A Spatial and Temporal Analysis of Benthic Organism Densities the North Alaskan Coast
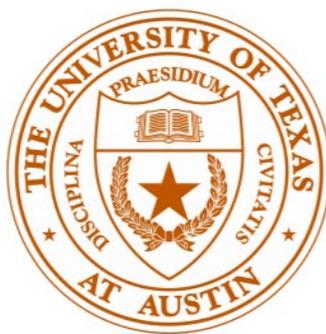
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The Problem

Benthic organisms, those that live along the seafloor, are a crucial part of coastal ecosystems. These organisms are typically invertebrates (Figure 1a) that are low on the food chain, meaning they provide a key food source for several types of higher-level species such as migratory birds, fish, and marine mammals (Wauchope, et al., 2017; Moore & DeMaster, 1997). Polar ecosystems, in particular, rely heavily on these organisms to sustain their complex food webs. The abundances and distributions of benthic invertebrates are a direct result of coastal water quality conditions. These conditions are influenced by freshwater inputs from land as well as natural seasonal and annual variations. The spatial variation of water conditions leads to a varied spatial distribution of benthic invertebrates as well (Beadle, 1931; Hayward et al. 2003). As polar ecosystems are increasingly impacted by global climate change, water quality conditions such as salinity and temperature are predicted to change, causing benthic invertebrate populations to change. This study aims to characterize the spatial and temporal variation in benthic invertebrate density in Simpson Lagoon, along the northern coast of Alaska (Figure 1b), to provide a dataset from which to base future analyses from.

Figure 1a: Benthic invertebrate, 1b: North coast of Alaska

Data Collection

Raw Data:

An Excel sheet was provided to me by a lab mate. These data were collected by members of the Beaufort Lagoon Ecosystem - Long Term Ecological Research (BLE-LTER) team. The sheet includes data from 1976, 2014, and 2019. Data for each sample site included longitude and latitude coordinates, organism count, organism weight, species name, calculated density per meter squared, the date the sample was collected, and additional auxiliary information. For the year 1976, water salinity and water temperature were also measured.

Downloaded Data:

1. Four digital elevation models (DEMs) were downloaded from the USGS National Map Viewer, https://viewer.nationalmap.gov/basic/. The DEMs were ⅓ 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 2020 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: GCS WGS 1984
6. Projection: NAD 1927 Alaska Albers

Data Preprocessing

Raw Data:

Clean-up Excel spreadsheet to ensure correct import into ArcGIS:

1. Remove columns that have unnecessary data (Station ID, Dates, Raw Count, Depth, etc.).
2. Separate data by year into individual files (1976, 2014, and 2019).
3. Calculate the average density value for each sampling point (unique latitude and longitude).
4. Convert to CSV files (Figure 2).

LATITUDE	LONGITUD	Cnt_m2	SURF_SAL	SURF_TEMP_C
70.50017	-149.838	12.02501	8.3	10
70.55667	-149.507	173.1602	10.3	6.4
70.54333	-149.508	408.4804	11.5	7
70.535	-149.51	258.6844	11.2	7.8
70.52	-149.52	140.5028	10.7	8.6
70.51167	-149.837	442.5204	11.7	9
70.535	-149.855	166.7182	13.1	5.5
70.50167	-149.833	65.41607	11.8	9.8
70.55833	-149.888	64.55533	12.4	6.8
70.55167	-149.875	165.368	13.8	4.5

Figure 2: Modified CSV file for 1976

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 ArcCatalog. All files in ArcCatalog were set to GCS WGS 1984.

ArcGIS Processing

1. Open a blank ArcMap file and add World Ocean basemap.
2. Set projection in the Data Frame properties to NAD 1927 Alaska Albers (meters).
3. Add DEMs and NHD shapefiles for rivers (NHDFlowline) and lakes (NHDWaterBody).
   a. Symbolize NHD shapefiles
   b. Use the Merge tool to join the shapefiles to create one flowline layer and one water body layer.
4. Use the Hillshade tool to create hillshade rasters from the DEMs.
   a. Z value: 0.000009 (conversion factor from decimal degrees to meters)
   b. Symbolize hillshades with standard deviation setting. Leave n default (adds contrast)
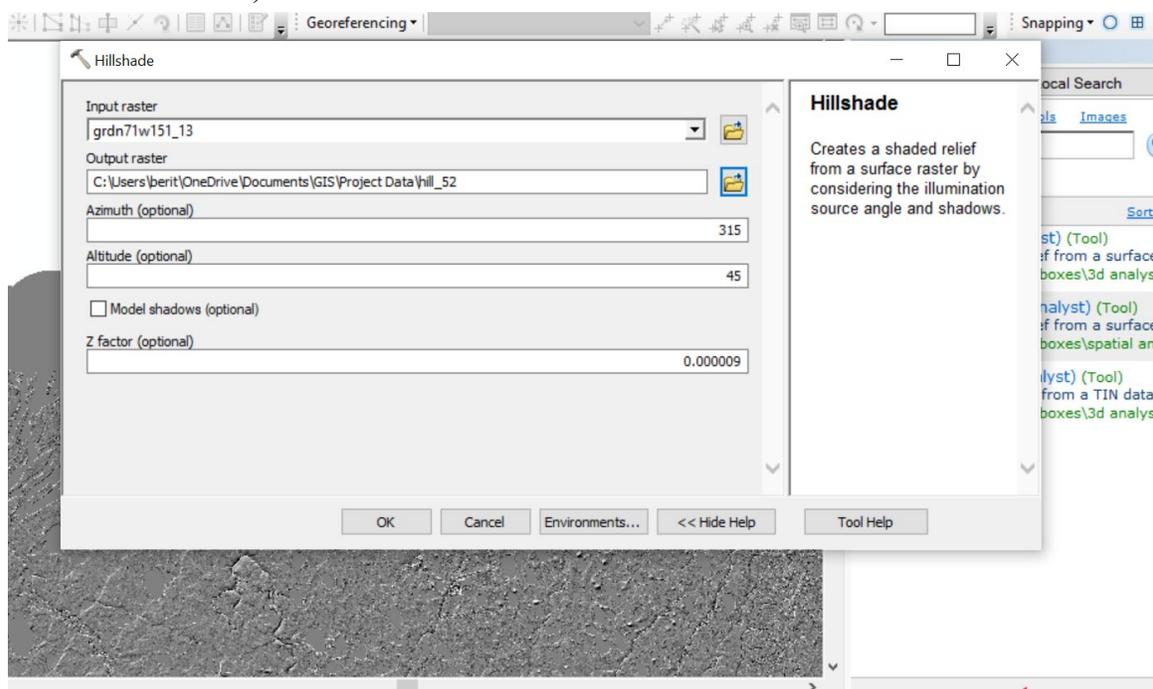
Figure 3: Hillshade tool used to create hillshades from the DEM data

