable and somewhat sporadic. One potential reason for this sporadic distribution is the variability in water characteristics along the coast, with marine invertebrates being susceptible to these variations. It is documented that arctic marine invertebrates can not handle the lower salinities (Beadle 1931) and relatively warmer temperatures (Hayward *et al.* 2003) characteristic of freshwater river inputs, with numerous river deltas found all along the Alaskan coast. Following this logic, perhaps one way to see where benthic organisms are abundant is by looking for the water characteristics that they favor. I hypothesize that the higher densities of these benthic organisms will be located where salinities are the highest (within the salinity spectrum of the region's dataset) and where the temperatures are the lowest (within the temperature spectrum of the region's dataset).

The area of interest in these coastal environments is the northern coast of Alaska (**Figure 1b**), aka the north slope, that is characterized by cold and salty water adjacent to flat tundra. Within this vast and flat land, I am focusing on the stretch of coast near the Sagavanirktok River (Sag River), to see the freshwater inputs affect on the coastal water's salinity and temperature. There are no mapped roads in this part of the Alaskan Arctic, with dirt roads routinely being washed out and hastily replaced, but the importance of this region are the waters of the coasts and lagoons anyways.



Figure 1a: A benthic invertebrate.



Figure 1b: The northern coast of Alaska.

Data Collection

Raw Data:

An excel sheet was provided to me by a team member of the Beaufort Lagoon Ecosystem - Long Term Ecological Research (BLE-LTER) team. The data is from 1976 and was a collaboration with the North Pacific Research Board on benthic organism's density and distributions across the entire northern coast of Alaska. Data on this spreadsheet included: longitude and latitude coordinates for sample sites, water salinity, water temperature, organism count, organism weight, species name, calculated density per meter squared, and date the sample was collected.

Downloaded Data:

1. Four digital elevation models (DEMs) were downloaded from the USGS National Map Viewer, <https://viewer.nationalmap.gov/basic/>. The DEMs were 1/3 arc-second, 1 x 1 degree extent models from 2017 with the following titles:
 - USGS NED 1/3 arc-second n71w148 1 x 1 degree ArcGrid 2017
 - USGS NED 1/3 arc-second n71w149 1 x 1 degree ArcGrid 2017
 - USGS NED 1/3 arc-second n71w150 1 x 1 degree ArcGrid 2017
 - USGS NED 1/3 arc-second n71w151 1 x 1 degree ArcGrid 2017
2. Three geodatabases were also downloaded from the USGS National Map Viewer, <https://viewer.nationalmap.gov/basic/>. The datasets were published in 2019 and included shapefiles of streams and coastlines, polygons of river deltas and tundra lakes, and had the following titles:
 - USGS National Hydrography Dataset Best Resolution (NHD) for Hydrologic Unit (HU) 8 - 19060304
 - USGS National Hydrography Dataset Best Resolution (NHD) for Hydrologic Unit (HU) 8 - 19060401
 - USGS National Hydrography Dataset Best Resolution (NHD) for Hydrologic Unit (HU) 8 - 19060402
3. World coastline shapefile was downloaded from desktop (R:) drive > geo-class > GEO-327g_386g > Project_Data > World > World_borders > :
 - TM_WORLD_BORDERS-0.3
4. Topographic basemap was downloaded from ArcGISOnline: Add Data > Add Basemap > Topographic
5. Geographic Coordinate System used: GCS_WGS_1984

Data Preprocessing

Raw Data:

Clean-up excel spreadsheet to ensure correct import into ArcGIS by:

1. Remove empty spaces in cells and remove cells with numbers and letters combined.
2. Remove columns that have unnecessary data (Dates, Site ID, etc.)
3. Convert to CSV file

LAT	LON	Taxon_Name1	Cnt_m2	wwg_m2	Raw_Cnt	Raw_wwg	SURF_SAL_psu	SURF_TEMP	DEPTH_m	GrabArea_m2
70.21	-147	MILIOLINELLA	10	0.0025	4	0.001	25.5	2	5.3	0.1
70.21	-147	CYCLOGYRA INVOLVENS	42.5	0.0425	17	0.017	25.5	2	5.3	0.1
70.21	-147	ELPHIDIELLA	77.5	0.015	31	0.006	25.5	2	5.3	0.1
70.21	-147	NEMERTEA	5	0.0225	2	0.009	25.5	2	5.3	0.1
70.21	-147	LUMBRINERIS FRAGILIS	47.5	0.0475	19	0.019	25.5	2	5.3	0.1
70.21	-147	TAUBERIA GRACILIS	87.5	0.0525	35	0.021	25.5	2	5.3	0.1
70.21	-147	ALLIA	65	0.1025	26	0.041	25.5	2	5.3	0.1
70.21	-147	ARICIDEA	32.5	0.025	13	0.01	25.5	2	5.3	0.1
70.21	-147	CLYMENURA POLARIS	22.5	0.1075	9	0.043	25.5	2	5.3	0.1
70.21	-147	MALDANIDAE	22.5	0.185	9	0.074	25.5	2	5.3	0.1
70.21	-147	MINUSPIO CIRRIFERA	505	0.6025	202	0.241	25.5	2	5.3	0.1
70.21	-147	SPHAERODOROPSIS MINUTA	12.5	0.01	5	0.004	25.5	2	5.3	0.1
70.21	-147	HAPLOSCOLOPLOS ELONGATUS	65	0.175	26	0.07	25.5	2	5.3	0.1
70.21	-147	AMPHICTEIS SUNDEVALLI	2.5	1.9025	1	0.761	25.5	2	5.3	0.1
70.21	-147	AMPHARETE ACUTIFRONS	112.5	0.6675	45	0.267	25.5	2	5.3	0.1
70.21	-147	AMPHARETE VEGA	57.5	0.1275	23	0.051	25.5	2	5.3	0.1
70.21	-147	TEREBELLIDES STROEMI	37.5	0.6575	15	0.263	25.5	2	5.3	0.1
70.21	-147	TRICHOBRANCHIDAE	10	0.06	4	0.024	25.5	2	5.3	0.1
70.21	-147	EXOGENE NAIDINA	45	0.005	18	0.002	25.5	2	5.3	0.1
70.21	-147	THARYX	5	0.0225	2	0.009	25.5	2	5.3	0.1
70.21	-147	THARYX	30	0.1725	12	0.069	25.5	2	5.3	0.1
70.21	-147	CHONE	17.5	0.01	7	0.004	25.5	2	5.3	0.1
70.21	-147	CHONE	30	0.2775	12	0.111	25.5	2	5.3	0.1
70.21	-147	EUCHONE ANALIS	2.5	0.215	1	0.086	25.5	2	5.3	0.1
70.21	-147	NEREIMYRA APHRODITOIDES	5	0.0225	2	0.009	25.5	2	5.3	0.1
70.21	-147	TUBIFICIDAE	102.5	0.02	41	0.008	25.5	2	5.3	0.1
70.21	-147	PORTLANDIA ARCTICA	15	2.0675	6	0.827	25.5	2	5.3	0.1
70.21	-147	LIOCYMA FLUCTUOSA	12.5	0.39	5	0.156	25.5	2	5.3	0.1

Figure 2: Modified CSV file ready for import into ArcGIS.

Downloaded Data:

All files downloaded from the USGS National Map Viewer, as well as the TM_WORLD_BORDERS-0.3 folder, were compressed files and had to be extracted before being copied into my ArcCatalog connected folder for this project.

ArcGIS Processing

1. Add DEM files and use “Hillshade” tool to convert them to hillshade rasters
 - a. Z-value was changed from default value of 1 to 0.00009.

