Final Report: Study

Comparing Spatial Distributions of the North Atlantic Right Whale and Commercial Shipping Lanes

FAES 300 – Internship 2

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1. Introduction:

The North Atlantic right whale (*Eubalaena glacialis*) is one of the rarest large whales in North America (Fortune et al., 2013). It can measure up to 17 meters long, weigh up to 70 tons and stands out among other whales with its large head and a highly curved jaw (Fortune et al., 2013). The whale is mostly black, with some callosities on its head and some white spots on its abdomen (Fortune et al., 2013) (see Figures 3 and 4 in the Appendix for illustrations of *E. glacialis*). They are typically solitary animals, although small clusters of individuals may be observed when a threat is nearby (Fortune et al., 2013). North Atlantic right whales have been recorded to live up to 70 years old (Fisheries and Oceans Canada, 2014). Like most baleen whales, the right whale feeds on zooplankton or small crustaceans (Fortune et al., 2013). As its name suggests, the North Atlantic right whale is distributed in the North Atlantic Ocean, mostly to the east, along the coasts (Fortune et al., 2013). From July to September, right whales are found in shallow coastal waters of the St. Lawrence, although sightings are quite rare (Fortune et al., 2013). In the past two decades, more and more observations have been reported on the Magdalen Islands, in Chaleur Bay, on the Lower North Shore and in the estuary (Fortune et al., 2013). During summer months, right whales frequent the eastern coasts of the United States and Canada, around the Scotian Shelf, in Bay of Fundy, Cape Cod, and the Gulf of Maine (Fortune et al., 2013). From October to April, the whales migrate south and reach their winter calving grounds off the coast of Florida and Georgia (Ward-Geiger et al., 2005).

The COSEWIC[1] has evaluated the species as endangered every decade since 1970 (Fortune et al., 2013). The IUCN[2] Red List has assessed the species as critically endangered as of 2020. With less than 350 total whales, less than 250 mature individuals, and a continuously declining population, this species is severely at risk (Cooke, 2020). The right whale was intensely hunted

[1] Committee on the Status of Endangered Wildlife in Canada
[2] International Union for Conservation of Nature

for several centuries and to this day has a high mortality rate caused by boat strikes (collision between a vessel and an animal) and bycatch (entanglement in fishing gear) (Ward-Geiger et al., 2005). The right whale has very little to no reactivity to passing boats, spends a lot of time on the surface and moves very slowly, which are important factors of mortality (Ward-Geiger et al., 2005). Between 2016 and 2017 alone, 17 young whales died from vessel strikes and bycatch (Christiansen et al., 2020). According to Fisheries and Oceans Canada (2014), the population trends of *E. glacialis* are so concerning, the species is estimated to go extinct in about 208 years.

Although the proximity with human activity is known to be the leading cause of death for the North Atlantic right whale, I could not find illustrations or maps of this proximity between the two anywhere online. Available literature has researched the juxtaposition of shipping lanes with the right whale's habitat and plotted the distribution of both separately. I however, seek to illustrate both distributions together, on the same plot. I also chose to perform this study on the North Atlantic right whale to reflect what I learned during my internship. I completed my internship at the University of Miami's Rosenstiel School of Marine and Atmospheric Science. As Ward-Geiger et al. (2005) mentioned, the right whales are distributed along Florida's coast. One of the master students I happened to share my office with is native to Florida and was quite passionate about these whales and their conservation. I learned a lot on the species from her and I took personal interest in it as well. This study was perfect to apply both my newly acquired skills in R and knowledge on the North Atlantic right whale.

During this study, our goal is to illustrate the spatial overlap between the North Atlantic right whale's distribution and major ship traffic such as commercial shipping lanes and major ports. By doing so, we could bring evidence that human shipping traffic actively participates in the decline of the species population. We will also discuss current regulations and recovery strategies aiming to protect *E. glacialis*.

2. Design of the study

To illustrate the spatial overlap between the distributions of *E. glacialis* and shipping traffic, we will plot these in R, using RStudio. R is a software used for statistical computing with its own programming language, and RStudio provides an interface to R to supply additional functionalities. Considering the scope of this study, recording data in the field would be impossible with our resources and time constraints. Instead, we gather information from various online databases. We need three types of data: occurrence data, environmental data, and data on shipping traffic. Occurrence data is recorded evidence that a certain species, occurred at a certain place, at a certain time. Here we download occurrence data of the North Atlantic Right Whale from GBIF[3].org, accessible here (Global Biodiversity Information Facility, 2022). The file is composed of 7964 occurrences of *E. glacialis*, in a CSV format (comma-separated values), a type of text file. The database scans for all available occurrence data on *E. glacialis* online, without removing erroneous data, or duplicates. The data is not restricted to a specific period, some of the oldest data included dates from up to 1965. Each recorded occurrence represents one instance where evidence of *E. glacialis* presence was observed. Each occurrence is not an individual whale but rather one of many locations where a whale was detected at a point in time. We then download environmental data, or a background map of the oceans and land that will help us illustrate the North Atlantic Right Whale's distribution and put it into context. Here we source it from Gebco[4].net as a raster of the North Atlantic Ocean, available here (British Oceanographic Data Centre, 2022). We choose a range of Nº70 to Sº10 and Wº-100 to Eº20. We use a TIF format (Tagged Image Format), an image format for storing raster graphics images (Wasser et al., 2018). A raster is a two-dimensional map format composed of gridded data that can be visualized when plotted (Wasser et al., 2018).

[3] Global Biodiversity Information Facility
[4] General Bathymetric Chart of the Oceans

Finally, we source the shipping traffic data from NCEAS[5] from an impressive study on the assessment of cumulative human impacts globally. The database is accessible here (Halpern et al., 2015). Download the "Commercial Shipping Lanes" dataset from 2013 named "raw_2013_shipping_mol.zip". The dataset is a collection of GPS[6] coordinates from 3'374 commercial vessels (representing around 11% of total ships at sea at the time), that recorded their locations between 2012 and 2013 (Halpern et al., 2015). Once the zip file is decompressed, a TIF file is accessible for use.

Below is a description of our spatial analysis in R, but you will find our code and its outputs (or rendering of the plots) attached further down. Instructions from Wasser et al. (2018) and Feng et al. (2017) were used, combined with personal knowledge to produce the code. My code is also available here from my GitHub account (Egret, 2022). Note that GitHub does not seem to display the outputs but they are shown below.

Firstly, the working environment is set up. This includes installing required packages, that provide specific functions we need (R Core Team, 2022). Several packages need to be installed such as the "raster" package, which provides functions for analyzing gridded data (i.e., individual data points in a geographic area); the "rgeos" package, which provides functions for analyzing spatial data; and the "rdgal" package used to manipulate geospatial data (R Core Team, 2022). The environmental data is then loaded and processed to only include ocean data. After loading, processing, and filtering our occurrence data, we plot it on top of the ocean data. Although *E. glacialis* can be found in some parts of Europe, its presence is much more important in the Western Atlantic. For our purposes, being the study of the distribution of the species along the eastern coasts of the United States and Canada, we will only keep occurrence data located in the western North Atlantic Ocean. The shipping traffic data is loaded, processed

[5] National Center for Ecological Analysis and Synthesis
[6] Global Positioning System

and plotted as well. And finally, we are able to plot the occurrence data on top of the ship traffic data to visualize both distributions layered on top of each other.