5. Use Draw toolbar to draw a rectangle around the coastline of interest.
   a. Use Convert Graphics to Feature tool to create a feature class.

b. Add layer
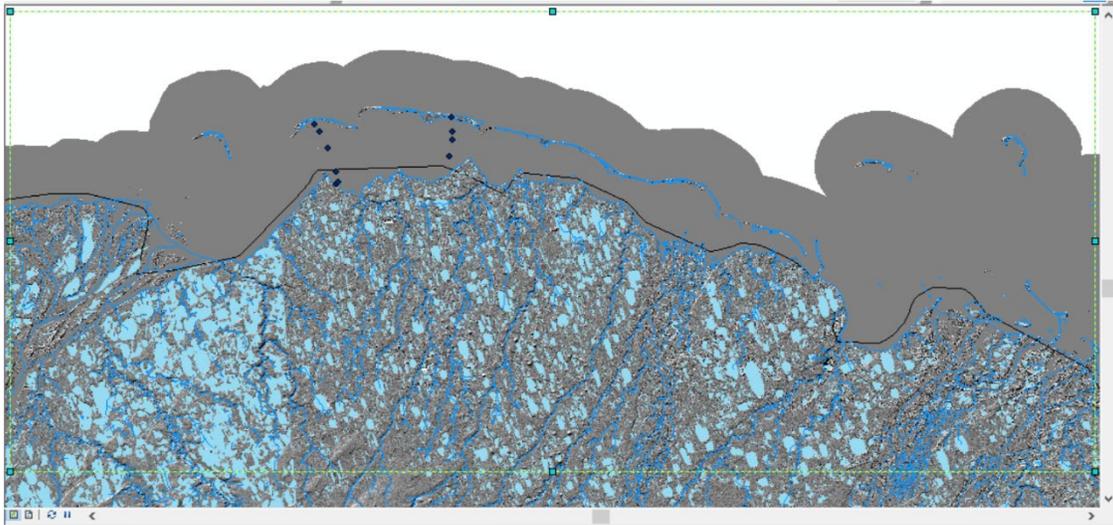
Figure 4: Area of interest rectangle drawn with the Draw toolbar

6. Add the TM World Border file. Symbolize with the Hollow symbol so only the line representing the coast is visible.
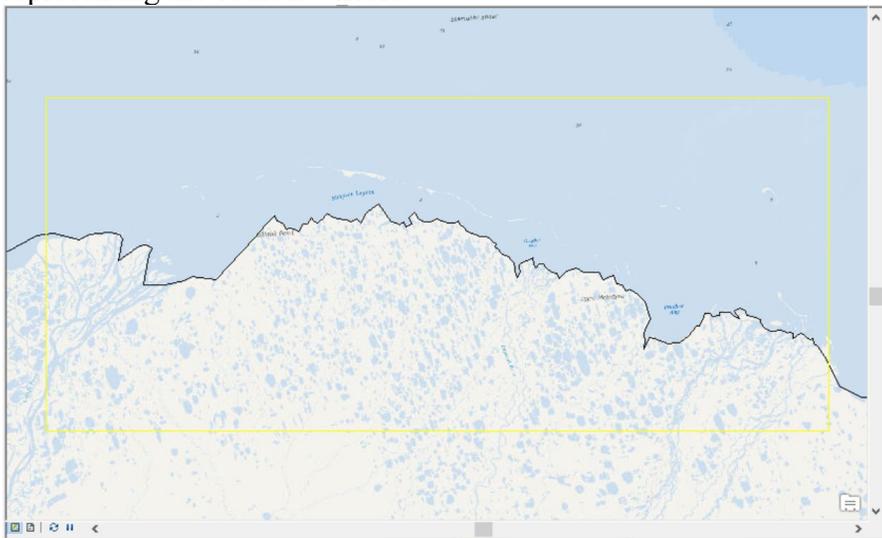
Figure 5: World Border (Coastline) added on top of base map