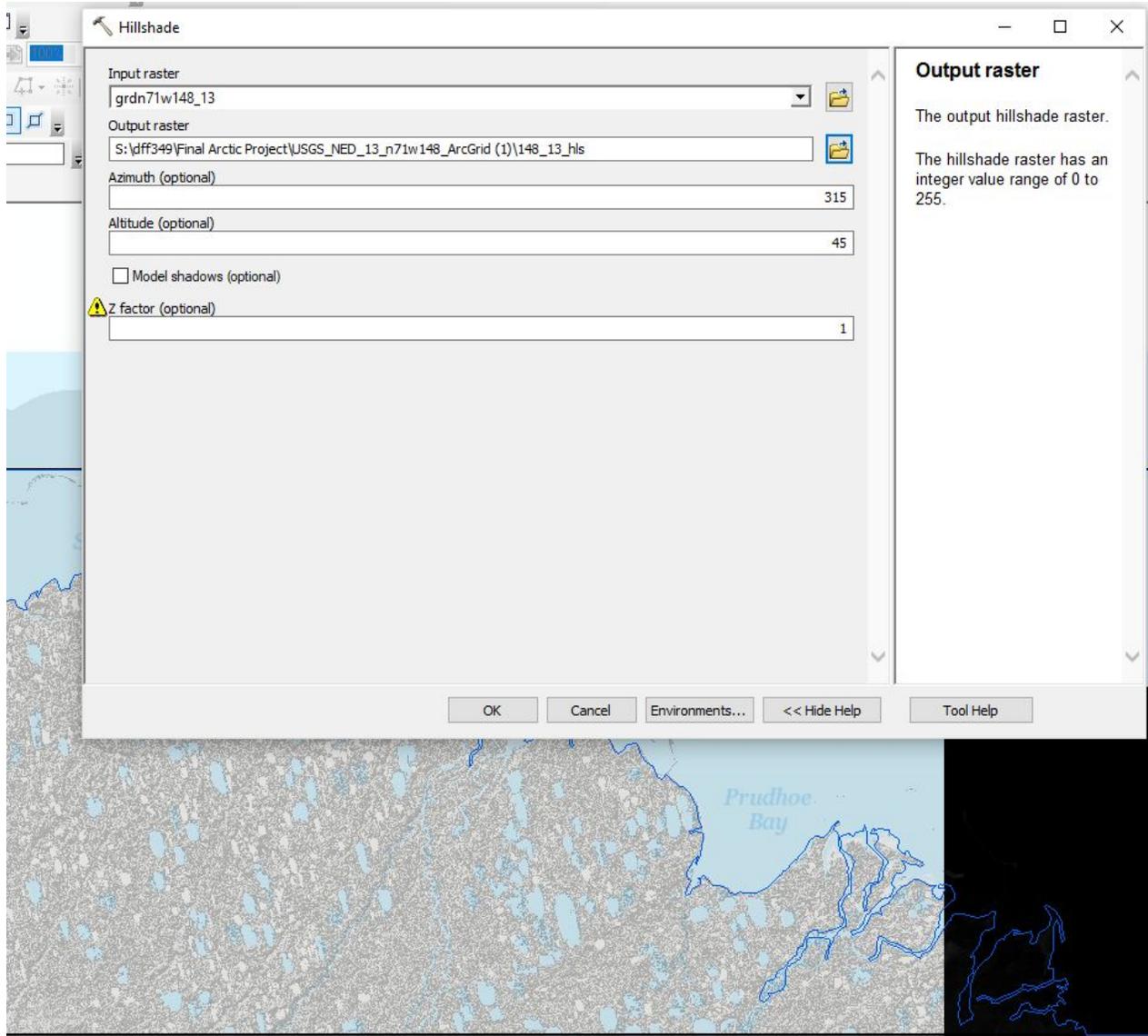


Figure 3: Converting the last DEM file (far right footprint) to a hillshade raster file.

- 2. Create a rectangle around the specific Alaskan coastline my dataset encompasses.**
 - a. Use the Draw Toolbar to create a rectangle around the area of interest.
 - b. Use Draw Toolbar > Drawing > Convert Graphics To Feature, to turn drawn rectangle into a polygon.
 - c. Replace the rectangle graphic with the new “area of interest” polygon shapefile.

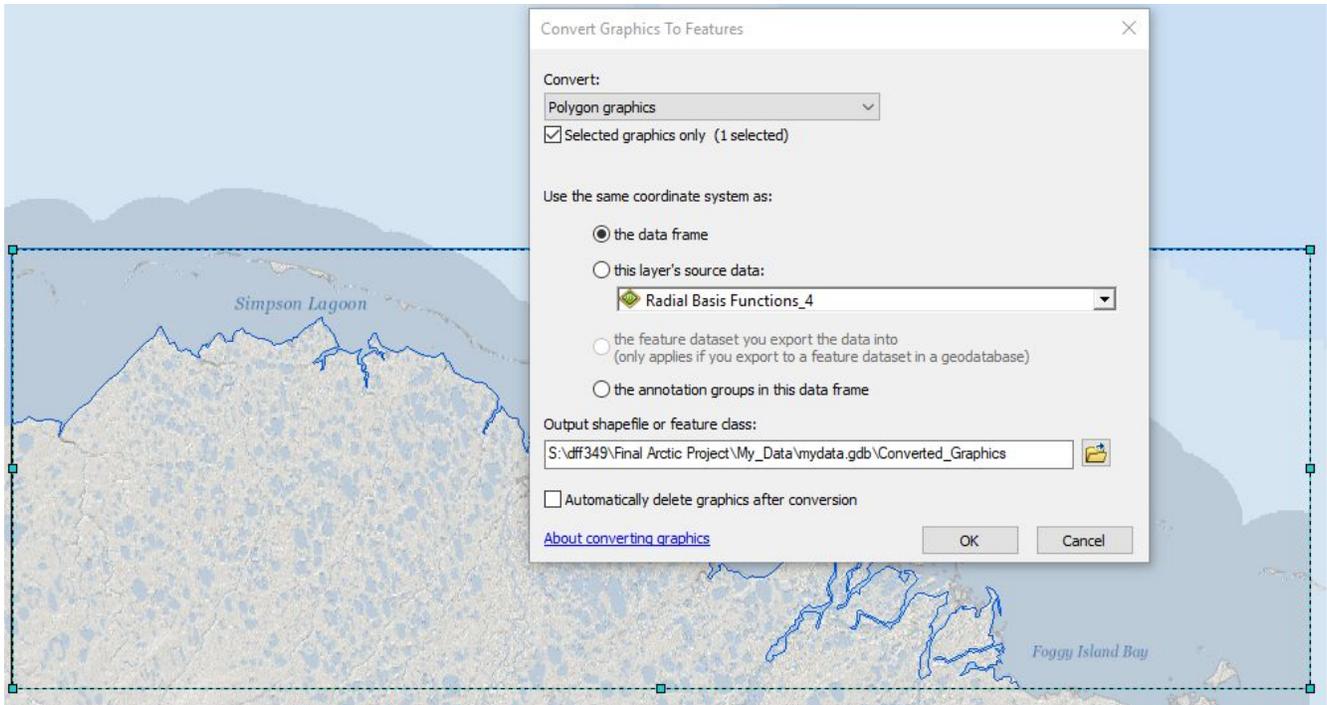


Figure 4: Using the same coordinate system as data frame, convert to “Polygon graphics”.

3. Add TM_WORLD_BORDERS-0.3, a shapefile of global coastlines

- a. Turn on “Editing” in Editor Toolbar to edit and add vertices to make rough outline more precise.

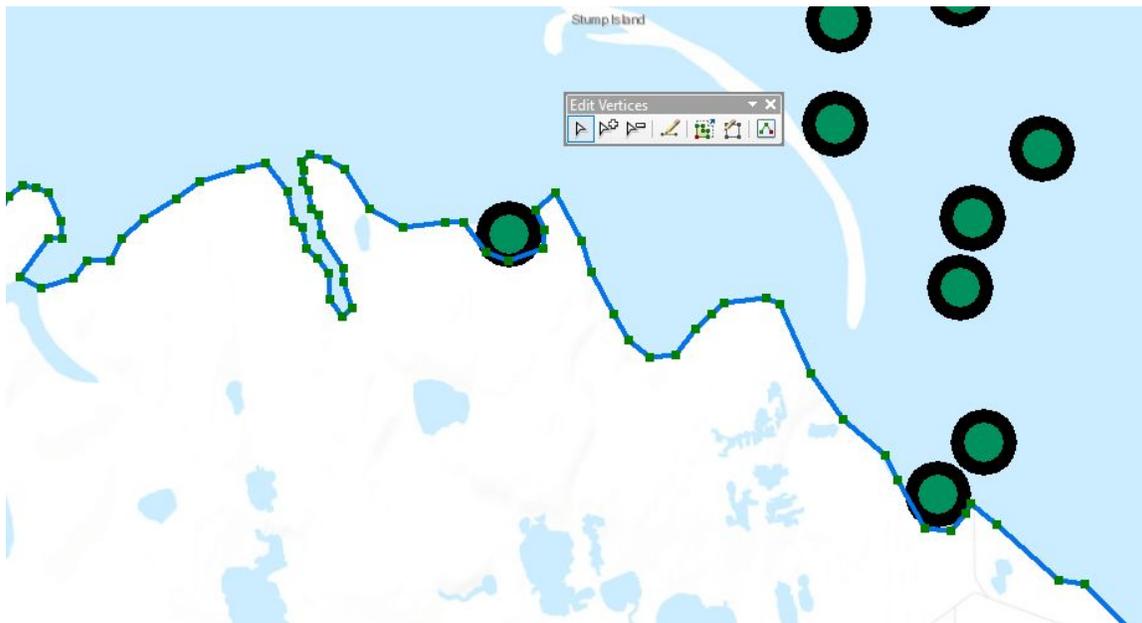


Figure 5: Utilizing “Edit Vertices” to adjust coastline, making sure in go around the data points (Green circles).