A. Set up the working environment

Set the working directory. The working directory is the file path R will follow to load or store files.

```
setwd("~/Desktop")
```

Load required packages. A package is a compilation of functions that may be downloaded to execute certain actions (R Core Team, 2022). These three packages allow us to process, analyze, manipulate, visualize and model spatial data among other things (R Core Team, 2022).

```
library("raster")
library("rgeos")
library("rgdal")
```

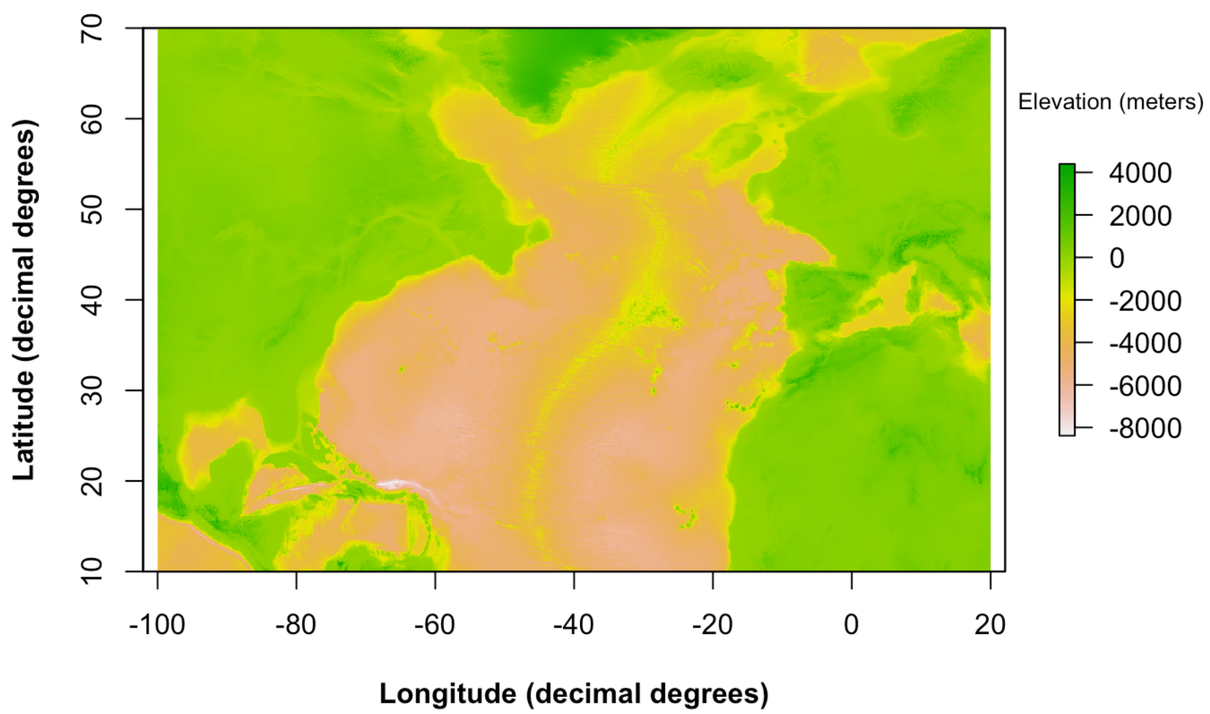
Load environmental data.

```
# load pre-downloaded file of environmental data
# name it "clim"
clim <- raster("gebco_2022_n70.0_s10.0_w-100.0_e20.0.tif")

# print the basic information about "clim"
print(clim)
## class      : RasterLayer
## dimensions : 14400, 28800, 414720000  (nrow, ncol, ncell)
## resolution : 0.004166667, 0.004166667  (x, y)
## extent     : -100, 20, 10, 70  (xmin, xmax, ymin, ymax)
## crs        : +proj=longlat +datum=WGS84 +no_defs
## source     : gebco_2022_n70.0_s10.0_w-100.0_e20.0.tif
## names      : gebco_2022_n70.0_s10.0_w.100.0_e20.0
## values     : -32768, 32767  (min, max)
```

This information tells us that the CRS (Coordinate Reference System) indicates the projection and datum (Wasser et al., 2018). Here we use a standard datum (WGS84), which is employed when data is collected via GPS (Wasser et al., 2018). We can also see that the raster has an extent of -90, -25, 20 and 65, or Wº-90, Eº-25, Sº20 and Nº65, in decimal degrees. An extent is the spatial extremes of an object (Wasser et al., 2018).

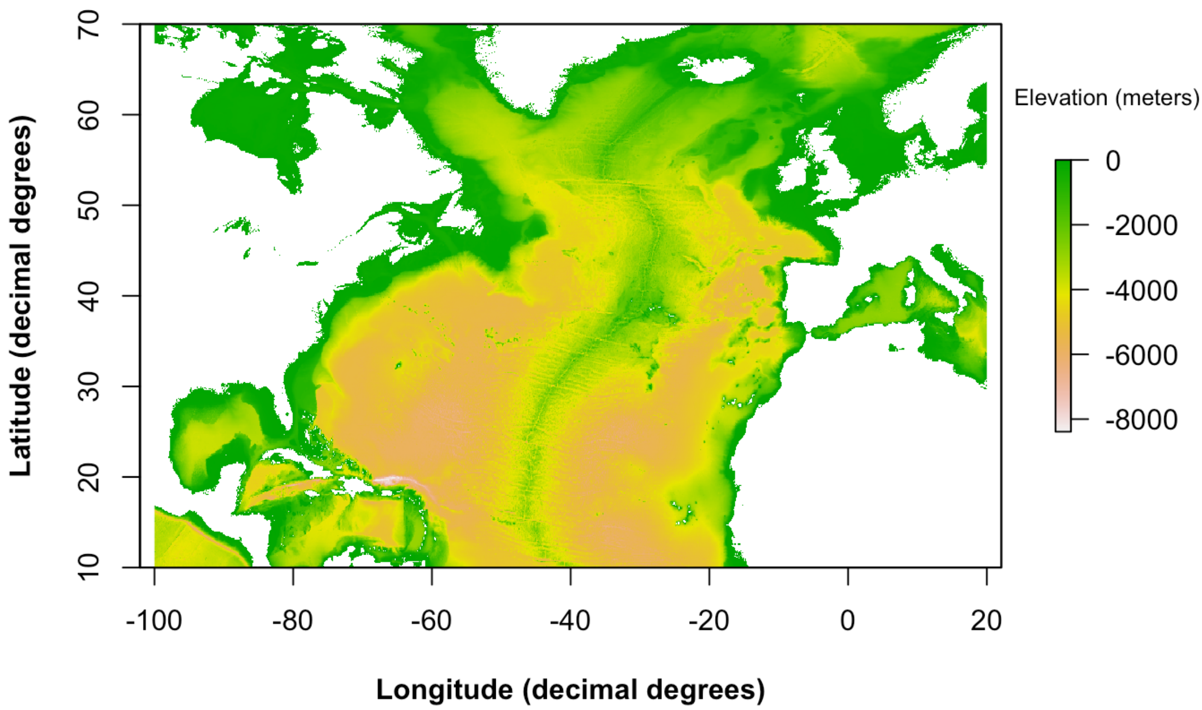
But most importantly, we notice that values from the gridded data range from -32768 to 32767 (the unit being meters). This entails that both above-surface and under-surface relief data is included. Let's visualize this:

```
# plot environmental data
plot(clim)

# label the plot
legend(21, 65, "Elevation (meters)", xpd = TRUE, bty = "n", cex = 0.8)
mtext(side = 1, line = 3, "Longitude (decimal degrees)", font = 2, cex = 1)
mtext(side = 2, line = 3, "Latitude (decimal degrees)", font = 2, cex = 1)
```



We can indeed observe both land and water elevation. However, we know that *E. glacialis* is found only in the ocean (Fortune et al., 2013). We then remove land data, which will allow us to better visualize the demarcation between land and water.

```
# remove data from areas above 0 meters in elevation from "clim"
clim[clim > 0] <- NA

# plot ocean data
plot(clim)

# label the plot
legend(21, 65, "Elevation (meters)", xpd = TRUE, bty = "n", cex = 0.8)
mtext(side = 1, line = 3, "Longitude (decimal degrees)", font = 2, cex = 1)
mtext(side = 2, line = 3, "Latitude (decimal degrees)", font = 2, cex = 1)
```



We can now observe a map of the North Atlantic Ocean which only includes ocean data.

B. Plotting the North Atlantic right whale's distribution

Load occurrence data.

```
# load pre-downloaded occurrence data
# name it "occ_raw" as in "raw occurrence data"
# Note that the file named "newdata.csv" is simply what I named my occurrence data to simplify its original name
occ_raw <- read.csv("newdata.csv")
```

Remove erroneous data with either the latitude or longitude missing, or duplicated data (based on the coordinates). Create subsets without erroneous data: "occ_clean" then "occ_unique".

