Maritime Incidents and Accidents:

Heatmap, Hotspot Map, and Hexbin methodology

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Introduction

The Maritime Incidents and Accidents dataset (referred to throughout this report as MIA) is a representation of incidents and accidents on the water. There is location data, narrative details of the events, dates and times, and quantitative data for results of the event (**injury, death**, etc.), as well as possible causal data, including weather and visibility.

The data was sourced from the Transportation Safety Board of Canada - Marine transportation occurrence data from January 1995, retrieved January 2023: https://www.tsb.gc.ca/eng/stats/marine/data-6.html.

The dataset is suitable for a heatmap, hotspot, and hexbin visualization demonstration because it contains many data points concentrated in a few regions (it covers a broad timespan, providing many points). This allows overlapping of points that show patterns in particular regions. Also, there are subsets of data, such as was mapped for this report, namely, numbers of deaths *per* incident. The Number of Deaths data column provides a weighting for each point, adding another element to the meaning of the visualization.

Heatmap Map

Technical Exploration

According to one COGS graduate and Esri employee, Heather Smith, “Heat Map symbology is good for quick and dynamic visualization” (Smith, 2019). A heatmap displays relative density of the data distribution (IBM, 2019), so it can be used to show a lot of occurrences geographically close to each other.

Comparison to Other Mapping Techniques

Many mapping options are available to represent the dataset in this example (Maritime Incidents and Accidents). Some would be equally as good or better than a heatmap, and some would not visualize the data effectively.

For example, if the data were to be plotted, point by point, as in a dot density map, with that many data points, a clustering effect could be visualized, but it would be almost impossible to interpret. See Figures 1 to 8 for a visual of the numbers breakdown between incidents and deaths, and how that shows up in the heatmap. A heatmap is effective in showing patterns and clusters, like a dot density map, and each point can be weighted with its inherent value and transparencies applied to visualize location, unlike a dot density map. However, a dot density map has the advantage of depicting occurrences in a “what you see is what you get” way (assuming points are not obscuring other points), unmanipulated by colour and size or algorithms.

Figures 1 to 7: Definition queries done in ArcGIS Pro.

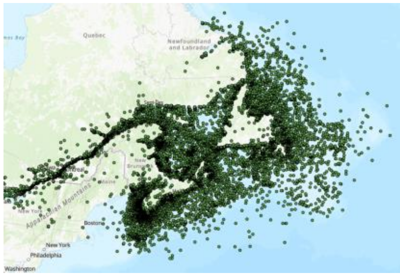


Figure 1: All data points

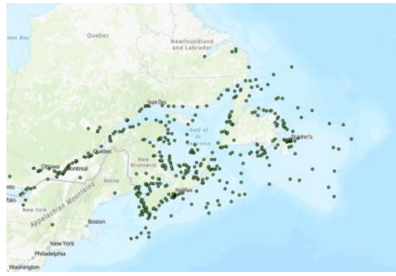


Figure 4:Total Deaths > 0

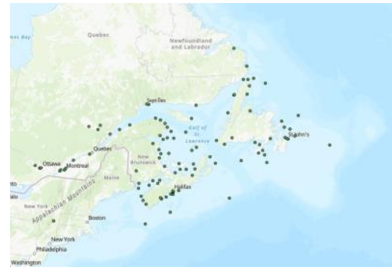


Figure 6:Total Deaths > 1

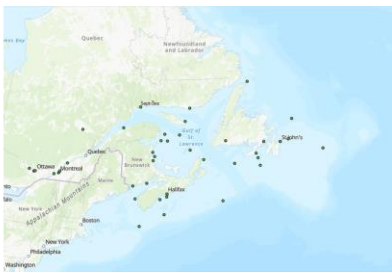


Figure 2: Total Deaths > 2

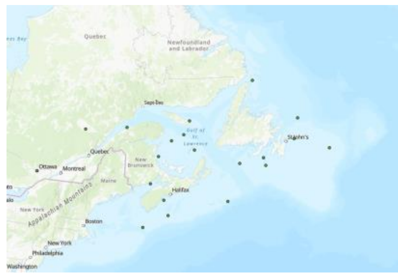


Figure 5: Total Deaths >3

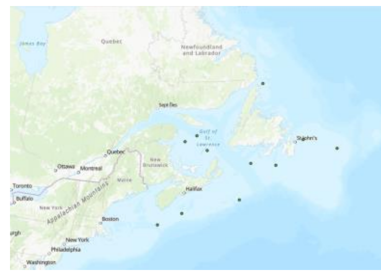


Figure 7: Total Deaths >4

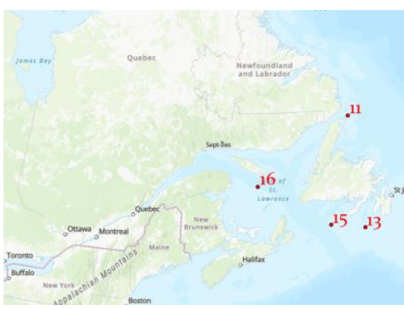


Figure 3: Total Deaths >5

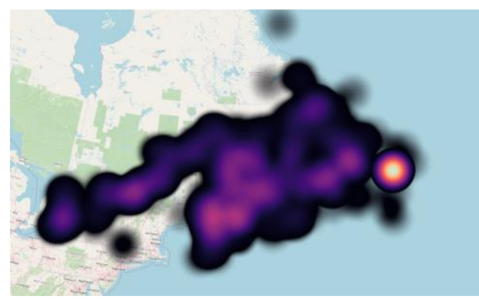


Figure 8: For comparison, all points symbolized as a heatmap.

In the case of having a value to each point, such as deaths per occurrence, a mapping option that visualizes this through colour or size is appropriate. A choropleth map shows data partitioned into distinct geographic “districts” (Wikimedia, 2023), like states or countries, and so would not be an appropriate map choice for the MIA dataset since the data was not associated with any distinct districts. The data does provide location codes, so a choropleth map could be created, but the author could not interpret the codes to do this.

Unlike a choropleth map, an isopleth map is not confined to predefined boundaries (Maptive, 2020) However, they are more suited to natural phenomena and other contiguous data types. It would not be very effective in visualizing isolated occurrences, such as there are in the MIA dataset.

Hotspot mapping and hexbin mapping will be discussed further on.

Workflow

1. Once the dataset is cleaned and the focus area determined and Clipped (this was done in ArcGIS Pro, but can be done in QGIS), open the .csv file in QGIS.
2. Set the coordinate system of the map (bottom right corner of the screen). The projection chosen for this map was WGS 84/UTM Zone 20, EPSG:32620.
3. On the .csv file, Export>Save Feature As, and save the feature as a .shp file. At this point, set the coordinate system to EPSG:32620.
4. When it's determined the data is in the right location, go to Symbology of the .shp file.
   i. Select Heatmap: Magma.
   ii. In the colour ramp, set the bottom marker (black) to full transparency.
   iii. Radius: 10mm; Maximum value: Automatic; Weight points by: TotalDeath (Figure 9).
   *The Rendering will take longer at a higher quality.
   iv. Under Layer Rendering, select a Multiply Blending mode to create transparency in high-density areas of the data.