4. **Incorporate modified coastline file and hillshade files into the “area of interest” polygon shapefile**
 - a. Use the “Clip” tool to include only the coastline file within the “area of interest” polygon shapefile.
 - b. Use the “Extract by Mask” tool to show only the parts of the hillshade rasters within the “area of interest” polygon shapefile.

5. **Modify clipped coastline to enclose the ocean, instead of the land.**
 - a. Turn on Editor Toolbar and Snapping Toolbar then use “Edit Vertices”.
 - b. Having the polygon enclose the ocean instead of the land will allow water parameter rasters to be masked properly.

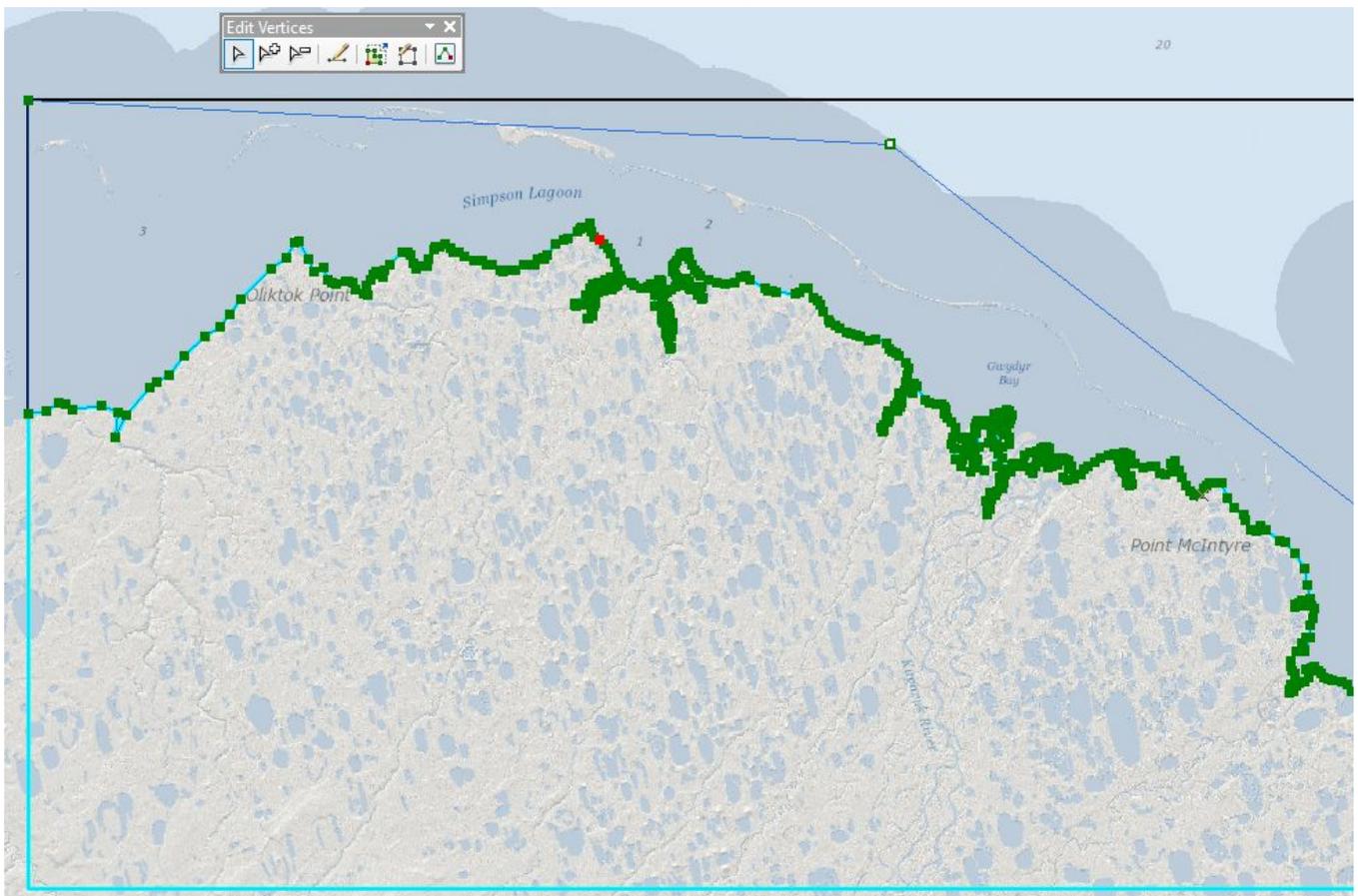


Figure 6: New outer vertices will be “snapped” to the outer corners of the “area of interest” polygon shapefile.

6. Create a Map Inset.

- a. Click “Insert” and then add “New Data Frame”
- b. Open Lab 2 folder > Mapproj.mdb (geodatabase) > “USA” feature dataset > add “states” feature class
- c. In TOC, go to New Data-Frame > “states” layer properties > “Definition Query” > then use “Query Builder” button to select for Alaska
- d. Create an “Extent Indicator” to highlight the coastal area of interest:
 - i. New Data Frame > Properties > Extent Indicator : Add “Layers” from “Other data frames:” to “Show extent indicator for these data frames:”
 - ii. Then within the same Extent Indicator > Option - Layers > Frame: Make Border and Background the color red.