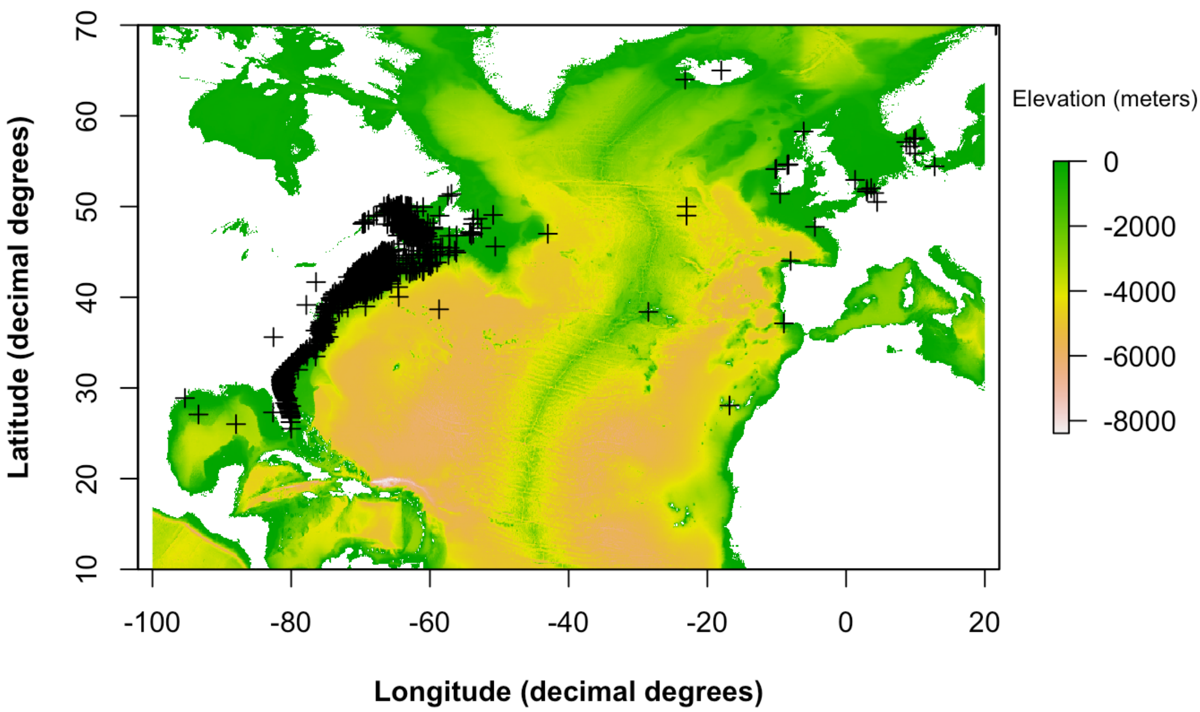
```
# remove erroneous coordinates
# name it "occ_clean"
# print amount of occurence data that was removed
occ_clean <- subset(occ_raw, (!is.na(decimalLatitude)) & (!is.na(decimalLongitude)))
cat(nrow(occ_raw) - nrow(occ_clean), "records are removed")
## 470 records are removed

# remove duplicates
# name it "occ_unique"
# print amount of occurence data that was removed
dups <- duplicated(occ_clean[c("decimalLatitude", "decimalLongitude")])
occ_unique <- occ_clean[!dups, ]
cat(nrow(occ_clean) - nrow(occ_unique), "records are removed")
## 410 records are removed
```

Up until now, we were working with a data frame, but this format has no spatial relationship with environmental layers. So we transform our data frame into spatial data.

```
# this tells R what the names of the longitude and latitude columns in our data frame so that it can associate it as coordinates
coordinates(occ_unique) <- ~decimalLongitude + decimalLatitude
```

Plot the data to look for erroneous occurrences located out of the known distribution of *E. glacialis*.

```
# plot ocean data
plot(clim)

# plot occurrence data on top of the ocean data
plot(occ_unique, add = TRUE)

# label the plot
legend(21, 65, "Elevation (meters)", xpd = TRUE, bty = "n", cex = 0.8)
mtext(side = 1, line = 3, "Longitude (decimal degrees)", font = 2, cex = 1)
mtext(side = 2, line = 3, "Latitude (decimal degrees)", font = 2, cex = 1)
```



Note that here and for the rest of this study, each point in the shape of a "plus sign" (+) represents one occurrence of a North Atlantic right whale. Each point is not an individual whale but rather one of multiple locations where a whale was detected.

Considering we know that *E. glacialis* is distributed throughout the North Atlantic Ocean, we can identify a couple points located outside of the known distribution, notably in the Gulf of Mexico. Restrict the location of the occurrence data to the eastern North Atlantic Ocean. Remove all points located outside of longitudes between -85° and -45° from the dataset.

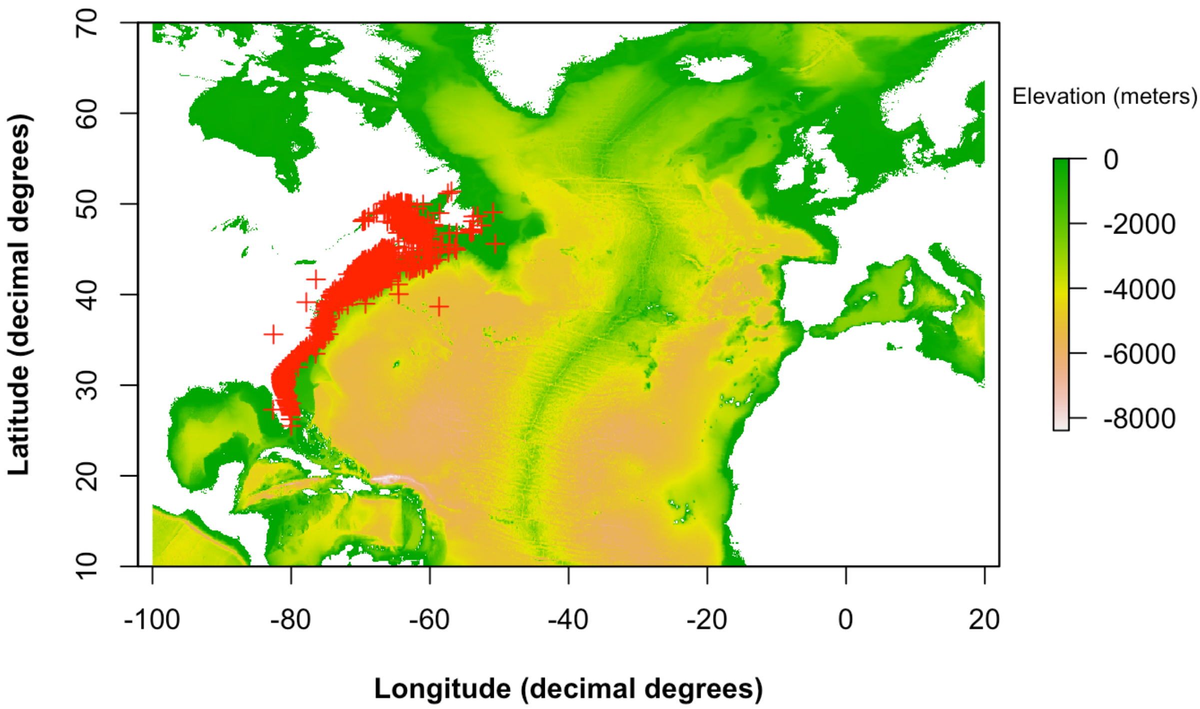
```
# only keep points with longitudes between -85° and -45°
occ_unique <- occ_unique[which(occ_unique$decimalLongitude > -85 & occ_uniq
ue$decimalLongitude < -45), ]
```

Thin occurrence data to keep only one occurrence point per pixel.

```
# keep one occurrence point per cell
# name final subset with thinned occurence data "occ_final"
cells <- cellFromXY(clim, occ_unique)
dups <- duplicated(cells)
occ_final <- occ_unique[!dups, ]
cat(nrow(occ_unique) - nrow(occ_final), "records are removed")
## 571 records are removed
```

After sorting our data, we now have 6469 occurrences. Let's plot them:

```
# plot ocean data
plot(clim)

# plot the final occurrence data on top of the ocean data
plot(occ_final, add = TRUE, col = "red")

# label the plot
legend(21, 65, "Elevation (meters)", xpd = TRUE, bty = "n", cex = 0.8)
mtext(side = 1, line = 3, "Longitude (decimal degrees)", font = 2, cex = 1)
mtext(side = 2, line = 3, "Latitude (decimal degrees)", font = 2, cex = 1)
```



C. Plotting the shipping traffic density

We then load our ship traffic data.