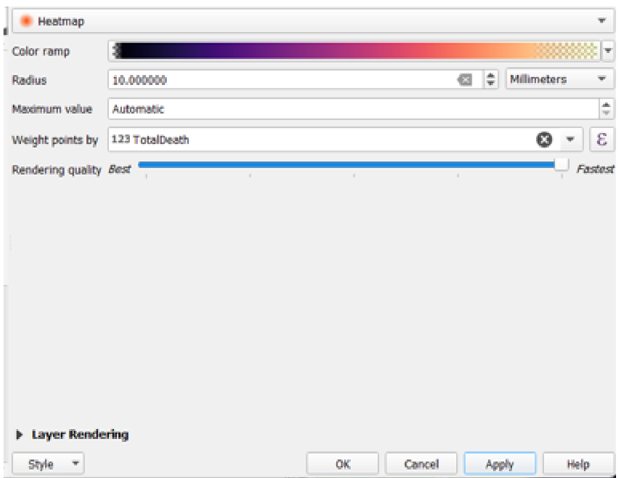


Figure 9:Heatmap parameters

Analysis

The data, clipped to the whole mid and south-eastern part of Canada, clearly shows phenomena in the coastal areas, including down the Gulf of St. Lawrence. There are high-significance areas on the north and south coasts of Newfoundland, all around Nova Scotia, and south on the St. Lawrence River near Montreal. The most striking visualization is off the east coast of Newfoundland. Upon investigating the data, in most cases, these areas of significance are often caused, not by many individual occurrences causing death on the sea, but by high death rates for individual events.

Observations, Troubleshooting, Notes

In looking for a quantitative element to map, it was observed that the column with the most entries was that of death counts per incident. However, that only accounted for 2% of the data, which did not seem sufficient at the time. So, significant research took place to solve this issue. A fishnet tool was applied in ArcGIS Pro to create regions to develop a quantitative field. There was also a misunderstanding of the requirements for a weighted value. Eventually, the number of deaths was determined to be a large enough field to be mapped.

Once the data was determined and prepared, it was brought into QGIS, but there were persistent issues with the projection. Below is a summarized series of events:

1. Symbolized the death data as a heatmap, but in rendering, everything disappeared.
2. Tried various workflows of projecting at different points of bringing in data, or projecting while exporting, etc. The result was data all over the map (see Figure 10), despite the coordinate system seeming to match on all fronts.

Figure 10: Data was persistently mis-projected

3. Finally, removed all layers and restarted from scratch.
4. Started the basemap and the .csv in the Pseudo-Mercator projection, then updated the basemap in the bottom right corner to the local projection (UTM Zone 20N). Then set the projection of the data layer while exporting it to a shapefile.
5. Used Extract/clip by extent tool to reduce the amount of data to the eastern provinces region.

Choosing the Radius:

There are various radius units to choose from with a heatmap. Some will remain consistent regardless of the zoom level of the screen, and some will not.

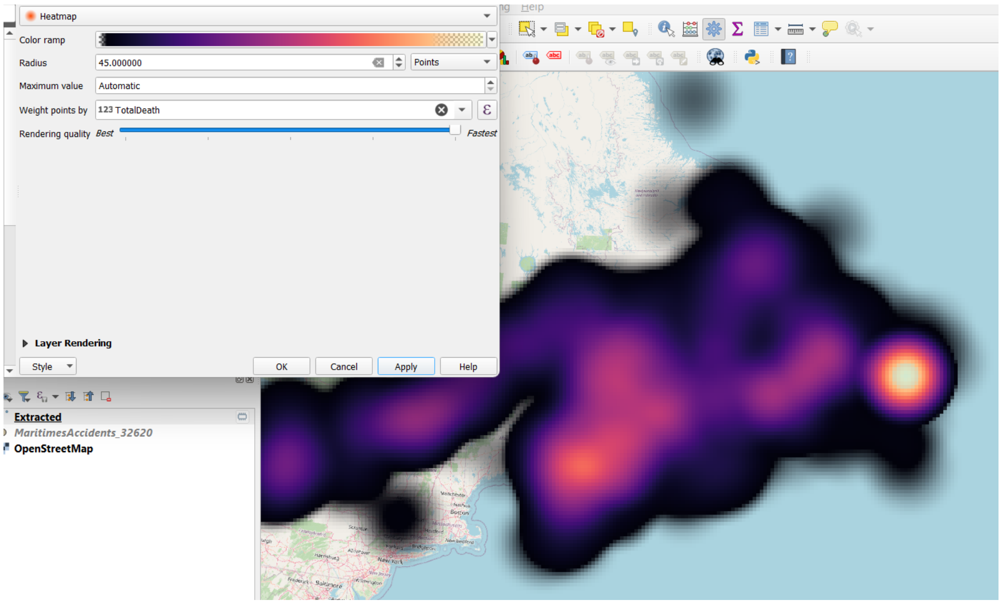


Figure 11: Radius using Points as the unit

If there are about 72 points per inch (esri, 2019) and there are about 25 mm per inch, then one mm has about 3 points in it (hence the similarity in Figures 11 and 12 using 45 points and 15mm, respectively).