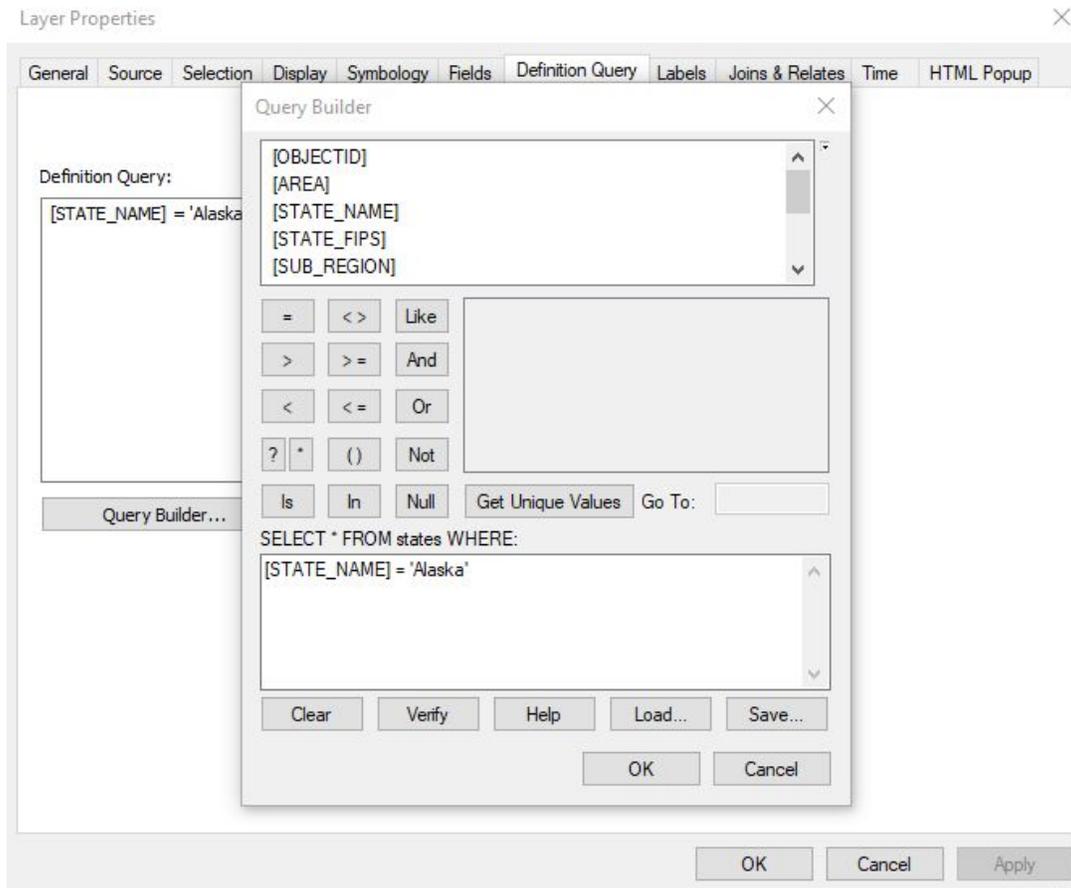


Figure 7: Query Builder expression: [STATE_NAME] = 'Alaska'.

7. Import CSV and assign the data geographic coordinates

- a. Use “Display X, Y Data” and set “LON” column in CSV file to “X-Field” and set “LAT” column to “Y-Field”.
- b. Change Geographic Coordinate System to GCS_WGS_1984.

8. Convert CSV file to a geodatabase feature class

- Convert file to a geodatabase feature class, rather than a shapefile to ensure the few blank cells that existed in the original CSV file are converted to “null-data” points and not given place-holder values of zero.
- Interpolation of this data will be misleading if false zeros are assigned.

9. Interpolate data of SURF_SAL_psu, Surf_Temp, and Cnt_m2 columns from CSV to create prediction maps

- Use the “Geostatistical Wizard” to run a Radial Basis Function
- Radial Basis Function is an exact form of interpolation like IDW, but more flexible. The method provides prediction surfaces that are comparable to the exact form of kriging, but with no assumptions about the data.

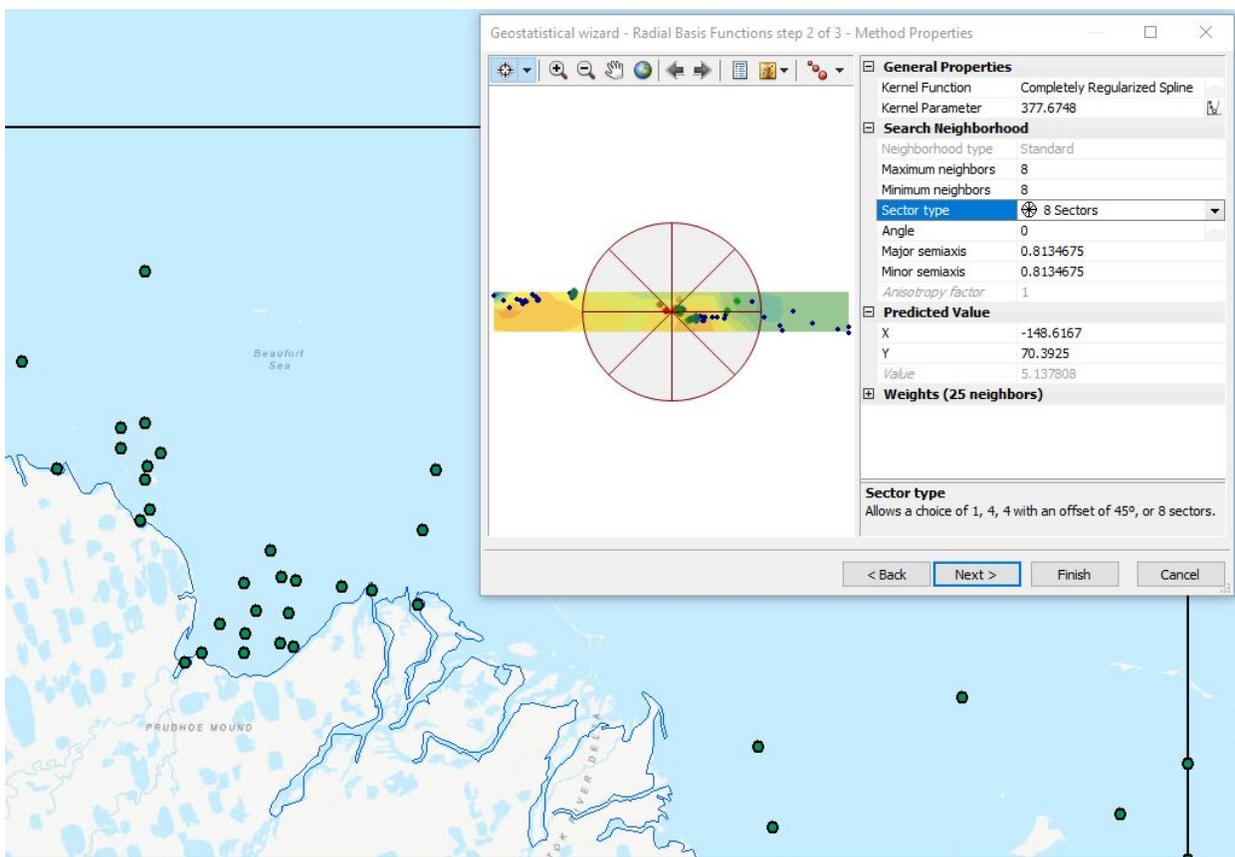


Figure 8: Radial Basis Function form of interpolation, “Sector type” changed from 1 to 8.

10. Convert Radial Basis Function prediction maps to raster files

- In TOC, right click on each Radial Basis Function Prediction Map > Data > Export to Raster
- “SURF_SAL_psu” raster renamed “Salinity”, “Surf_Temp” raster renamed “Temperature”, and “Cnt_m2” raster renamed “Organism Density”.
- Change symbology from Stretched to Classified with 10 classes, in order to increase the data range classes to convert into ranks for raster algebra.