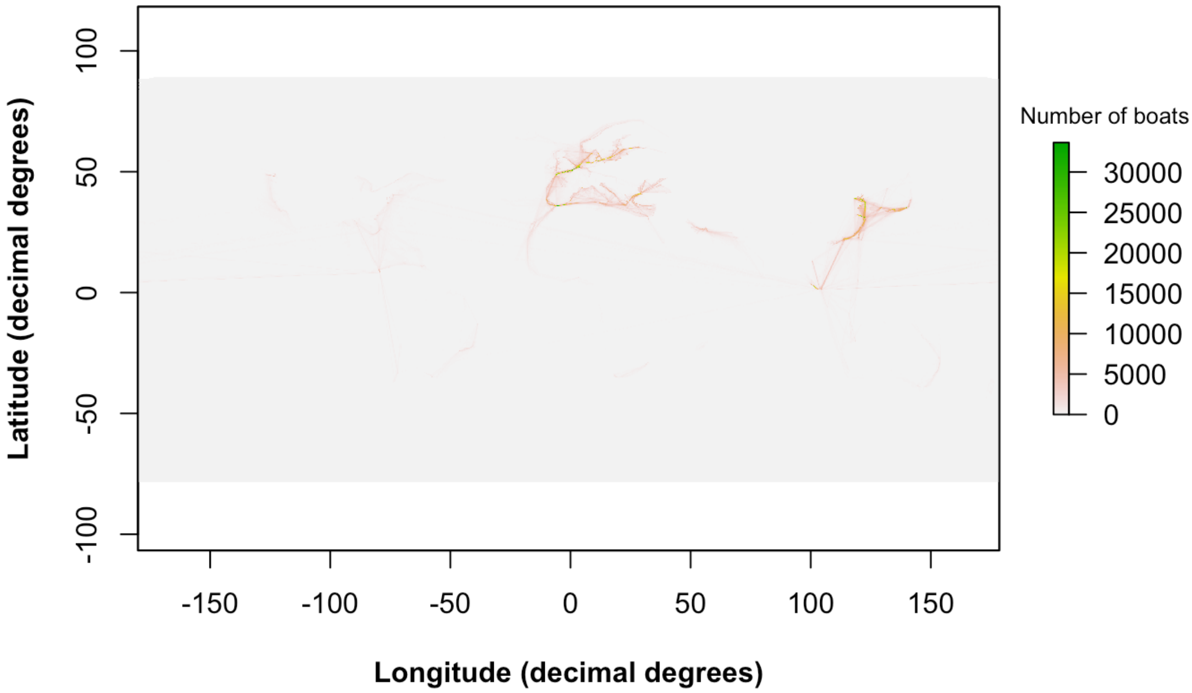
```
# load pre-downloaded file of ship traffic data
# name it "shippingmap"
shippingmap <- raster("raw_2013_shipping_mol/shipping.tif")

# print the basic information about "shippingmap"
print(shippingmap)
## class       : RasterLayer
## dimensions : 19305, 38610, 745366050  (nrow, ncol, ncell)
## resolution : 934.4789, 934.4789  (x, y)
## extent      : -18040095, 18040134, -9020067, 9020047  (xmin, xmax, ymin,
ymax)
## crs         : +proj=moll +lon_0=0 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no
_defs
## source      : shipping.tif
## names       : shipping
## values      : 0, 45226.26  (min, max)
```

We see that the extent is made of very large numbers (-18040095 and 18040134 for xmin and xmax for example). This is because this projection is in meters. We will convert this projection to match the one used in part 1 with longitudes and latitudes in decimal degrees.

```
# assign the ship traffic data the same crs as our ocean and occurrence dat
a: +proj=longlat +datum=WGS84.
# name it "shipping_longlat"
shipping_longlat <- projectRaster(shippingmap, crs='+proj=longlat +datum=WG
S84')
```

Plot ship traffic data with proper crs to visualize it.

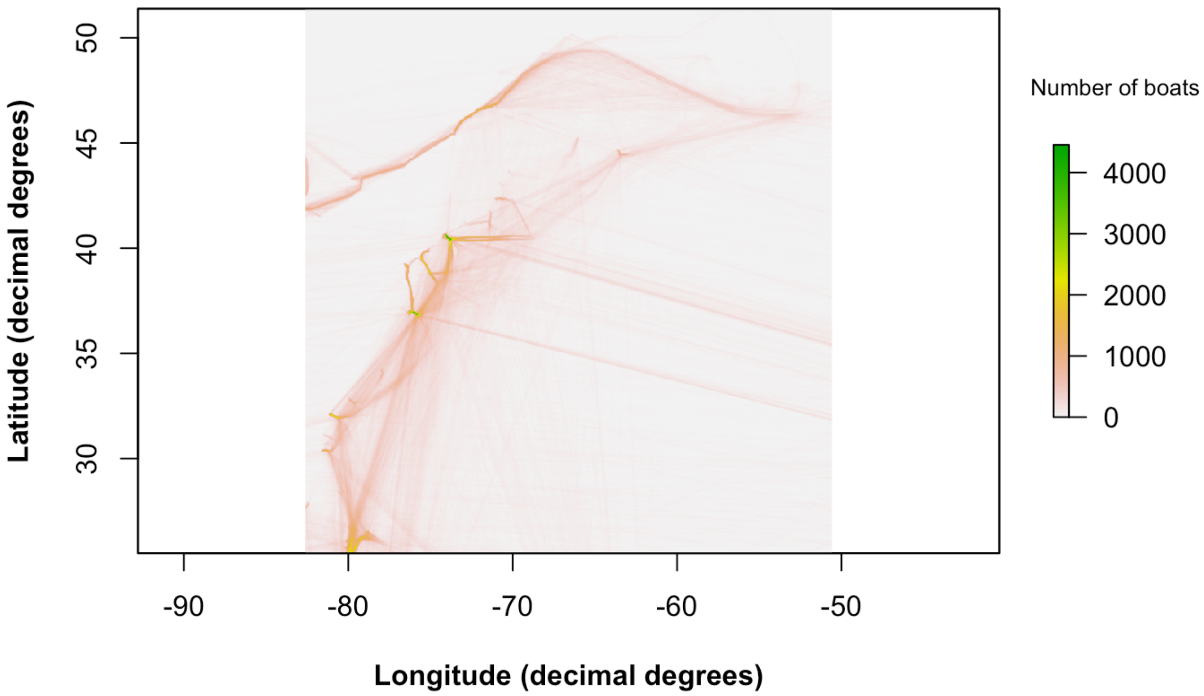
```
# plot ship traffic data
plot(shipping_longlat)

# label the plot
legend(170, 85, "Number of boats", xpd = TRUE, bty = "n", cex = 0.8)
mtext(side = 1, line = 3, "Longitude (decimal degrees)", font = 2, cex = 1)
mtext(side = 2, line = 3, "Latitude (decimal degrees)", font = 2, cex = 1)
```