7. Use the Editor toolbar to edit and add vertices to the coastline to improve the accuracy.
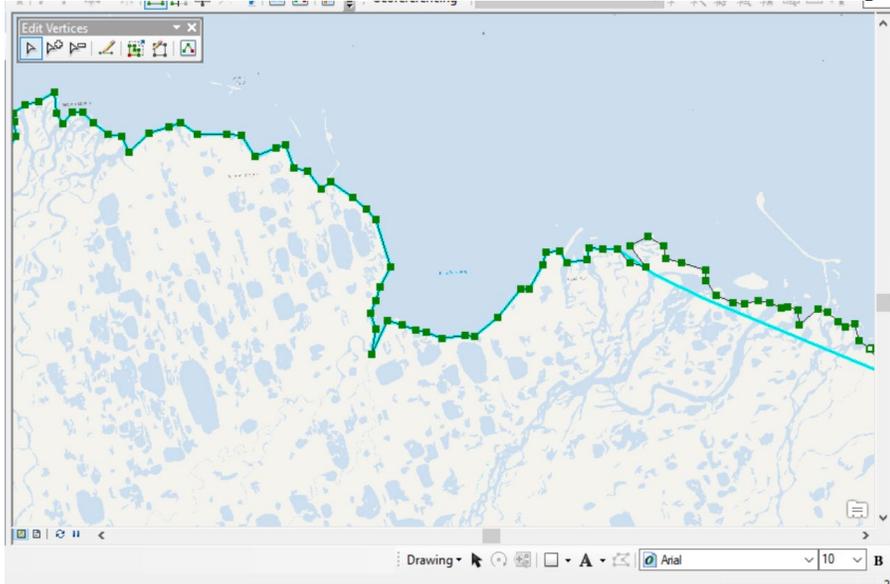
Figure 6: Editing coastline by adding vertices

8. Clip the edited coastline file to the area of interest rectangle.
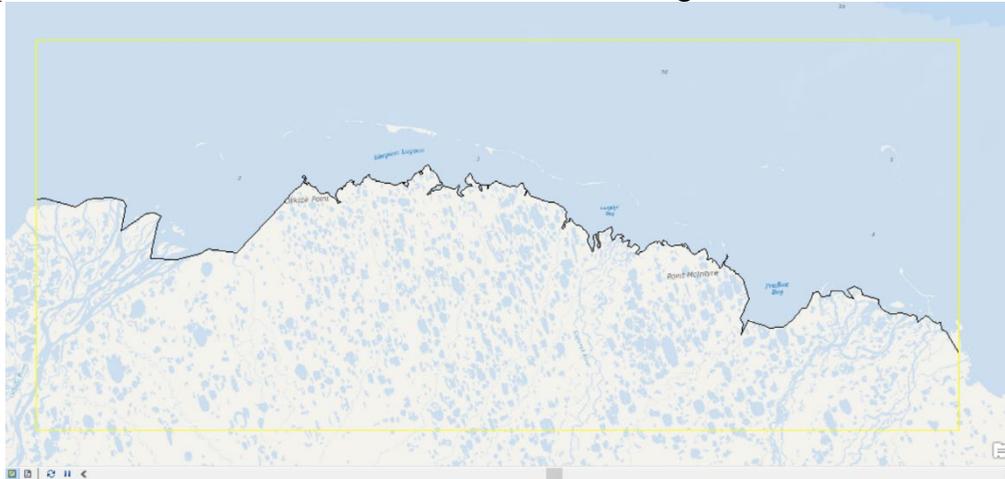
Figure 7: Clipped and edited coastline

9. Use the Extract by Mask tool to clip the hillshades to the AOI.
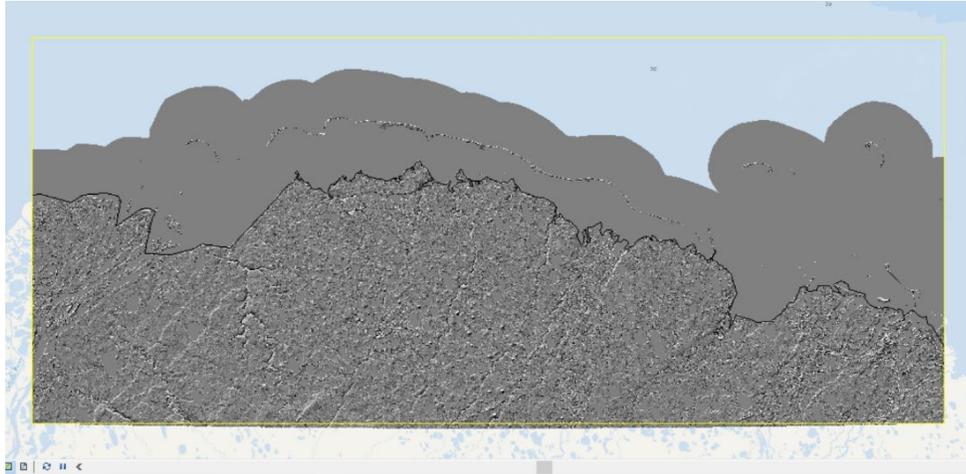
Figure 8: Clipped hillshades

10. Clip the flowline and water body shapefiles to the coastline polygon using the Clip tool.
11. Import the cleaned CSV files from 1976, 2014, and 2019.
    a. Display XY Data: Use LONGITUDE as X-field and LATITUDE as Y-field.
12. Create a file geodatabase in ArcCatalog.
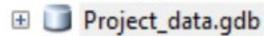
Figure 9: My geodatabase in ArcCatalog