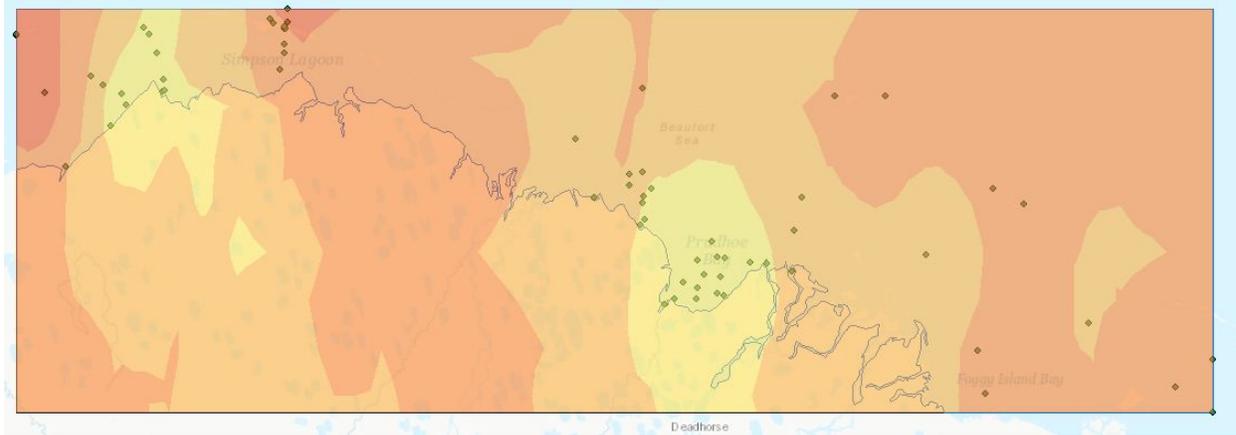


Figure 9a: Interpolation product after Radial Basis Function

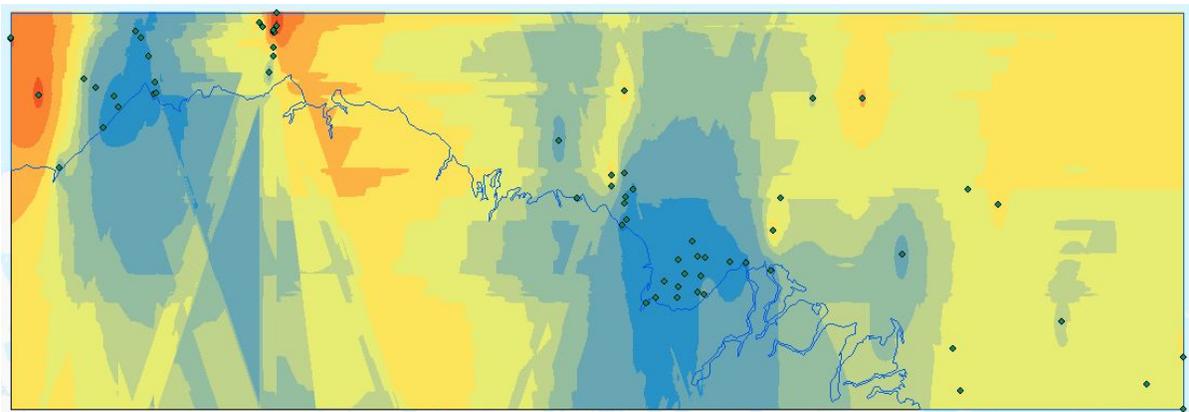


Figure 9b: Raster file after interpolation conversion

11. Use “Extract by Mask” tool to view only the predicted raster data along the coast and within the area of interest rectangle.

- a. The coastline shapefile should not only separate the land from the sea, but also define the area of interest rectangle out at sea.

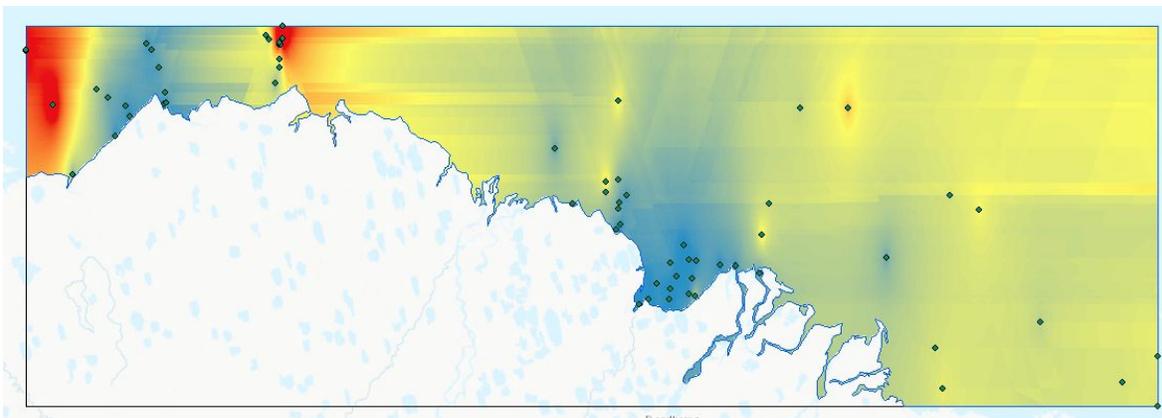


Figure 10: A raster mask like this is perfect for focusing on the data predictions over the water, which is the only place it is relevant.

12. Reclassify “Salinity” and “Temperature” rasters to shared ranking system

- a. Use “Reclassify” tool to create a ranking system with values of 1 to 4, corresponding to my designation of what salinity and temperature ranges benthic marine organisms prefer the least (1) and the most (4).
- b. Rationale For Ranking System:
 - i. Freshwater has a salinity value of 0 ppt and normal seawater has salinity values around 30-35 ppt. Marine organisms become physiologically stressed and susceptible to death if they are exposed to freshwater.
 - ii. Polar marine invertebrates have smaller thermal tolerance ranges than lower latitude organisms, with some invertebrates showing preference for lower temperatures. Arctic surface water temperatures are roughly on average 0-3 °C.

Table 1: Ranking system created to represent the salinity and temperature ranges most favored by benthic marine organisms.

Rank	Salinity (ppt)	Temperature (°C)
1 (Lowest Organism Preference)	1-14	10-14
2	14-20	6.1-10
3	20-24	2.5-6
4 (Highest Organism Preference)	24-35	0-2.4

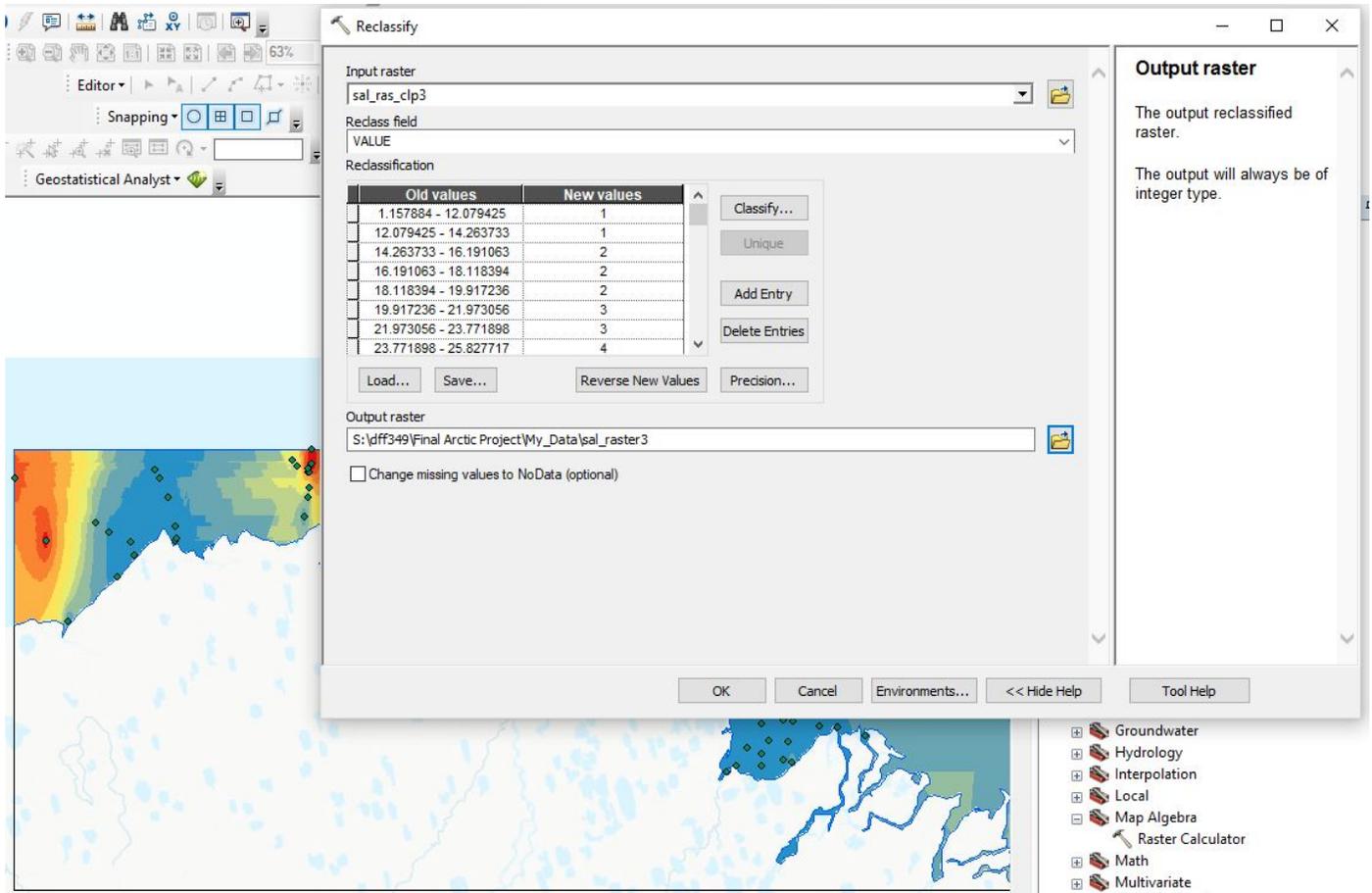


Figure 11: Reclassifying salinity raster (sal_ras_clp3) to shared ranking system.