D. Layering both plots

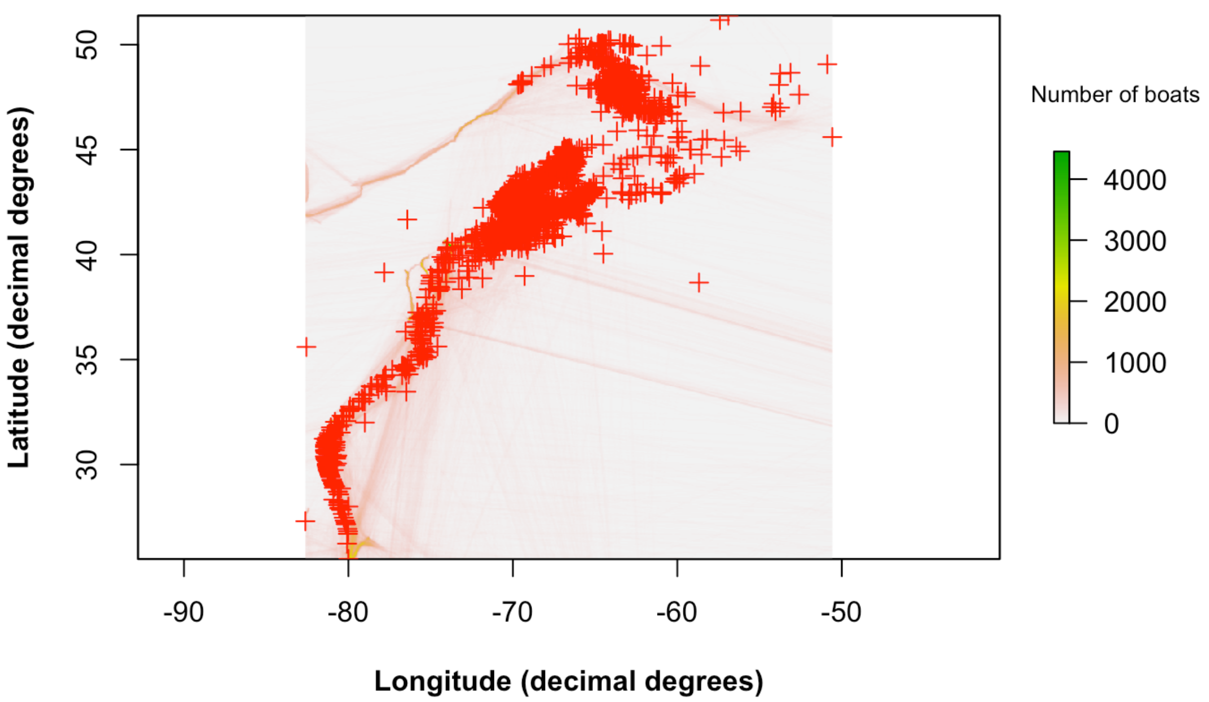
Now that we have plotted our occurrence data and ship traffic data separately, we then clip the ship traffic data to match the extent of our occurrence data. We do this by cropping "shipping_longlat" to match the extent of "occ_final". The "crop" function creates a rectangular shape framing the distribution of the occurrence data, then masks any ship traffic data located outside the rectangle (R Core Team, 2022).

```
# crop ship traffic data to match the extent of the occurrence data
# name it "new_extent"
new_extent <- crop(shipping_longlat, (occ_final))

# plot ship traffic data with cropped extent
plot(new_extent)

# label the plot
legend(-41, 49, "Number of boats", xpd = TRUE, bty = "n", cex = 0.8)
mtext(side = 1, line = 3, "Longitude (decimal degrees)", font = 2, cex = 1)
mtext(side = 2, line = 3, "Latitude (decimal degrees)", font = 2, cex = 1)
```



Plot the occurrence data on top of the ship traffic data to visualize both distributions layered on top of each other.

```
# plot ship traffic data
plot(new_extent)

# plot occurrence data on top of the ship traffic data
plot(occ_final, add = TRUE, col = "red")

# label the plot
legend(-41, 49, "Number of boats", xpd = TRUE, bty = "n", cex = 0.8)
mtext(side = 1, line = 3, "Longitude (decimal degrees)", font = 2, cex = 1)
mtext(side = 2, line = 3, "Latitude (decimal degrees)", font = 2, cex = 1)
```



To better illustrate whether both distributions overlap, reduce the size and opacity of the points representing occurences of North Atlantic right whales. This final plot will be attached in the results section.

```
# plot ship traffic data
plot(new_extent)


# plot occurrence data with reduced size and opacity on top of the ship tra
ffic data
plot(occ_final, add = TRUE, col = rgb(red = 1, green = 0, blue = 0, alpha =
0.3), cex = 0.5)


# label the plot
legend(-41, 49, "Number of boats", xpd = TRUE, bty = "n", cex = 0.8)
mtext(side = 1, line = 3, "Longitude (decimal degrees)", font = 2, cex = 1)
mtext(side = 2, line = 3, "Latitude (decimal degrees)", font = 2, cex = 1)
```

3. Results and Discussion

Figure 1, which is also present is part D of the design of the study, represents plotted ship traffic data from 2013 in the western North Atlantic Ocean. Locations with the highest density of boats are areas with proximity to major ports. Some of these ports can be identified as New York, Baltimore, Norfolk, Savannah, Jacksonville, Fort Lauderdale, Miami, and many other ports along the east coast of the United States. Brightly colored lines represent major shipping lanes, taken by a high volume of ships (Halpern et al., 2015). We can observe that green-colored areas were frequented by more than 3'000 boats. As mentioned previously, the plotted data represents the activity of 3'374 commercial vessels between 2012 and 2013 (Halpern et al., 2015). This only amounts to around 11% of total ships at sea at the time (Halpern et al., 2015). After some calculations, we can approximate that around 27'000 boats frequented some of the locations with the highest density over the span of a year, such as the New York port for example.

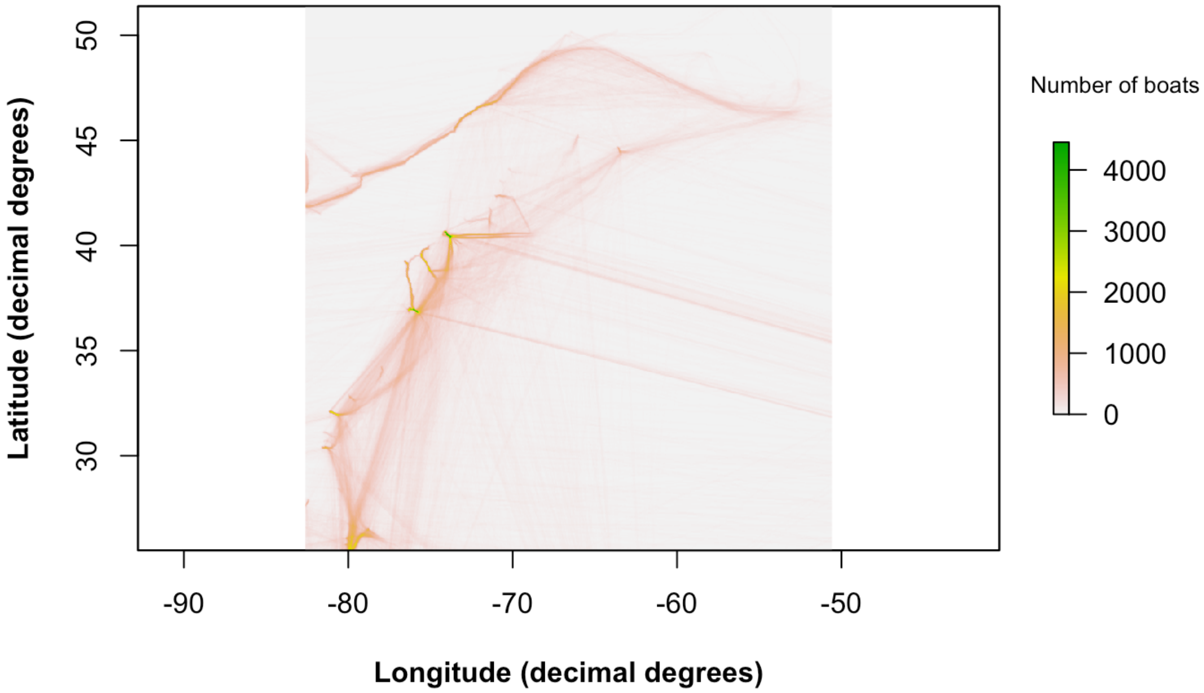


Figure 1: Plot of ship traffic data from 2013 illustrating commercial shipping routes in the western North Atlantic Ocean.

Figure 2 is a copy of Figure 1, except occurrence data of *E. glacialis* was layered on top of the ship traffic data, in the western North Atlantic Ocean as well. We can observe closely related patterns in the figure. The distribution of North Atlantic right whales coincides with the main vessel routes and major ports along the easten coasts of the United States and Canada. It is especially obvious when looking back and forth between Figures 1 and 2. Most areas with high density ship traffic concur with *E. glacialis* presence.