13. Convert CSV data into feature classes by Exporting the data and adding it as a layer.

Name	Type
area_of_int	File Geodatabase Feature Class
data_1976	File Geodatabase Feature Class
data_2014	File Geodatabase Feature Class
data_2019	File Geodatabase Feature Class

Figure 10: Contents of the geodatabase, showing feature classes created from each CSV file
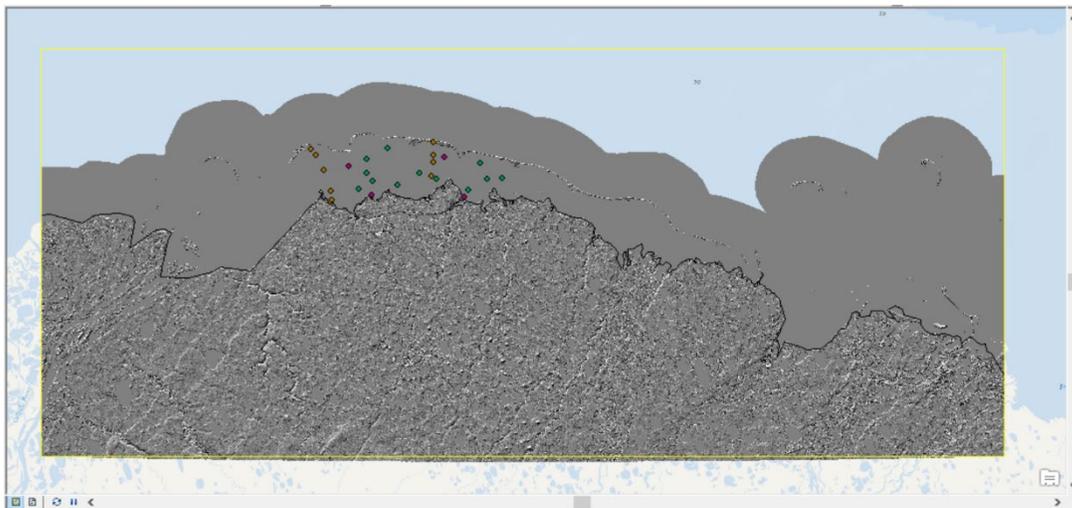
Figure 11: Feature classes representing CSV data added to the AOI

14. Use the TIN tool to create TINs for each data set. Set height field to Cnt_m2 (and Sal and Temp for 1976).
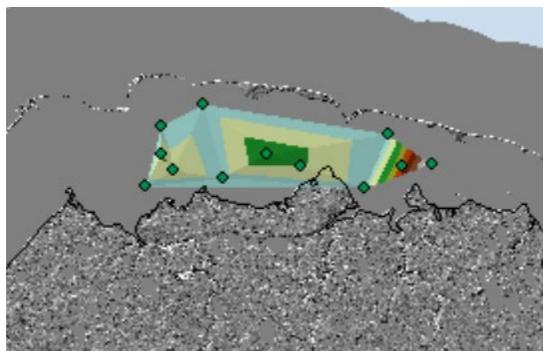
Figure 12: TIN showing the density of benthic organisms represented as height, created from 2014 data

15. Use the TIN to Raster tool to convert the 3D TIN to a raster surface.
    a. The Z-factor is meaningless, so use a value of 1.
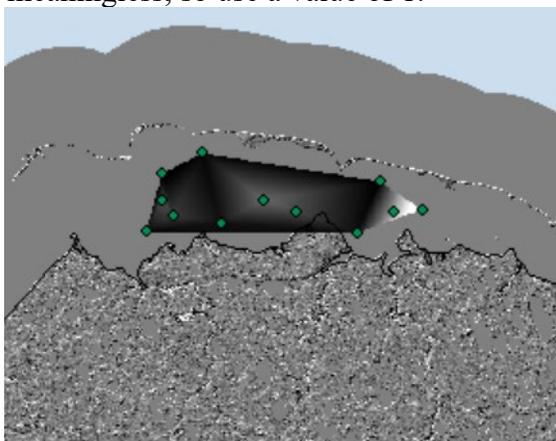
Figure 13: Raster generated from the TIN for 2014

16. Use Cut and Fill tool to compare rasters over time.
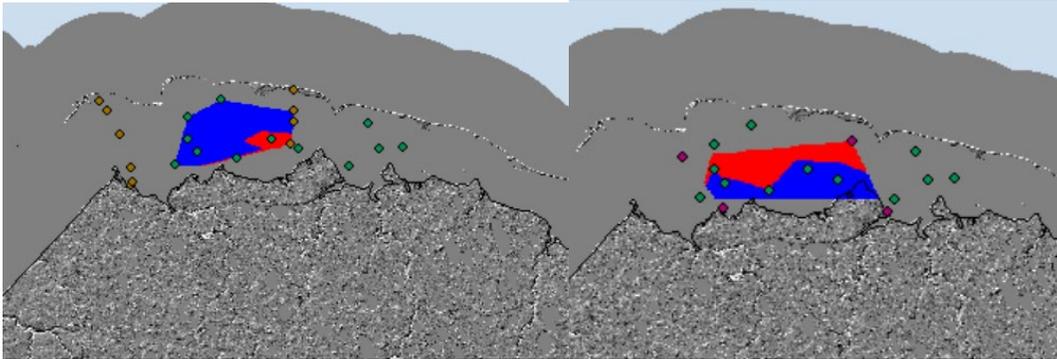
Figure 14: Cut and Fill surfaces generated with 1976 and 2014 data (a) and 2014 and 2019 data (b). Blue shows net gain and red shows net loss of benthic diversity.