13. Add the two reclassified “Salinity” and “Temperature” rasters together

- Use “Raster Calculator” tool to see where the highest ranks of salinity values overlaps with the highest ranks of temperature values.
- Output raster will have a scale of 2-8, corresponding to where the two input raster’s 1-4 scale overlapped.
- Output raster renamed “Salinity and Temperature” and is **Figure 15**.

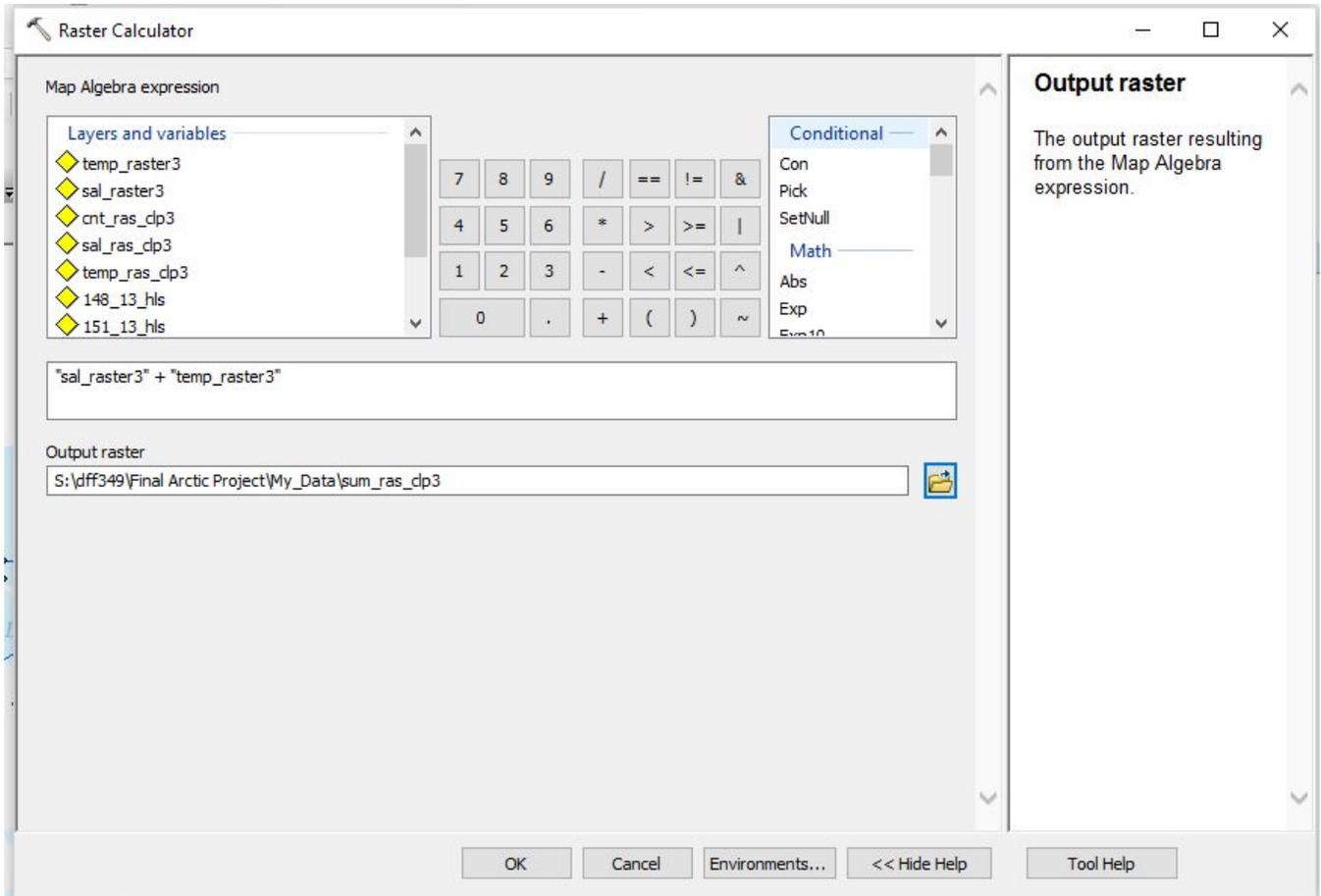


Figure 12: Map algebra expression: “Salinity” + “Temperature”.

14. Reclassify “Organism Density” and “Salinity and Temperature” rasters to shared ranking system

- a. Use “Reclassify” tool to create a ranking system with values of 1 to 3, corresponding to lower organism density and combined salinity/temperature rank (1) and highest organism density and combined salinity/temperature rank (3).

Table 2: Ranking system created to represent the highest marine benthic organism density and most optimum salinity/temperature ranks.

Rank	Organism Density (#/m ²)	Optimum Sal/Temp Rank
1 (Lowest Organism Density Overlaps Least Optimum Sal/Temp)	7-46	2-3
2	47-68	4-5
3 (Highest Organism Density Overlaps Most Optimum Sal/Temp)	69-247	6-8

15. Add the two reclassified “Salinity and Temperature” and “Organism Density” rasters together

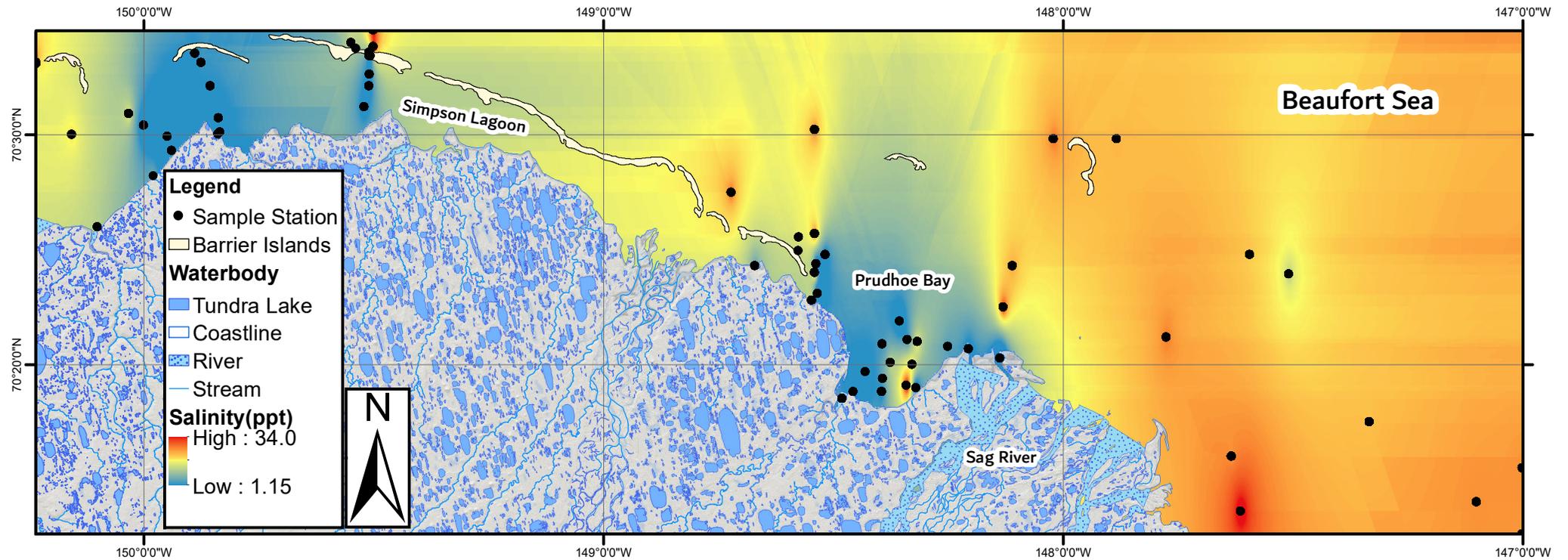
- a. Use “Raster Calculator” tool to see where the highest organism density ranks overlap with the most optimum salinity and temperature ranks.
- b. Output raster displays a value ranking system where the highest rank of 6 (darkest blue) corresponds to coastal waters where highest 3 rankings from “Salinity and Temperature” reclassified raster overlap with organism densities of 69-247 organisms/m² from “Organism Density” reclassified raster.
- c. Output raster is **Figure 17**

Data

Maps:

Sample Station Salinity and Interpolated Values North Alaskan Coast 1976

Danny Fraser
12/2/2019



Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere
 Projection: Mercator Auxiliary Sphere
 Datum: WGS 1984
 False Easting: 0.0000
 False Northing: 0.0000
 Central Meridian: 0.0000
 Standard Parallel 1: 0.0000
 Auxiliary Sphere Type: 0.0000
 Units: Meter



Figure 13: Salinity values across Simpson Lagoon, Prudhoe Bay, and the Beaufort Sea. Sample station data points included for reference. Values are lower in Prudhoe Bay, reflecting the freshwater inputs of the Sag River.