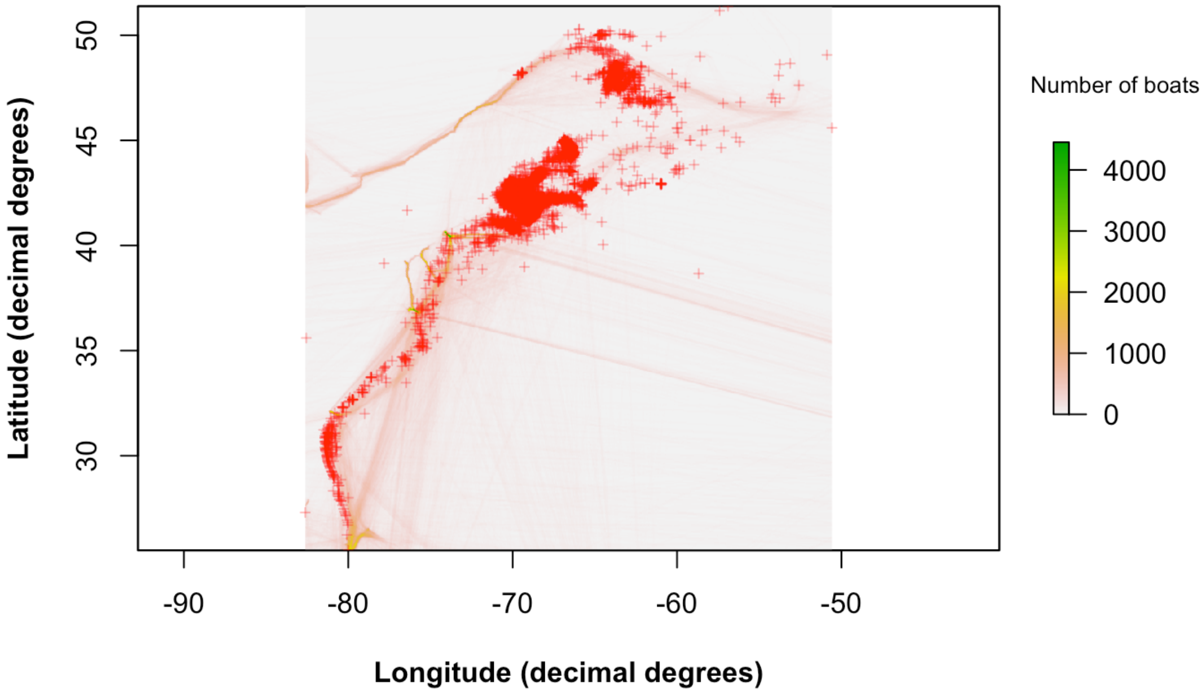


Figure 2: Plot of *Eubalaena glacialis* occurrence data layered on top of plotted ship traffic data (from 2013) in the western North Atlantic Ocean.

The proximity between both distributions entails that *E. glacialis* must share its habitat with the ships. The species has a habit of staying in shallow waters to avoid predation, which further brings the whales in proximity with ports as well as departing and arriving vessels (Fortune et al., 2013). In addition to coexisting within the same environment, the species seems to be mostly unresponsive to boats (Nowacek et al., 2004). According to a 2004 study from Nowacek et al., when North Atlantic right whales were exposed to sounds of approaching, or already present vessels, the whales showed no response. When exposed to alert signals, the whales did react, but responded by actively swimming to the surface (Nowacek et al., 2004). Both of these findings suggest that the behavior of *E. glacialis* may further expose them to collisions with vessels (Nowacek et al., 2004). A possible reason as to why the whales are unresponsive is the relative novelty of vessel traffic of this magnitude (Fisheries and Oceans Canada, 2014). With such an extensive lifespan, *E. glacialis* has not had the opportunity to adapt to the danger (Fisheries and Oceans Canada, 2014). Loud sounds may also mask whale vocalization such as mating calls, and possibly impair mating opportunities (Fisheries and Oceans Canada, 2014). It was mentioned earlier that North Atlantic right whales can live up to 70 years old (Fisheries and Oceans Canada, 2014). However, in the past few decades, the whales have had an average lifespan of 45 years (Fisheries and Oceans Canada, 2014). In addition to deaths resulting from vessel strikes being the leading cause of reduced lifespan, an important number of whales survive a strike but are left severely injured (Fisheries and Oceans Canada, 2014). Morbidity, describing the state of suffering from illness or medical condition, is often not considered in death rates caused by boat strikes (Fisheries and Oceans Canada, 2014). As of 2014, around 7% of *E. glacialis* populations were recorded to have "major wounds on the back or tail peduncle caused by propellers" (Fisheries and Oceans Canada, 2014). Because some carcasses are in poor condition, the real cause of death is not always determined, and carcasses may not be found at all (Fisheries and Oceans Canada, 2014). The true number of deaths resulting from strikes is therefore unknown, and most likely underestimated (Fisheries and Oceans Canada, 2014). Another concerning factor in the species' status is the low genetic diversity among *E. glacialis* populations. According to Fisheries and Oceans Canada (2014), various genetic analyses of North Atlantic right whales showed some of the lowest genetic diversity among large mammals, which may impair the species' reproductive rates. Mates with similar genetic backgrounds have a higher chance of fetal loss and lower reproductive rates (Fisheries and Oceans Canada, 2014). Additionally, female right whales have a higher mortality rate than males, "approximately 7% between 2010 and 2015, compared to about 4 % for males over the same period" according to Christiansen et al. (2020), causing further decline in calving rates and total population trends. Although these trends are still subject to research, the important overlap between the distribution of *E. glacialis* and commercial vessel activity, combined with the behavioral patterns exhibited by the species, is one of— if not the main—reason as to why its population is unable to recover (Fisheries and Oceans Canada, 2014).

The proximity between both distributions entails that *E. glacialis* must share its habitat with the ships, around 27'000 ships in some areas as calculated previously; and commercial shipping by boat will not decline anytime soon, in fact, it will only increase in the future. Regulations that aim to minimize threats are therefore necessary for cooperation and coordination in the recovery of *E. glacialis*. According to Fisheries and Oceans Canada (2014), relocation of the whales is not a viable option, and would most likely result in higher mortality rates and reduced reproductive rates. Although the species has a recovery action plan in place, and is included in international legislation and trade controls, only part of its range is protected (see Figure 5 in the Appendix) (Fisheries and Oceans Canada, 2014). Recent US and Canadian regulatory actions such as relocating shipping lanes and slowing down vessels have shown to successfully reduce ship strikes. In 2003, a shipping lane connecting the Bay of Fundy to the port of Saint John in New Brunswick was deviated to reduce the proximity between high densities of North Atlantic right whales and passing ships, resulting in less collisions (Fortune et al., 2013). According to Fortune et al. (2013), when ship speeds are above 28 km/h, lethality is close to 100% in case of strike. However, the lethality drops to less than 50% when ships travel under 22 km/h (Fortune et al., 2013). In 2008, the International Maritime Organization designated "Areas to Be Avoided" (ATBA) in the Roseway Basin, Nova Scotia (Fortune et al., 2013). The ATBA is a voluntary avoidance of the Roseway Basin, a critical habitat known to be used as feeding and socializing habitat by the whales (Fortune et al., 2013). With a high level of compliance, the ATBA can reduce the chances of vessel strikes by over 80% (Fortune et al., 2013).

Ideally, the next step would be to expand and enforce these strategies. While measures have been implemented in Canada and the United States to reduce these collisions, accidents are still occurring, and marine traffic is expected to increase significantly in the species' range over the next few decades (Fisheries and Oceans Canada, 2014). Additionally, identifying critical habitat of *E. glacialis* and adapting management strategies to individual populations is necessary to improve recovery plans.

We will now discuss some issues that arose in this study's methodology. When this project started, the results were planned to be analyzed statistically. I intended to quantify the overlapping between both distributions. But I quickly realized after doing some research that implementing a test of this type was out of my skill set. Most options I found produced coefficients of overlapping of two entities' densities but only for numerical data, not spatial. The "overlapEst()" function from the "overlap" package offers this for instance (Ridout et al. 2009). The "gIntersection()" function from the "rgeos" package is able to evaluate the intersection between two spatial objects but I still could not operate it in my situation, because my data was of invalid class (Bivand et al., 2021). In the future, I hope to learn how to quantify the overlapping of multiple distributions.