17. Use the Extract by Mask tool to mask the cut and fill surface to mask out the portions that were interpolated over land.
    a. Modify the coastline polygon to enclose the ocean rather than land by moving the bottom two vertices to the top two corners and snapping them to the vertices. Essentially flips coastline file. Allows for masking of water data.
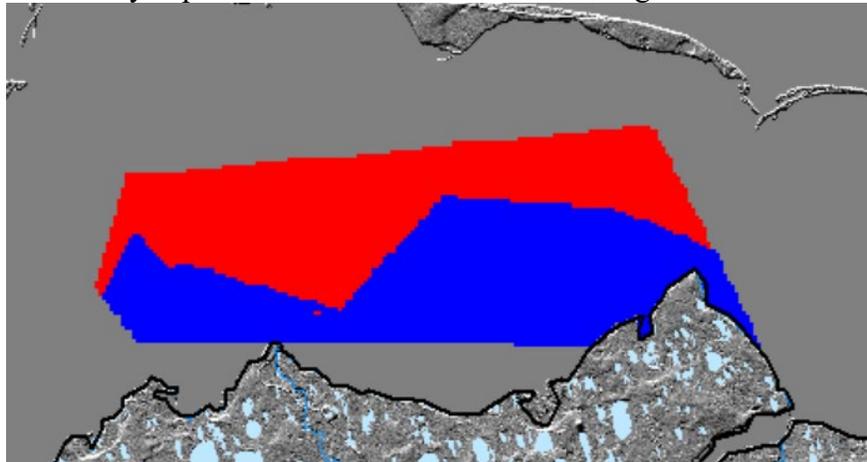
Figure 15: Masked Cut and Fill surface for 2014 and 2019
    b. Re-symbolize the masked cut and fill surfaces by importing the symbology from the original cut and fill surfaces.
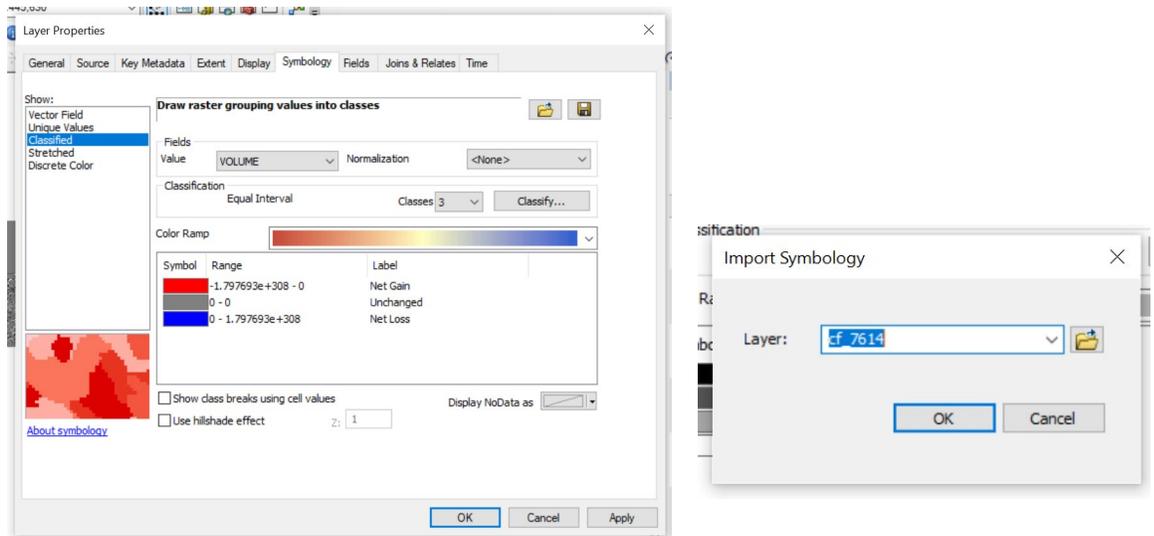
Figure 15: a) Default symbology for cut and fill surfaces. b) Importing this symbology from a cut and fill surface to the masked surface

18. Create a map inset. Insert a new data frame. Add the "states" feature class from the Lab 2 class folder. Go to New Data Frame properties, select states layer properties, go to Definition Query, and use the Query Builder function to select for Alaska. Go to Extent Indicator in the Data Frame properties. Add "Layers" to "Show extent indicator for these data frames". Click the Frame button in Options-Layers and make the border and background red.
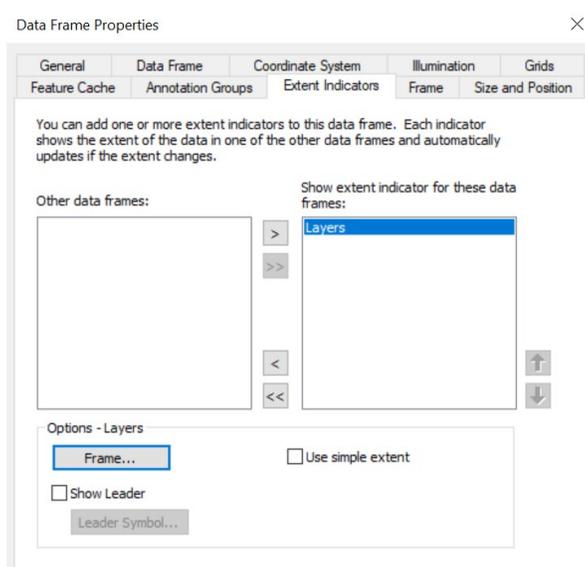
Figure 16: Extent Indicator properties within the Data Frame properties