Sample Station Temperatures and Interpolated Values North Alaskan Coast 1976

Danny Fraser
12/2/2019

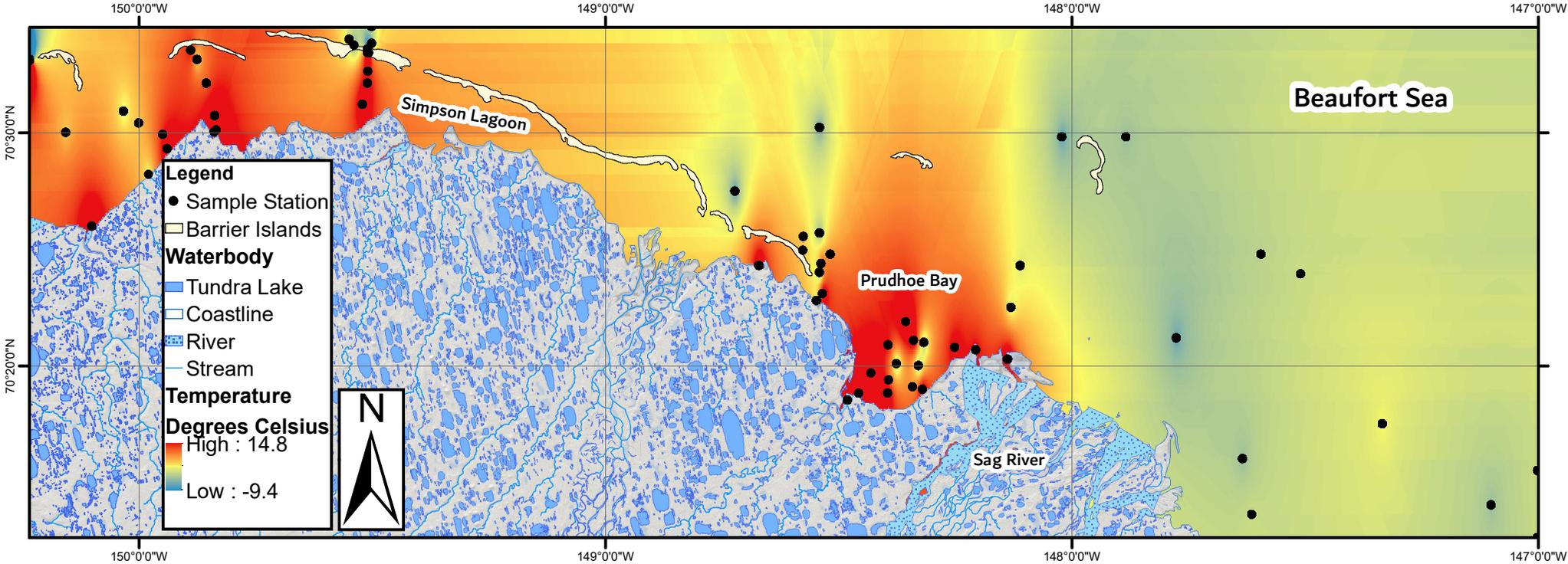
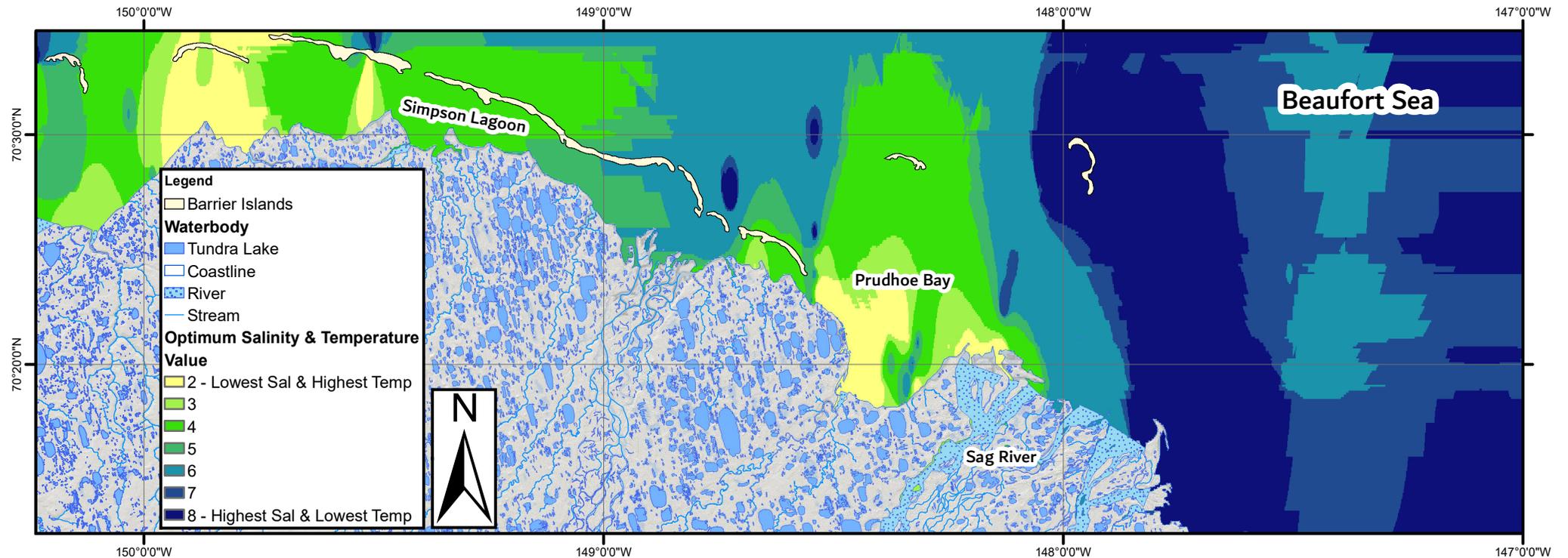


Figure 14: Water temperature values across Simpson Lagoon, Prudhoe Bay, and the Beaufort Sea. Sample station data points included for reference. Water temperature values are higher in Prudhoe Bay, reflecting the relatively warmer fluvial waters of the Sag River.