If you read the proposal for this report, you may remember mentions of plotting occurrence data using the Maxent model. You may also notice that Maxent is not included in my study. For context, Maxent is a program that uses presence-only data to predict how a species is distributed while considering environmental conditions (Harte, 2011). Maxent is based on the theory of maximum entropy, and was named after it (MAXimum ENTropy) (Harte, 2011). Entropy stands for randomness. Maximum entropy therefore stands for maximum randomness (Penfield, 2003). In the context of the Maxent model, the most suitable distribution is the most random one, that also meets the constraints of our existing knowledge (Harte, 2011). The goal being to remove any possible bias (Harte, 2011). In contrast to other models that use presence and absence data, the program uses presence-only data mainly because the data often lacks information on locations where a species was not observed (i.e., observers often report when evidence of a species is present but don't necessarily think of reporting absence of evidence) (Yackulic et al., 2013). The product is a prediction, or probability of how a species is distributed while being subject to environmental constraints (Harte, 2011). Throughout my internship, I learned how to use Maxent by following this tutorial (Feng et al., 2017) . Everything worked perfectly when identical environmental layers were used, as done in the tutorial. These environmental layers, sourced from Worldclim.org, were raster graphics of the world. The issue is that they only included land data, with no data on bodies of water. This was not an issue when predicting the distribution of land animals, until I tried to apply it to the North Atlantic right whale. Using a marine mammal as my species of choice was important to me to reflect the nature of my internship and the knowledge I gained on the North Atlantic right whale during the summer. R, understandably, could not process the distribution of a marine animal with no data on its environment, the ocean. I tried to solve this issue for weeks. I attempted to invert the environmental data and tried to add ocean data to the existing file among other things. I eventually realized I needed a new source of environmental data, which I found from the General Bathymetric Chart of the Oceans database. Using this new environmental data, a raster of the North Atlantic Ocean, I was never able to implement Maxent. Without the guidance of a tutorial, my abilities were limited, and I decided not to use Maxent to predict distributions in my project, but rather simply plot occurrence data.

An issue I kept running into as I was working on this project was my lack of support when attempting advanced programs and simulations. While I was doing my internship and developing projects, I could knock on my supervisor's door for help when exhausting all options. When I left Miami, I started working on this final report and understood how the initial tutorial I was following didn't pertain to what I was trying to do. After emailing my supervisor for help, she gave me some advice at first, but was hard to get ahold of after that. Of course, she had every right to, my internship had ended, and she was not obligated to offer her help. This however left me to build this study entirely by myself and rely on question-and-answer networks like Stack Exchange and Stack Overflow for specific questions I had related to R. Unfortunately, I was not able to solve every issue I had, but I truly enjoyed the process. I hope to develop similar but more in-depth projects in the future. In fact, learning how to program in R and creating species distribution models was so rewarding, I am looking forward to taking the GIS[7] for Natural Resource Management class this Fall and am actively researching career options that would include it.

4. Conclusion

With less than 350 live individuals globally and a continuously declining population, *Eubalaena glacialis* is severely at risk (Cooke, 2020). The IUCN Red List has assessed the species as critically endangered as of 2020, with its leading causes of mortality being humans, through boat strikes and bycatch. The distribution of North Atlantic right whales heavily coincides with the main vessel routes and major ports along the easten coasts of the United States and Canada (Fisheries and Oceans Canada, 2014). During this study, we were able to illustrate this spatial overlap using R, producing a final plot with both, occurrence data of *E. glacialis* and shipping traffic data layered on top of each other. The plot showcases the proximity between both distributions, which entails that *E. glacialis* must share its habitat with the ships. The North Atlantic right whale also exhibits behavior that further exposes it to strikes, such as having little to no reactivity to passing boats, spending a lot of time on the surface, and traveling at very slow speeds (Ward-Geiger et al., 2005). Protecting critical *E. glacialis* habitat, relocating shipping lanes, reducing vessel speeds, and implementing "Areas to Be Avoided" are among management strategies that have shown to successfully decrease ship strikes

[7] Geographical Information System

(Fisheries and Oceans Canada, 2014). However, while measures have been implemented in Canada and the United States to reduce these collisions, these regulations are either voluntary, or not extensive enough, and accidents are still occurring (Fortune et al., 2013). As marine traffic is expected to increase significantly in the species' range over the next few decades, recovery strategies need to be expanded and enforced to reduce mortality rates (Fisheries and Oceans Canada, 2014). Additionally, identifying critical habitat of *E. glacialis* and adapting management strategies to individual populations is necessary to improve recovery plans (Fisheries and Oceans Canada, 2014). Failure to act will likely cause further decline of the species' population and increase its vulnerability to extinction (Fisheries and Oceans Canada, 2014).

5. References

Bivand, R. & Rundel, C. 2021. Geometry Intersections. Available at https://rgeos.r-forge.r-project.org/reference/topo-bin-gIntersection.html. (accessed 2 September 2022). Geometry Engine - Open Source.

British Oceanographic Data Centre. 2022. Gridded Bathymetry Data Download. Available at https://download.gebco.net. (accessed 2 September 2022). General Bathymetric Chart of the Oceans.

Christiansen, F., Dawson, S. M., Durban, J. W., Fearnbach, H., Miller, C. A., Bejder, L., et al. 2020. Population comparison of right whale body condition reveals poor state of the North Atlantic right whale. Marine Ecology Progress Series, 640, 1-16. https://www.int-res.com/abstracts/meps/v640/p1-16/.

Cooke, J. G. 2020. Eubalaena glacialis. Available at https://dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T41712A178589687.en. (accessed 2 September 2022). The IUCN Red List of Threatened Species.

Egret, D. 2022. Comparing Spatial Distributions of the North Atlantic Right Whale and Commercial Shipping Lanes. Available at https://github.com/dianeegret/distribution-models/blob/main/Eubalaena_glacialis_ship_distribution_model.md. (accessed 2 September 2022). GitHub. Montreal, CA.

Feng, X., Walker, C., & Gebresenbet, F. 2017. A brief tutorial on running Maxent in R. Available at https://github.com/shandongfx/workshop_maxent_R/blob/master/code/Appendix1_case_study.md (accessed 2 September 2022). GitHub. University of Arizona, AZ.

Fisheries and Oceans Canada. 2014. Recovery Strategy for the North Atlantic Right Whale (*Eubalaena glacialis*) in Atlantic Canadian Waters. Species at Risk Act Recovery Strategy Series.

Fisheries and Oceans Canada, Ottawa. https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/recovery-strategies/north-atlantic-right-whale.html.

Fortune, S. M. E., Trites, A. W. 2013. North Atlantic right whale (*Eubalaena glacialis*): COSEWIC assessment and status report 2013. Committee on the Status of Endangered Wildlife in Canada, Government of Canada. https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/cosewic-assessments-status-reports/north-atlantic-right-whale-2013.html#cn-tphp.

Global Biodiversity Information Facility. 2022. GBIF Occurrence Download. Available at https://doi.org/10.15468/dl.d76ekt https://www.gbif.org/occurrence/download/0333030-210914110416597. (accessed 2 September 2022). GBIF.org. Copenhagen, DK.

Halpern, B., Frazier, M., Potapenko, J., Casey, K., Koenig, K., et al. 2015. Cumulative human impacts: raw stressor data (2013). Available at doi:10.5063/F1S180FS. (accessed 2 September 2022). The Knowledge Network for Biocomplexity.

Harte, J. 2011. Maximum entropy and ecology: a theory of abundance, distribution, and energetics. OUP Oxford. DOI:10.1093/acprof:oso/9780199593415.001.0001.

Nowacek, D. P., Johnson, M. P., & Tyack, P. L. 2004. North Atlantic right whales (Eubalaena glacialis) ignore ships but respond to alerting stimuli. Proceedings of the Royal Society of London. Series B: Biological Sciences, 271(1536), 227-231. https://royalsocietypublishing.org/doi/abs/10.1098/rspb.2003.2570?casa_token=mzA7obY3G50AAAAA:rWmIw2SIoHvIhafng7uzQ2EXV-2Xp6mMiQ2Hk0Ju9n3snOoLscZqaM4-fZH_4qpGyHCkLuYVLtpABxM.

Penfield Jr, P. 2003. Principle of maximum entropy: Simple Form. Massachusetts: Massachusetts Institute of Technology. https://mtlsites.mit.edu/Courses/6.050/2003/notes/chapter9.pdf.

R Core Team. 2022. Available CRAN packages by name. Available at https://cran.r-project.org/web/packages/available_packages_by_name.html. (accessed 2 September 2022). R Foundation for Statistical Computing. Vienna, AT.