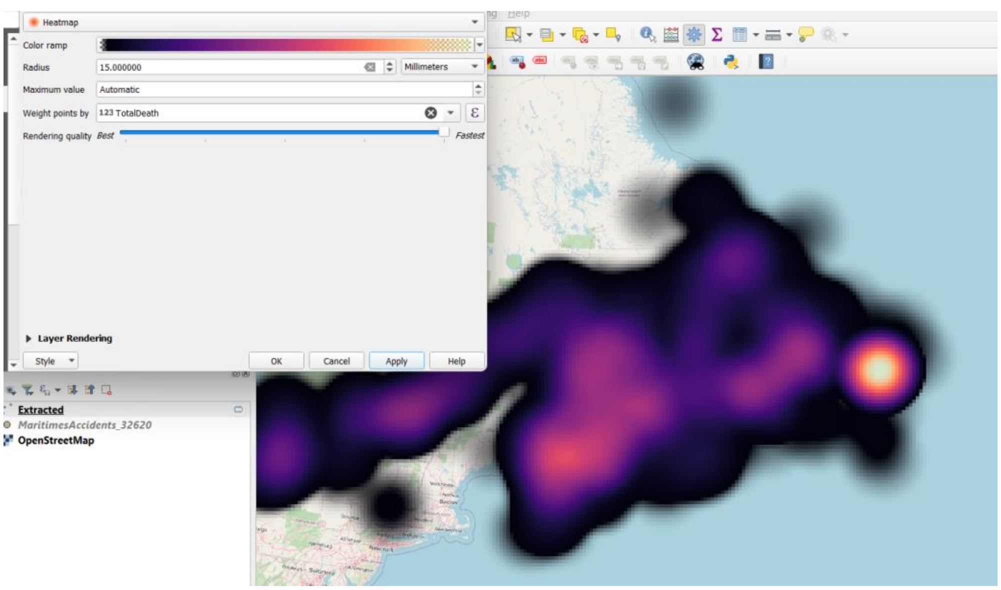


Figure 12: Radius using millimetres as the unit

Hotspot Map

Technical Exploration

The primary purpose of the Kernel Density map is to visualize the density of features. The use of this technique is to show high or low occurrence rates in given regions. Each point may also carry a quantitative value that would add more weight to different points, and thus be symbolized accordingly (typically a brighter or more saturated colour). For example, if counting residents in a neighbourhood, number of houses could be visualized, but if a house has more than one person in it, it would be weighted according to the number (esri, 2011). The result is a raster, and each cell in that raster has a value representing relative density (esri, n.d.) symbolized by colour or saturation to show that.

Comparison to Other Mapping Techniques

Hotspot maps, such as the Kernel Density map, and heatmaps are often confused and the terms used interchangeably. However, where a heatmap visualizes the density of points (and thus, the visualization can change as you zoom in and out on the screen), a Kernel Density map uses Kernel Density Estimation (KDE), an algorithm that generalizes data. The distance between points is calculated and "[i]f there are more points grouped locally, the estimation is higher as the probability of seeing a point at that location increases" (Kernel Density Estimation, n.d.). It is a statistical application that is not used in a basic heatmap.

Workflow

Creating a hotspot map follows a similar workflow in QGIS as creating a heatmap. The specifications here are specific to the dataset MIA.

1. Once the dataset is cleaned and the focus area determined and Clipped (done in ArcGIS Pro, but can be done in QGIS), open the .csv file in QGIS.
2. Set the coordinate system of the map (bottom right corner of the screen). The projection chosen for this map was WGS 84/UTM Zone 20, EPSG:32620.
3. On the .csv file, Export>Save Feature As, and save the feature as a .shp file. At this point, set the coordinate system to EPSG:32620.
4. When it is determined the data is in the right location, find a search bar in the bottom left of the screen. Search for Heatmap (Kernel Density Estimation). This will open a parameters screen with a brief explanation of the tool.
5. Choose the data to be visualized, the radius and pixel size. Optionally, Weight from Field can be selected. For example, choosing Number of Deaths per accident would give a greater value to data points with more than one death associated with the event (see Figure 13).

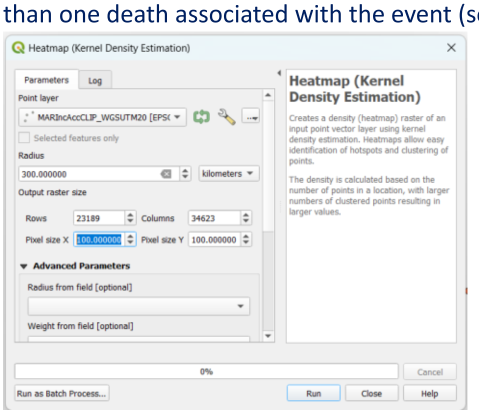


Figure 13: Setting up the Hotspot map

6. When the tool finishes running, the result is a raster with one band. It has a stretched symbology from min to max. The maximum value in the raster depends on the radius applied and the spatial distribution of the points (ndawson, 2014).
7. To symbolize the MIA map, Singleband pseudocolor was the Render type; Magma colour ramp with the final colour point at full transparency; Classify was selected, and under Layer Rendering, a Multiply Blending Mode was selected to add transparency in high-density areas. The rest was left at default (see Figure 14 for parameters and Figure 15 for the resulting visualization).

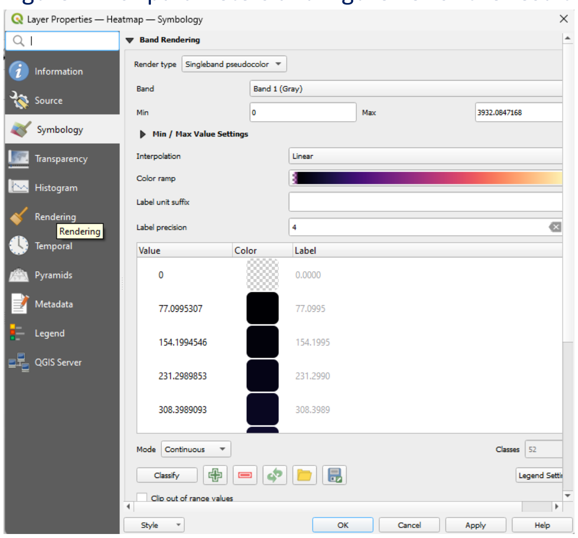


Figure 14: Symbolizing the Hotspot map

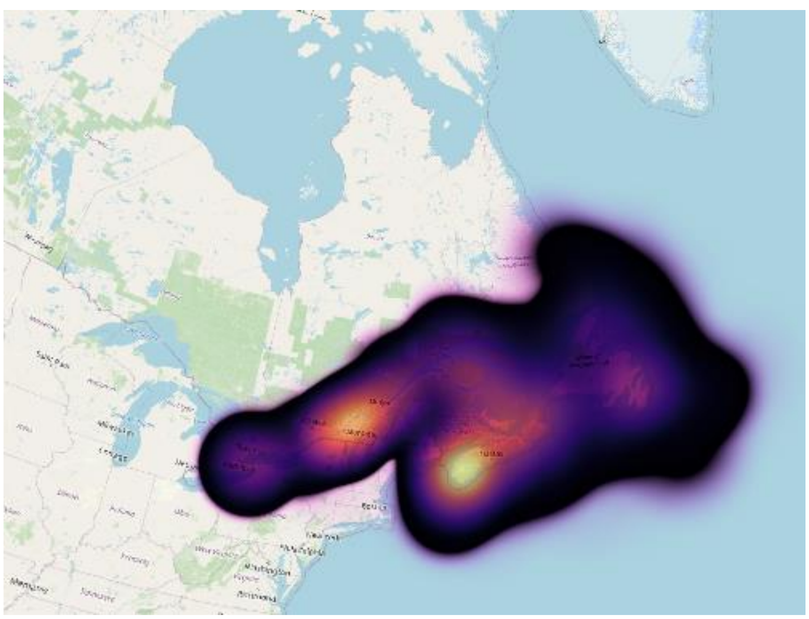


Figure 15: Rendering of the given parameters for the hotspot map

Analysis

Figure 15 shows the resulting hotspot map. Unlike the heatmap, no weight was given to the points, meaning all would have a value of 1 (See Observations, Troubleshooting, Notes on this point). The result shows a clustering of numerous events around the coasts and down the St. Lawrence River, but the most high-density areas are the western end of Nova Scotia, and mid-way down the St. Lawrence. The purple glow around the whole visualization has to do with how each data point is evaluated with the KDE. The centre of each point has the highest value, and that value decreases toward the edges, like a bell curve (esri, 2011).