Data Presentation- Maps

Change in Benthic Organism Density from 1976 to 2014
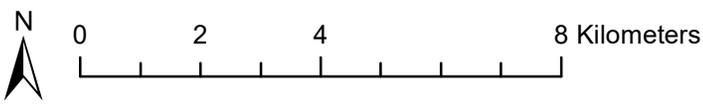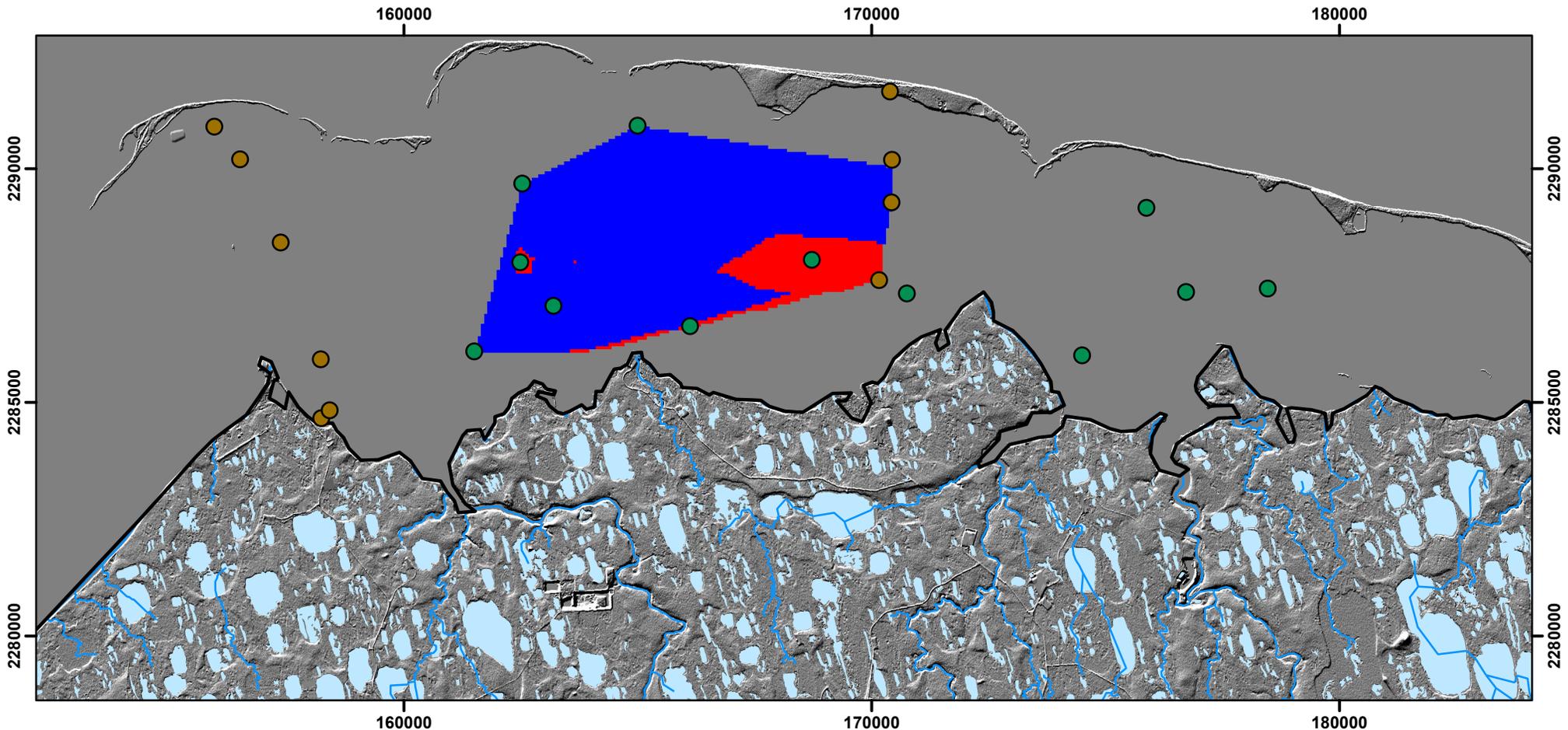
Legend

▭	Coastline
—	Rivers
▪	Lakes
●	1976 Data Points
●	2014 Data Points

Change: 1976-2014
Density

🟥	Net Gain
⬜	Unchanged
🟦	Net Loss

Coordinate System: NAD 1927 Alaska Albers Meters
Projection: Albers
Datum: North American 1927
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: -154.0000
Standard Parallel 1: 55.0000
Standard Parallel 2: 65.0000
Latitude Of Origin: 50.0000
Units: Meter

Figure 18: Change in Benthic Organism Density in Simpson Lagoon, Alaska.
Sample data points are included for reference.