Ridout, M. S., & Linkie, M. 2009. Estimating overlap of daily activity patterns from camera trap data. Journal of Agricultural, Biological, and Environmental Statistics, 14(3), 322-337. https://link.springer.com/article/10.1198/jabes.2009.08038.

Ward-Geiger, L. I., Silber, G. K., Baumstark, R. D., & Pulfer, T. L. 2005. Characterization of ship traffic in right whale critical habitat. Coastal Management, 33(3), 263-278. https://doi.org/10.1080/08920750590951965.

Wasser, L., Jones, M. A., Stachelek, J., Deer, L., Brym, L., et al. 2018. Data Carpentry Introduction to Geospatial Raster and Vector Data with R. Available at https://datacarpentry.org/r-raster-vector-geospatial/. (accessed 2 September 2022). Zenodo. Geneva. CH.

Yackulic, C. B., Chandler, R., Zipkin, E. F., Royle, J. A., Nichols, J. D., Campbell Grant, E. H., & Veran, S. 2013. Presence-only modeling using MAXENT: when can we trust the inferences?. Methods in Ecology and Evolution, 4(3), 236-243. https://besjournals.onlinelibrary.wiley.com/doi/10.1111/2041-210x.12004.

6. Appendix

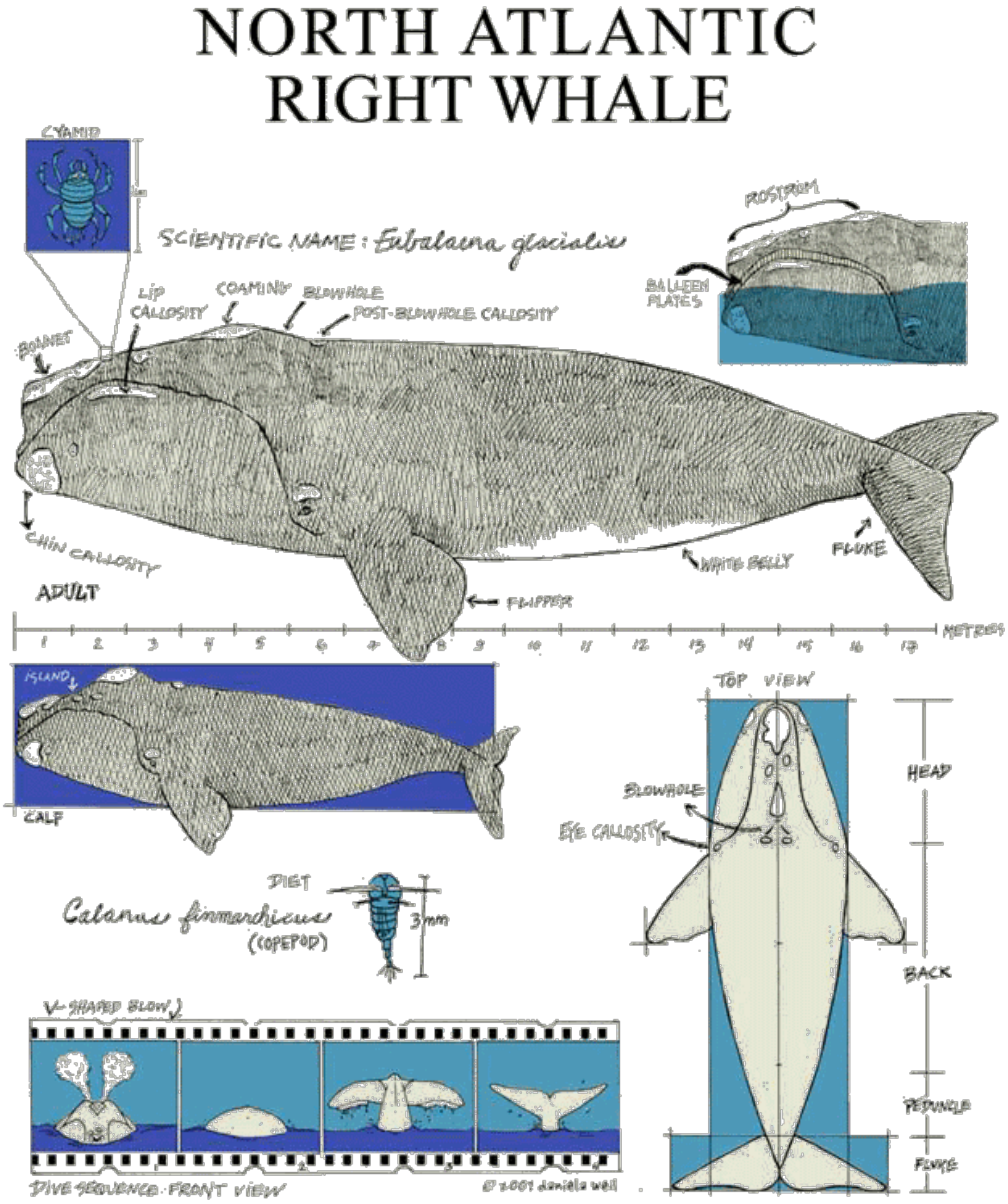


Figure 3: Schematic depiction of the North Atlantic right whale’s anatomy (adult and calf).

Credit: Fisheries and Oceans Canada.

Figure 4: Photography of a North Atlantic right whale. Cape Cod, Massachusetts.

Credit: Center for Coastal Studies/NOAA.

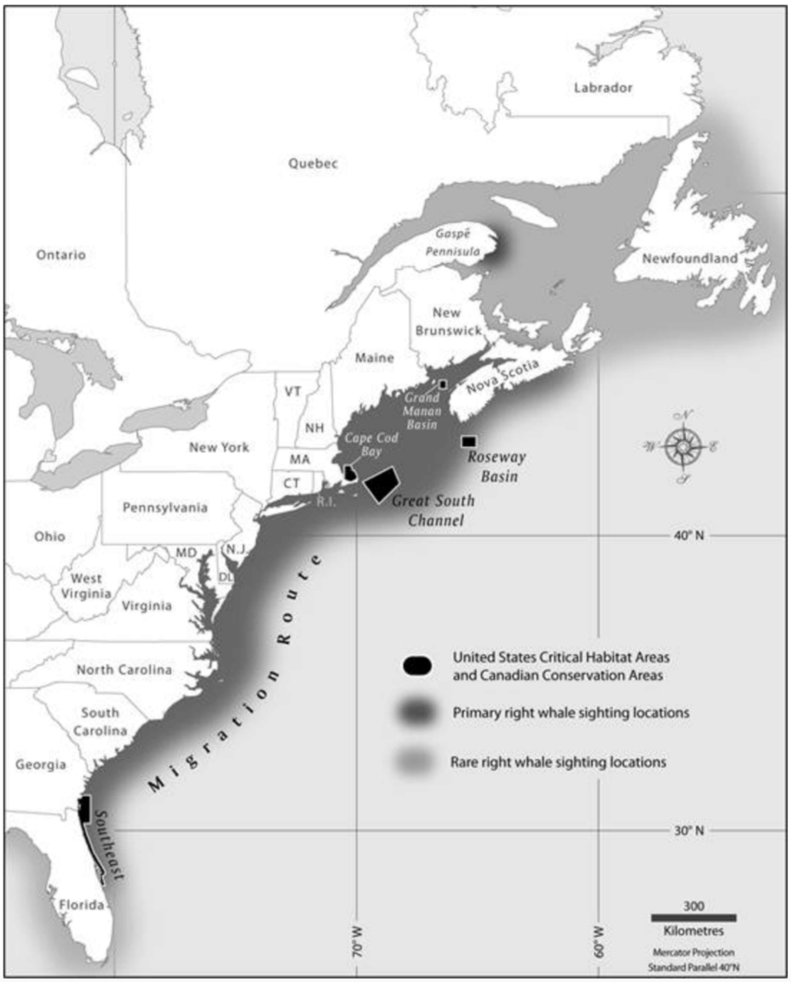


Figure 5: Map illustrating the distribution of *Eubalaena glacialis* in the eastern North Atlantic Ocean and locations within its distribution that are protected under the U.S. Endangered Species Act.

Credit: Fisheries and Oceans Canada.