Observations, Troubleshooting, Notes

The parameters initially attempted in running the KDE were much smaller measurements: 100km and 200km, and 5px and 10px. The tool would not run with these values. It would run at 20px but was very slow. When a classmate indicated that the tool took 24 hours at 50px, it was decided to run this dataset at 300km and 100px. Even at that level, it took over 33 hours to complete. It was an accidental omission not setting the weighted value of death rates, but that may (or may not?) have caused the tool to take longer to run. See Appendix for the log.

It is possible the reason the map took so long to render was that the weighting was not applied. That meant that a *qualitative* feature was being mapped. It was advised to use a quantitative data, or to use the field calculator to derive a numeric field, like an output of counts.

Hexbin Map

Technical Exploration

The primary purpose of the Hexbin map is to visualize number of occurrences in each section of a grid, in this case, deaths per accident in each hexagon.

Comparison to Other Mapping Techniques

The hexbin map is the same idea as a choropleth map, except a choropleth map has predetermined regions, like countries or provinces. With a hexbin map, the hexagons serve as regions. In many cases, it may be appropriate to map by region, if the phenomenon is potentially caused by, or would be attended to by those regions. With a hexbin map, the cartographer can make the hexagons any size, covering any area, and they can therefore create a truer visualization of a phenomenon that is not politically bound.

Workflow

Creating a hexbin map follows a similar workflow in QGIS as creating a heatmap or hotspot map. The specifications here are specific to the dataset MIA, with a weighting on Number of Deaths.

1. Once the dataset is cleaned and the focus area determined and Clipped (done in ArcGIS Pro, but can be done in QGIS), open the .csv file in QGIS.
2. Set the coordinate system of the map (bottom right corner of the screen). The projection chosen for this map was WGS 84/UTM Zone 20, EPSG:32620.

3. On the .csv file, Export>Save Feature As, and save the feature as a .shp file. At this point, set the coordinate system to EPSG:32620.
4. In the bottom left search bar, find the Create Grid tool and set the following parameters (Figure 16):

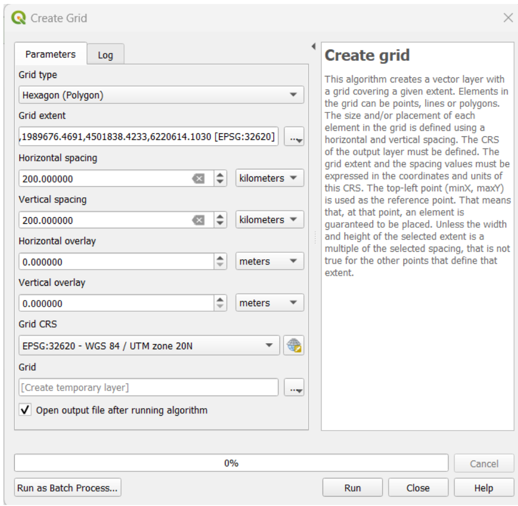


Figure 16:Parameters for Create Grid tool

The result will be a grid of 200km hexagons over the study area. It is advisable to rename the layers. For example, “Grid200km”.

5. In the top ribbon, select Vector > Analysis > Count Points in Polygon (or, search for the tool in the search bar). Fill in the following parameters (Figure 17):

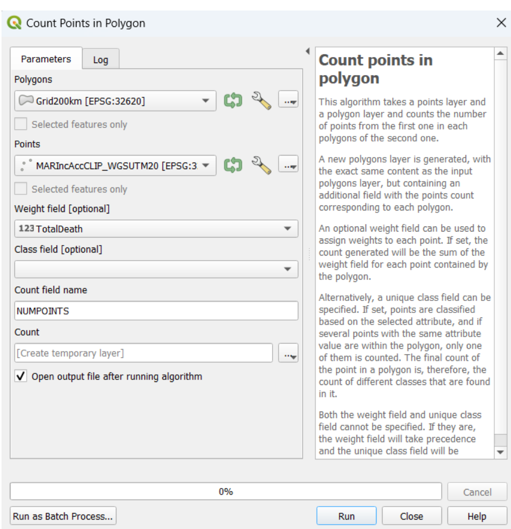


Figure 17:Count Points in Polygon tool parameters

6. Once it runs (under 1 minute), open the Attributes table and find the new column NUMPOINTS to see the number of points in each hexbin. This data column is what will be stylized.

The map was styled using Natural Breaks to highlight low and high areas. Also, an extra category was created and given a value of 0.0-0.0 so that occurrences with 0 deaths are removed from the map. Transparencies were added to the points and polygons for better visualization (see Figures 18 and 19).

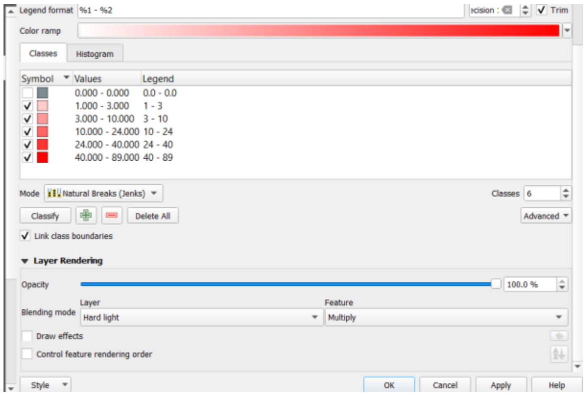


Figure 18:Symbology for Hexbin

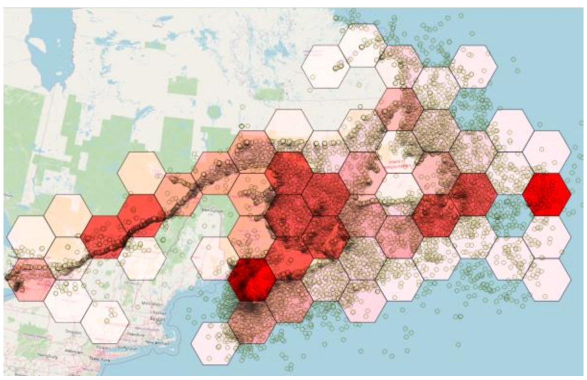


Figure 19:Resulting Hexbin Symbology

Analysis

The primary motivation in stylizing the map as seen in Figure 19 was to highlight the incidents with high death rates and to permit equal space for incidents with low death rates. This is an inherent value of the hexbin map: that even if an occurrence is symbolized with a light colour, it still gets a hexagon equal in size to all others. This gives visual value to the data, particularly important when dealing with an issue like lives lost – even one matters.