Optimum Salinity and Temperature Overlap For Benthic Organism Preference North Alaskan Coast 1976

Danny Fraser
12/2/2019



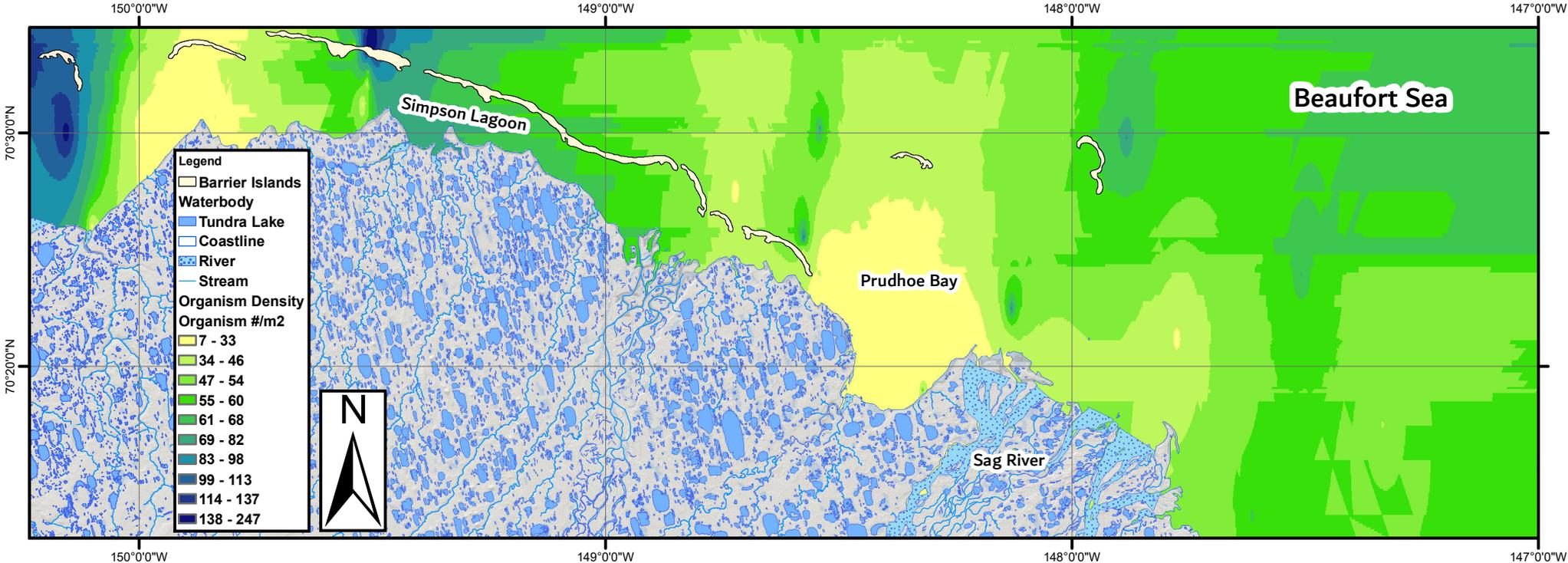
Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere
 Projection: Mercator Auxiliary Sphere
 Datum: WGS 1984
 False Easting: 0.0000
 False Northing: 0.0000
 Central Meridian: 0.0000
 Standard Parallel 1: 0.0000
 Auxiliary Sphere Type: 0.0000
 Units: Meter



Figure 15: Output raster showing the coastal waters where lowest salinity and highest temperature overlap (value=2) and highest salinity and lowest temperature overlap (value=8). Sample station data points omitted for clarity.

Benthic Organism Density Distribution North Alaskan Coast 1976

Danny Fraser
12/2/2019



Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere
 Projection: Mercator Auxiliary Sphere
 Datum: WGS 1984
 False Easting: 0.0000
 False Northing: 0.0000
 Central Meridian: 0.0000
 Standard Parallel 1: 0.0000
 Auxiliary Sphere Type: 0.0000
 Units: Meter



Figure 16: Benthic organism density is lowest in Prudhoe Bay and west of Simpson Lagoon, corresponding to lower salinities and higher temperatures. Sample station data points omitted for clarity.

Overlap of Optimum Salinity, Temperature, and Organism Density North Alaskan Coast 1976

Danny Fraser
12/2/2019

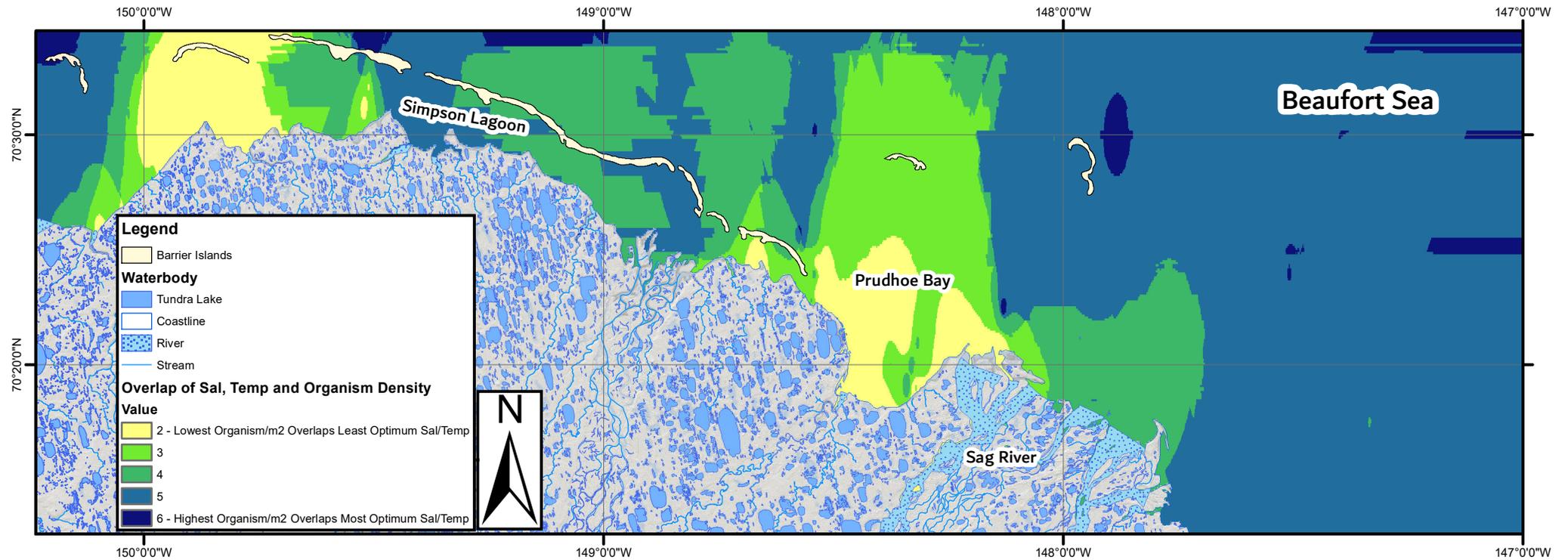


Figure 17: Output raster showing the coastal waters where lowest organism density and least optimum salinity/temperature values overlap (value=2) and highest organism density and most optimum salinity/temperature values overlap (value=6). Sample station data points omitted for clarity.

Conclusion:

Freshwater inputs from the Sag River are shown to cause lower salinity and higher water temperatures relative to the Beaufort Sea, as illustrated in **Figures 13** and **14** respectively. The reclassified and raster calculated map in **Figure 15**, which shows these two water characteristics with respect to marine organism preference, further illustrates these water characteristic variations that come from the Sag River. The prevailing winds and longshore currents during the time these samples were taken must have been pushing the fluvial waters westward, since the warm, freshwater plume is slightly west of the Sag River delta. A second area of low salinity and warmer temperatures is just west of Simpson Lagoon, with the Colville River just outside of the western limit to the data frame or human activity from oil platforms around Simpson Lagoon possibly explaining this.

Benthic organism density distribution is mapped in **Figure 16**, and visually comparing this map to **Figure 15** shows that higher marine organism density overlaps well with higher salinity values and lower water temperatures. Furthermore, the two areas on these maps where salinity is lowest and water temperature is highest overlaps even better with the areas that see the lowest organism densities. A map visualising this overlap in optimum salinity and temperature ranges with benthic organism density is given in **Figure 17**. The raster in **Figure 17** quantifies and color codes this overlap, with the highest rank of 6 (darkest blue) corresponding to coastal waters where the highest 3 salinity/temperature rankings from **Figure 15** overlap with organism densities of 69-247 #/m² from **Figure 16**. Conversely, the lowest rank of 2 (lightest yellow) corresponds to coastal waters where the lowest 2 salinity/temperature rankings from **Figure 15** overlap with organism densities of 7-46 #/m² from **Figure 16**.

ArcGIS has allowed these three different datasets to be illustrated clearly so that anyone can see this ecological relationship along the Alaskan coast. I was able to quantify and visualize how salinity and temperature variations in coastal waters can affect the distribution of the organisms living there. Benthic organisms are well known to be an important link in arctic marine food webs, feeding and supporting numerous marine life. A better understanding of how the variable water characteristics along the Alaskan coast correlate to higher benthic organism density will be beneficial to local fishermen and whale watchers alike, since fish and some whales feed off of these very same benthic invertebrates.

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