Change in Benthic Organism Density from 2014 to 2019

Figure 17: Change in Benthic Organism Density in Simpson Lagoon, Alaska.
Sample data points are included for reference.
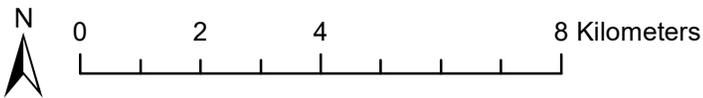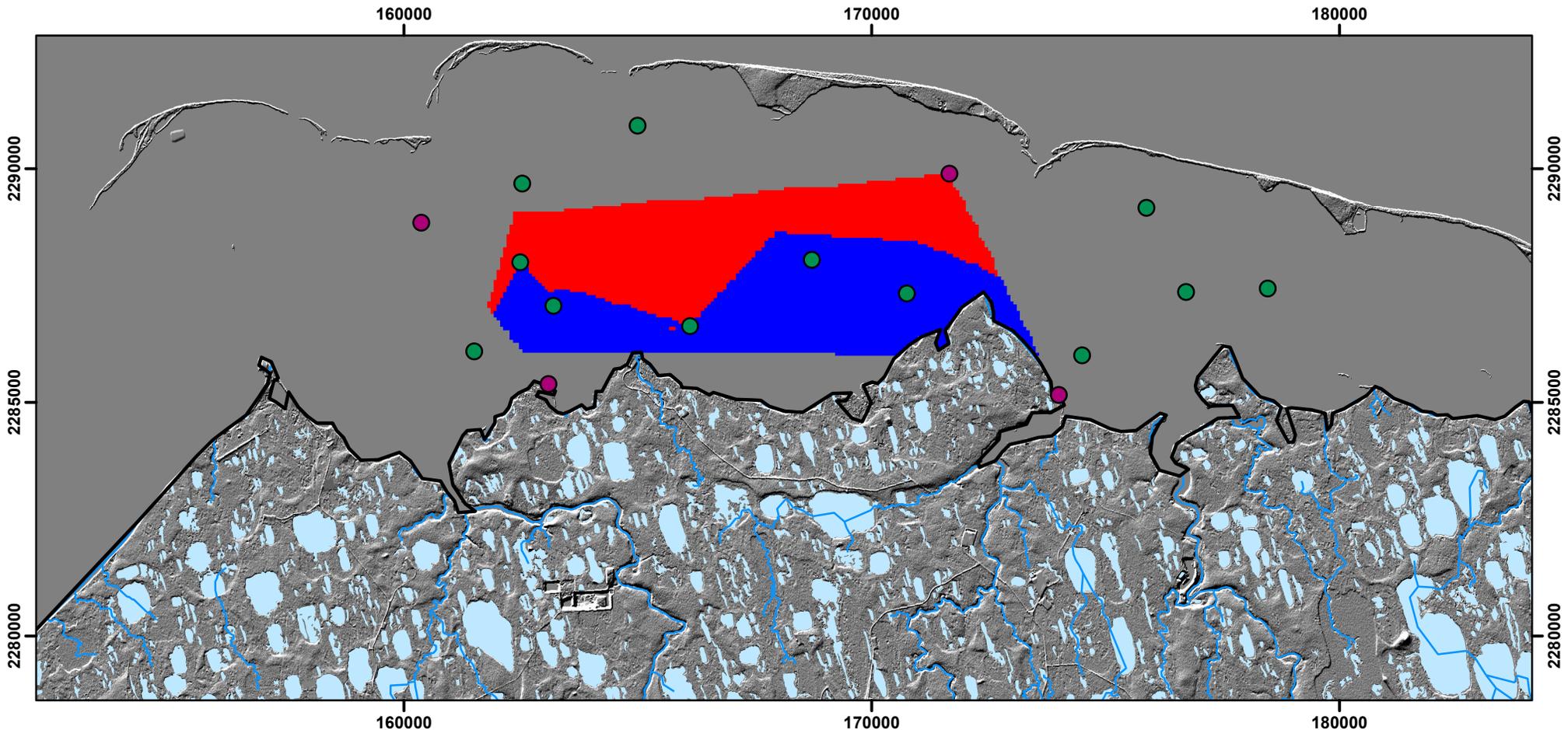
Legend

Coastline

Rivers

Lakes

● 2014 Data Points

● 2019 Data Points

Change: 2014-2019
Density

Net Gain

Unchanged

Net Loss

Coordinate System: NAD 1927 Alaska Albers Meters
Projection: Albers
Datum: North American 1927
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: -154.0000
Standard Parallel 1: 55.0000
Standard Parallel 2: 65.0000
Latitude Of Origin: 50.0000
Units: Meter

N

0   2   4   8 Kilometers

Alaska

Figure 19: Interpolated surface of salinity (ppt). Sample data points are included for reference.