The high death rate of the incident off the coast of Newfoundland is the main factor in that hexagon's colour saturation. Other areas of significance, which could be seen in the other maps in this report, are in the Montreal area along the St. Lawrence River, and off the west coast tip of Nova Scotia. A pattern is visible from that area up into the Gulf of St. Lawrence. Areas of low significance, not surprisingly, are inland occurrences.

Observations, Troubleshooting, Notes

It took several attempts to accomplish the desired outcome (see Figure 20).

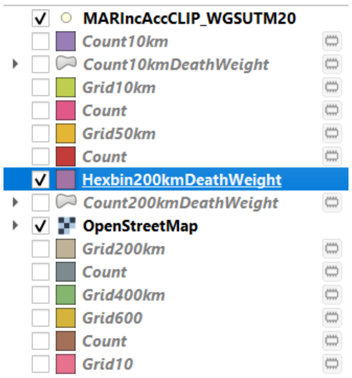


Figure 20:Several attempts were made for an accurate NUMPOINTS field.

When the tools were first run, despite the parameters being the same as they were in the successful run (see Figure 21 and 22), the NUMPOINTS field resulted in all zeros (see Figure 23).

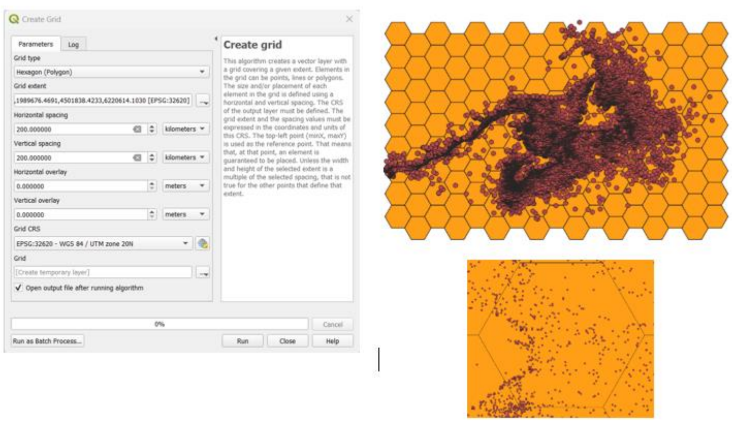


Figure 21:An early attempt at the Create Grid tool and the results.

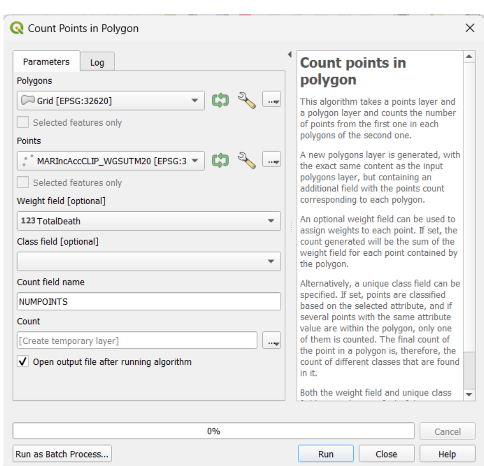
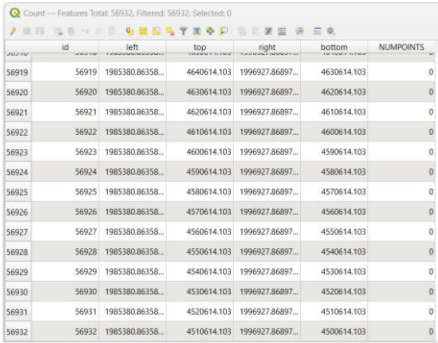


Figure 22:Count Points in Polygon tool in an early attempt resulting in NUMPOINTS field being all 0's.



Count — Features Total: 56932, Filtered: 56932, Selected: 0

	id	left	top	right	bottom	NUMPOINTS
56919	56919	1985380.86358...	4640614.103	1996927.86897...	4630614.103	0
56920	56920	1985380.86358...	4630614.103	1996927.86897...	4620614.103	0
56921	56921	1985380.86358...	4620614.103	1996927.86897...	4610614.103	0
56922	56922	1985380.86358...	4610614.103	1996927.86897...	4600614.103	0
56923	56923	1985380.86358...	4600614.103	1996927.86897...	4590614.103	0
56924	56924	1985380.86358...	4590614.103	1996927.86897...	4580614.103	0
56925	56925	1985380.86358...	4580614.103	1996927.86897...	4570614.103	0
56926	56926	1985380.86358...	4570614.103	1996927.86897...	4560614.103	0
56927	56927	1985380.86358...	4560614.103	1996927.86897...	4550614.103	0
56928	56928	1985380.86358...	4550614.103	1996927.86897...	4540614.103	0
56929	56929	1985380.86358...	4540614.103	1996927.86897...	4530614.103	0
56930	56930	1985380.86358...	4530614.103	1996927.86897...	4520614.103	0
56931	56931	1985380.86358...	4520614.103	1996927.86897...	4510614.103	0
56932	56932	1985380.86358...	4510614.103	1996927.86897...	4500614.103	0

Figure 23: NUMPOINTS field was all 0's in early attempts.

It was just trying different spacing with and without weighting in several iterations and combinations, and finally coming back to one of the original settings where the NUMPOINTS field was populated with accurate numbers.

Before altering the values in the symbology, the bottom value was 0-3 deaths per occurrence. This resulted in a map with minimal variance of colour, combining occurrences resulting in death with those that did not result in deaths, and not giving the weight due to the incidents resulting high death rates (see Figures 24 and 25).

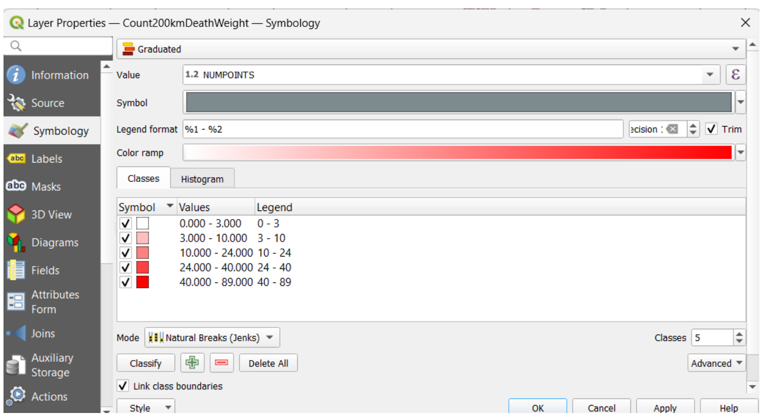


Figure 24:Symbology for Hexbin map with results that were difficult to interpret.

Because of one event's high death toll off Newfoundland's coast, I used Natural Breaks just to get the other occurrences on the map. However, it doesn't accurately display the vast difference in numbers of deaths between occurrences/areas without the other parameters also being altered (see Figure 25).

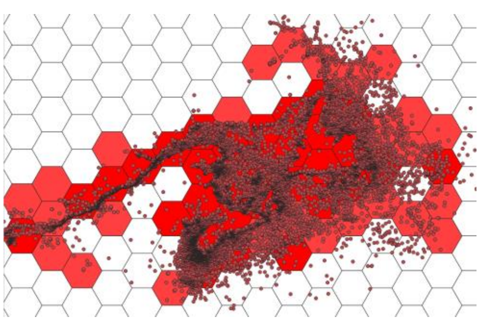


Figure 25: Visualization of a Hexbin map where colours are virtually indiscernible.

Conclusion

Heatmaps, Hotspot maps, and Hexbin maps are similar in that they visualize data clusters, however, the approach each takes in doing so varies. A heatmap is a basic and easily-manipulated map in terms of displaying the data, but "for a reliable and defensible density analysis, [a hotspot map] will give you more control" (Smith, 2019). Unlike the proximity factor approach used by the heatmap and hotspot map, the hexbin accomplishes a cluster map by creating regions that were not there before and counts the points within.

Knowing the subtle but consequential differences of how each map is created will help choose the right map for the right purpose.

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Appendix

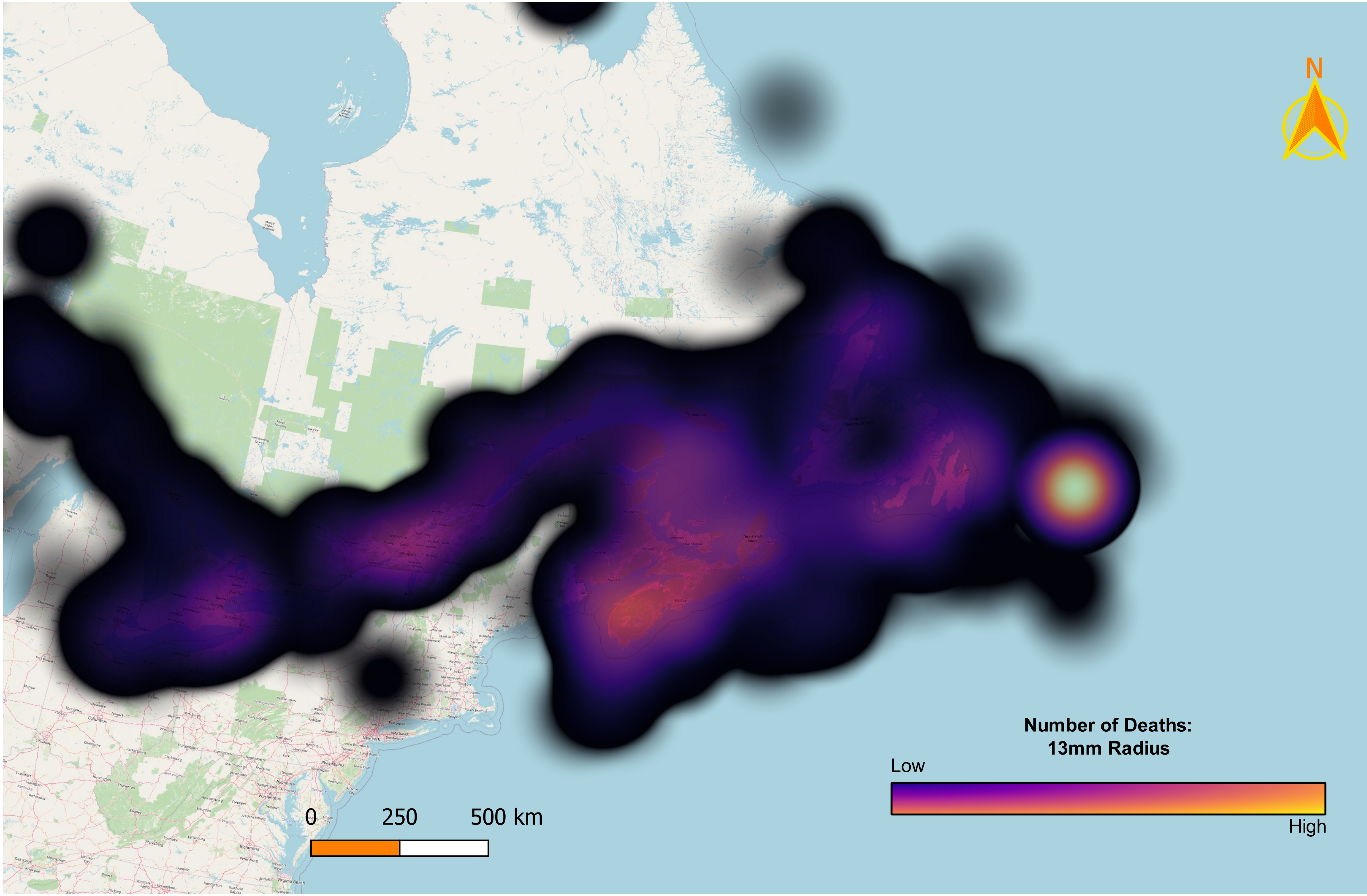
Hotspot Log

```
QGIS version: 3.22.10-Bia?owie?a

QGIS code revision: 6a63fd37

Qt version: 5.15.3

Python version: 3.9.5

GDAL version: 3.5.1

GEOS version: 3.10.3-CAPI-1.16.1

PROJ version: Rel. 9.0.1, June 15th, 2022

PDAL version: 2.4.2 (git-version: 6cb4e7)

Algorithm started at: 2023-04-04T19:17:37

Algorithm 'Heatmap (Kernel Density Estimation)' starting…

Input parameters:

{ 'DECAY' : 0, 'INPUT' :
'C:\\Users\\rebec\\OneDrive\\Documents\\ArcGIS\\Projects\\MARIncAccCLIP_WGSUTM20.shp', 'KERNEL' : 0,
'OUTPUT' : 'TEMPORARY_OUTPUT', 'OUTPUT_VALUE' : 0, 'PIXEL_SIZE' : 5, 'RADIUS' : 200, 'RADIUS_FIELD' : '',
'WEIGHT_FIELD' : '' }


Could not create destination layer

Execution failed after 0.02 seconds


Loading resulting layers

Algorithm 'Heatmap (Kernel Density Estimation)' finished

QGIS version: 3.22.10-Bia?owie?a

QGIS code revision: 6a63fd37

Qt version: 5.15.3

Python version: 3.9.5

GDAL version: 3.5.1

GEOS version: 3.10.3-CAPI-1.16.1

PROJ version: Rel. 9.0.1, June 15th, 2022

PDAL version: 2.4.2 (git-version: 6cb4e7)

Algorithm started at: 2023-04-04T19:17:58

Algorithm 'Heatmap (Kernel Density Estimation)' starting…

Input parameters:

{ 'DECAY' : 0, 'INPUT' :
'C:\\Users\\rebec\\OneDrive\\Documents\\ArcGIS\\Projects\\MARIncAccCLIP_WGSUTM20.shp', 'KERNEL' : 0,
```

```
'OUTPUT' : 'TEMPORARY_OUTPUT', 'OUTPUT_VALUE' : 0, 'PIXEL_SIZE' : 5, 'RADIUS' : 200000, 'RADIUS_FIELD' :
'', 'WEIGHT_FIELD' : '' }


Could not create destination layer

Execution failed after 0.01 seconds


Loading resulting layers

Algorithm 'Heatmap (Kernel Density Estimation)' finished

QGIS version: 3.22.10-Bia?owie?a

QGIS code revision: 6a63fd37

Qt version: 5.15.3

Python version: 3.9.5

GDAL version: 3.5.1

GEOS version: 3.10.3-CAPI-1.16.1

PROJ version: Rel. 9.0.1, June 15th, 2022

PDAL version: 2.4.2 (git-version: 6cb4e7)

Algorithm started at: 2023-04-04T19:18:19

Algorithm 'Heatmap (Kernel Density Estimation)' starting…

Input parameters:

{ 'DECAY' : 0, 'INPUT' :
'C:\\Users\\rebec\\OneDrive\\Documents\\ArcGIS\\Projects\\MARIncAccCLIP_WGSUTM20.shp', 'KERNEL' : 0,
'OUTPUT' : 'TEMPORARY_OUTPUT', 'OUTPUT_VALUE' : 0, 'PIXEL_SIZE' : 10, 'RADIUS' : 200000, 'RADIUS_FIELD' :
'', 'WEIGHT_FIELD' : '' }


Could not create destination layer

Execution failed after 0.01 seconds


Loading resulting layers

Algorithm 'Heatmap (Kernel Density Estimation)' finished

QGIS version: 3.22.10-Bia?owie?a

QGIS code revision: 6a63fd37

Qt version: 5.15.3

Python version: 3.9.5

GDAL version: 3.5.1

GEOS version: 3.10.3-CAPI-1.16.1

PROJ version: Rel. 9.0.1, June 15th, 2022

PDAL version: 2.4.2 (git-version: 6cb4e7)

Algorithm started at: 2023-04-04T19:18:28
```

```
Algorithm 'Heatmap (Kernel Density Estimation)' starting…

Input parameters:

{ 'DECAY' : 0, 'INPUT' :
'C:\\Users\\rebec\\OneDrive\\Documents\\ArcGIS\\Projects\\MARIncAccCLIP_WGSUTM20.shp', 'KERNEL' : 0,
'OUTPUT' : 'TEMPORARY_OUTPUT', 'OUTPUT_VALUE' : 0, 'PIXEL_SIZE' : 20, 'RADIUS' : 200000, 'RADIUS_FIELD' :
'', 'WEIGHT_FIELD' : '' }


Execution failed after 3682.09 seconds (1 hour 1 minute 22 seconds)


Loading resulting layers

Algorithm 'Heatmap (Kernel Density Estimation)' finished

QGIS version: 3.22.10-Bia?owie?a

QGIS code revision: 6a63fd37

Qt version: 5.15.3

Python version: 3.9.5

GDAL version: 3.5.1

GEOS version: 3.10.3-CAPI-1.16.1

PROJ version: Rel. 9.0.1, June 15th, 2022

PDAL version: 2.4.2 (git-version: 6cb4e7)

Algorithm started at: 2023-04-04T20:20:49

Algorithm 'Heatmap (Kernel Density Estimation)' starting…

Input parameters:

{ 'DECAY' : 0, 'INPUT' :
'C:\\Users\\rebec\\OneDrive\\Documents\\ArcGIS\\Projects\\MARIncAccCLIP_WGSUTM20.shp', 'KERNEL' : 0,
'OUTPUT' : 'TEMPORARY_OUTPUT', 'OUTPUT_VALUE' : 0, 'PIXEL_SIZE' : 100, 'RADIUS' : 300000, 'RADIUS_FIELD' :
'', 'WEIGHT_FIELD' : '' }


Execution completed in 121874.57 seconds (33 hours 51 minutes 15 seconds)

Results:

{'OUTPUT':
'C:/Users/rebec/AppData/Local/Temp/processing_UlWKYb/054f68d5d02f440dbe41ebbfe7b81acc/OUTPUT.tif'}


Loading resulting layers

Algorithm 'Heatmap (Kernel Density Estimation)' finished
```