Interpolated Raster Surface of Surface Temperature in 1976
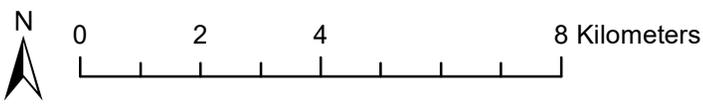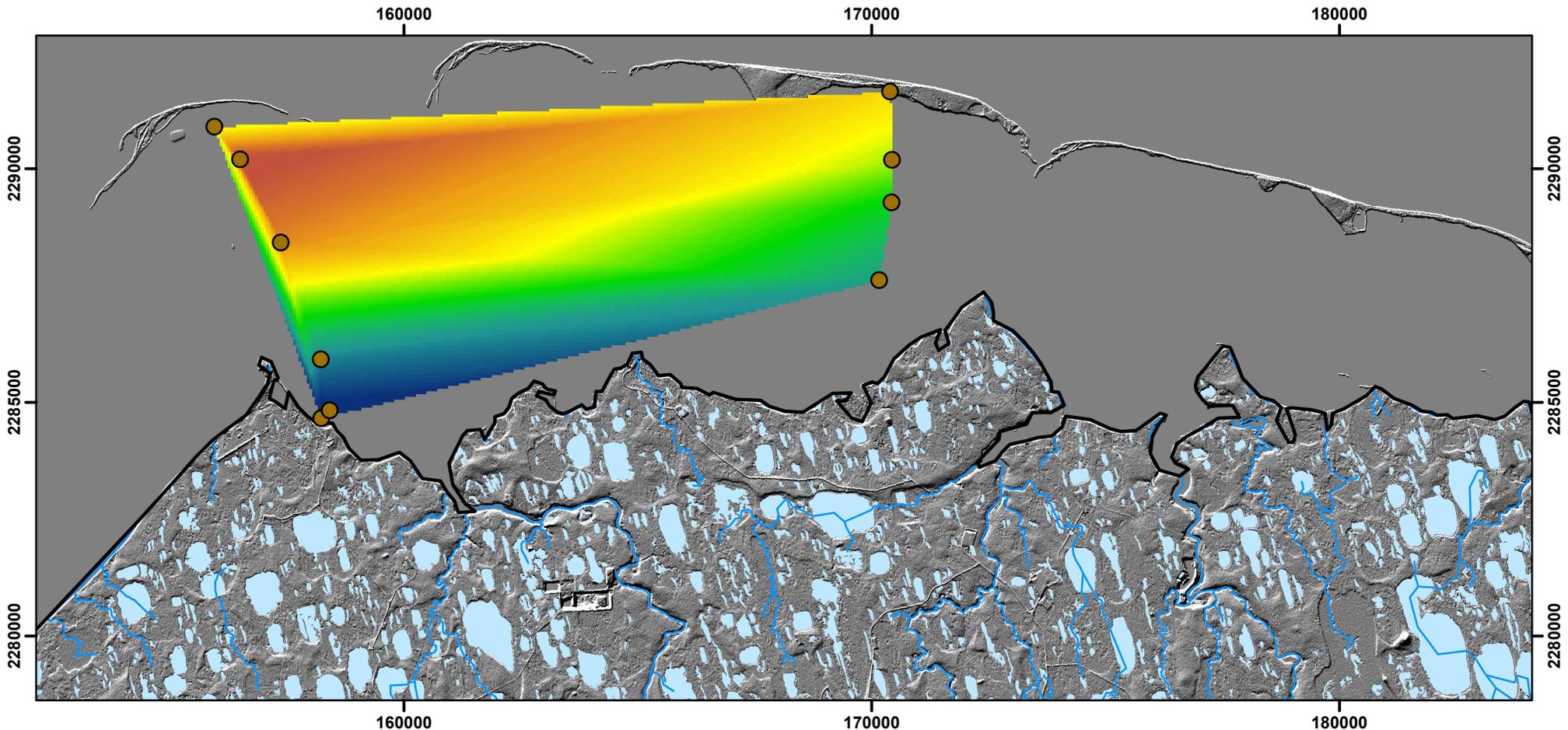
Legend

Coastline
Rivers
Lakes
● 1976 Data Points

Temperature

Celsius
High : 9.97488
Low : 4.52853

Coordinate System: NAD 1927 Alaska Albers Meters
Projection: Albers
Datum: North American 1927
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: -154.0000
Standard Parallel 1: 55.0000
Standard Parallel 2: 65.0000
Latitude Of Origin: 50.0000
Units: Meter

Alaska

N
0 2 4 8 Kilometers

Figure 20: Interpolated surface of temperature (degrees Celsius). Sample data points are included for reference.

Conclusion

Maps displaying the changes in benthic invertebrate density between 1976 and 2014 (Figure 17) and between 2014 and 2019 (Figure 18) show an overall net loss. In total, there are more blue cells, representing net loss, than red cells, representing net gain. Ecologically, this makes sense as climate change has been causing lower salinities and higher temperatures, both conditions that are unfavorable for benthic invertebrates (Beadle, 1931; Hayward, et al., 2013). It appears that there was a greater loss of invertebrates from 1976 to 2014, but this is likely due to the longer time frame of comparison. Additionally, the maps show the spatial distributions of these changes, which can be used in conjunction with water quality data to further analyze potential causes of fine-scale variations in benthic invertebrate density.

Surface salinity and temperature data was provided for 1976. Maps displaying spatial distributions of these water quality parameters are shown in Figures 19 and 20. Surface salinity appears to be higher off the coast which makes sense as freshwater inputs from land decrease the salinity close to the coast. Temperature displays an opposite distribution with warmer water closer to the coast. This is likely because water along the coast is shallower and easier to warm. These maps are not useful for any type of temporal analysis because data is present for a single year, however they can act as a supporting proof of concept for well-established knowledge on spatial distributions of salinity and temperature in coastal systems.

This study faced several limitations. Data points were not located at the same sites across the different years, making direct temporal comparisons more difficult. There were also very few unique sampling sites with multiple density observations at each site, requiring an averaging of the observations. Averaging the observations reduces the sampling resolution of the data. The small sample size made it difficult to produce a wide-spread interpolated surface, so I had to create a TIN instead. This study could be vastly improved with data from additional sampling sites that match previously sampled sites to allow for better spatial and temporal comparisons.

Literature Cited

Beadle, L.C., 1931. The effect of salinity changes on the water content and respiration of marine invertebrates. Journal of Experimental Biology, 8(3), pp.211-227.

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