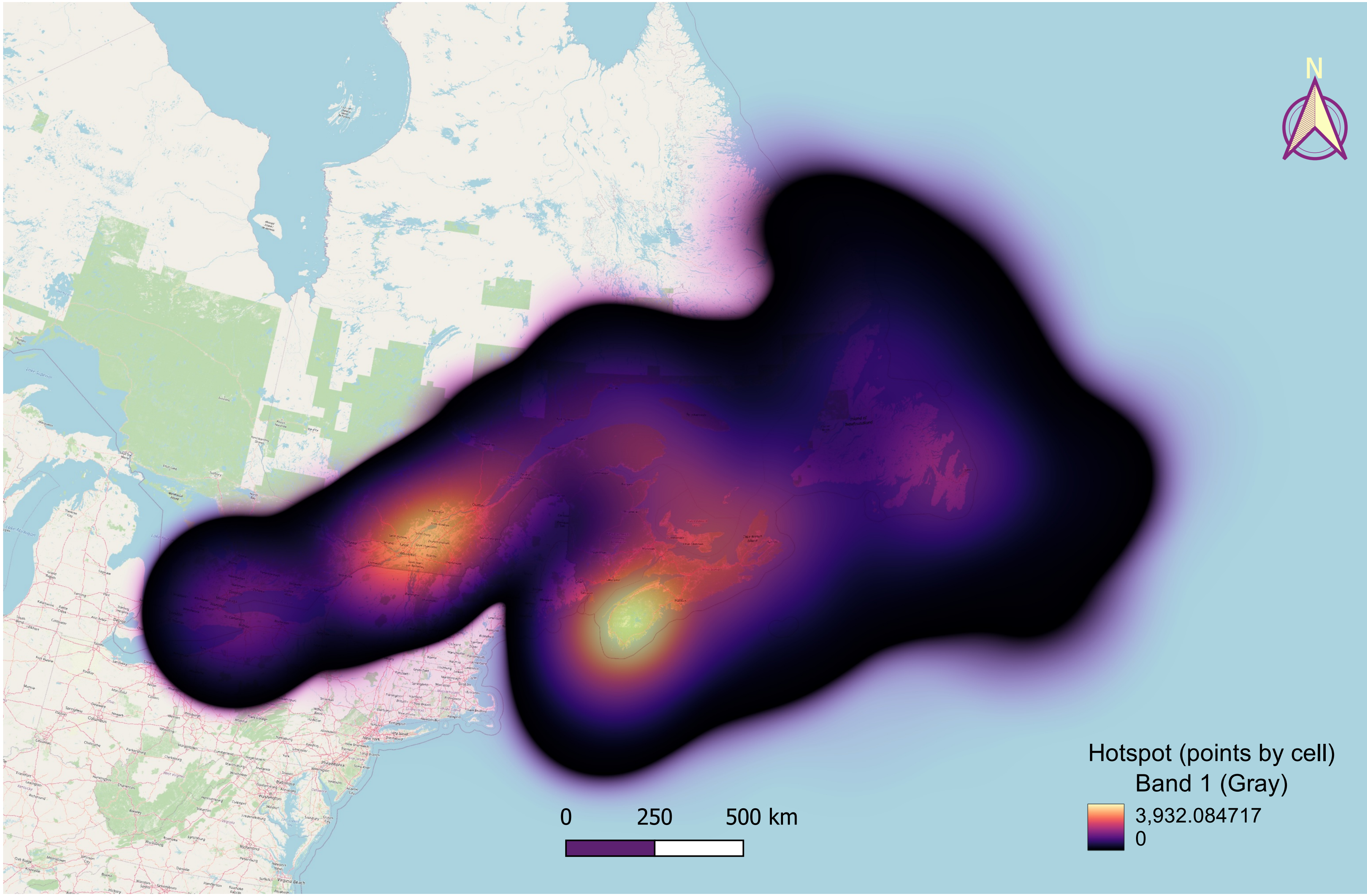
Heatmap: Number of Deaths in Maritime Incidents and Accidents in Eastern Canada



This map is produced as a portion of the requirements of the GIS: Cartography and Geovisualization program of the Centre of Geographic Sciences, NSCC, Lawrencetown, Nova Scotia. The product is unedited, unverified and intended for educational purposes only.
Cartography by Rebecca McCarthy, April 2023

Data Source
Canada, T. S. (1995. Retrieved Jan. 2023). Marine transportation occurrence data from January 1995. Retrieved from http://bit.ly/3zy03KH

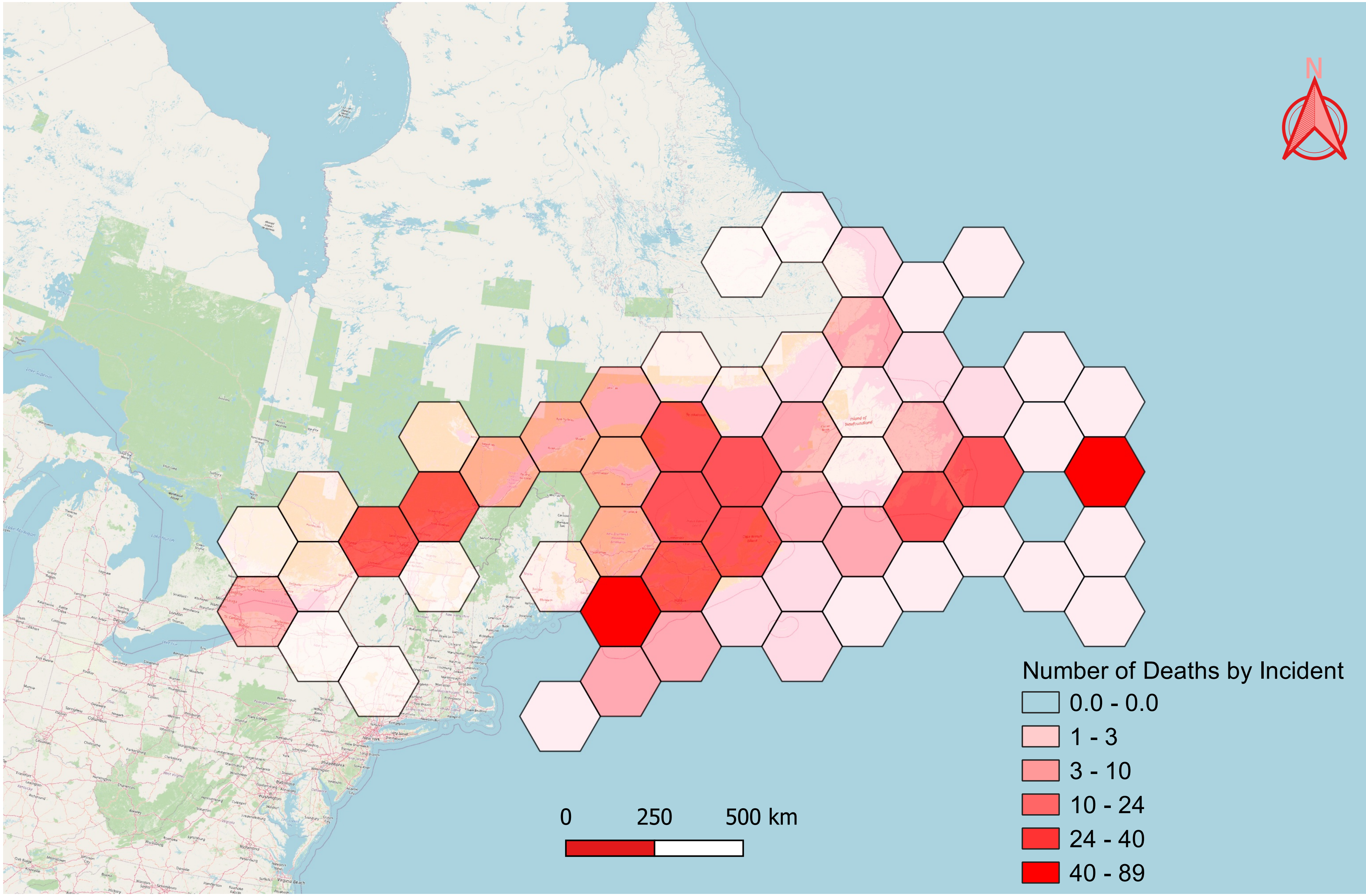
Hotspot Map: Maritime Incidents and Accidents in Eastern Canada



This map is produced as a portion of the requirements of the GIS: Cartography and Geovisualization program of the Centre of Geographic Sciences, NSCC, Lawrencetown, Nova Scotia. The product is unedited, unverified and intended for educational purposes only.
Cartography by Rebecca McCarthy, April 2023

Data Source
Canada, T. S. (1995. Retrieved Jan. 2023). Marine transportation occurrence data from January 1995. Retrieved from http://bit.ly/3zy03KH

Hexbin Map: Number of Deaths in Maritime Incidents and Accidents in Eastern Canada



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Cartography by Rebecca McCarthy, April 2023

Data Source
Canada, T. S. (1995. Retrieved Jan. 2023). Marine transportation occurrence data from January 1995. Retrieved from http://bit.ly/3zy03KH