Species Distribution Modeling Using Acoustic Tag Detections

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OCEAN TRACKING NETWORK

FACT Fish Move.

Disclaimer

Ecologist ⟷ Statistician

Photo credit: Jon Pye

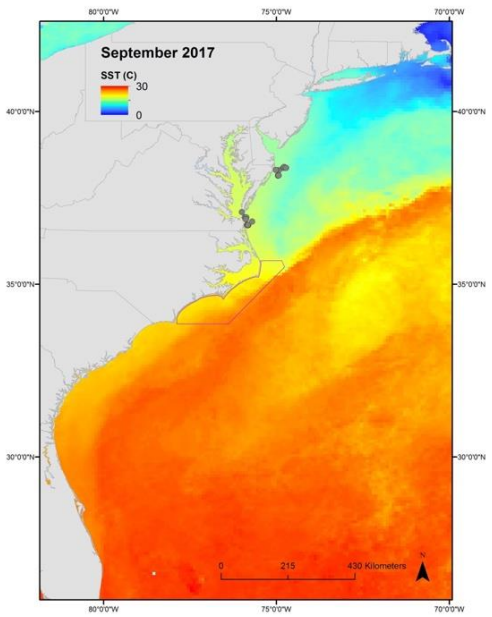
Overview

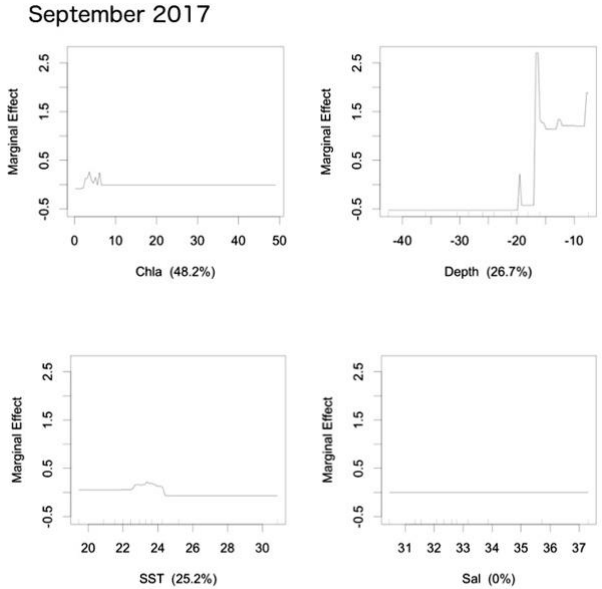
- Species distribution model basics
- Setting up acoustic telemetry data for SDMs
- Getting and using environmental data
- Case Study: Dusky sharks off the US Mid-Atlantic region
- Case Study: Setting up an SDM in Minas Passage

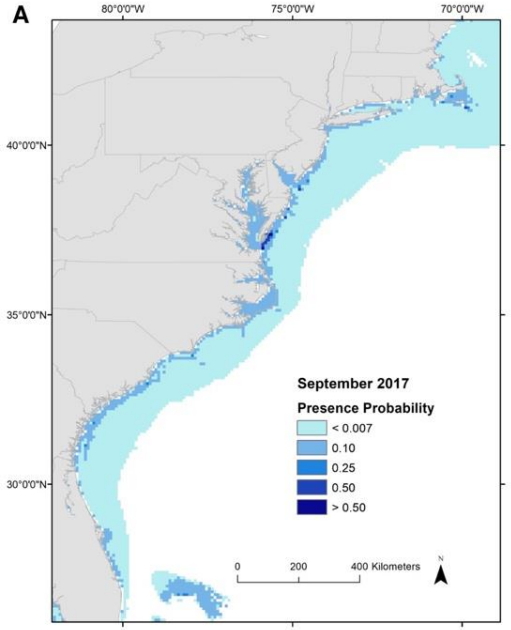
Species Distribution Model Basics

What is a species distribution model?

- Predictive model of the probability of a species being present
  - Based on relationships between species and environmental conditions
  - “Fish forecasting”





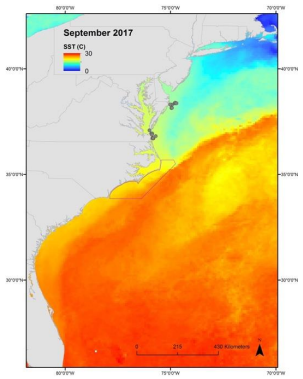


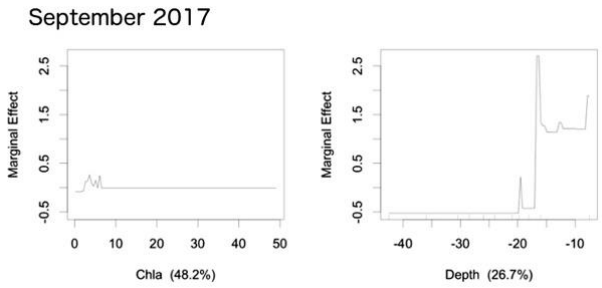
Species Distribution Model Basics

Usually proceeds in two main steps:

Step 1 – Model training

- Establish relationships between species presence/absence/abundance and environmental conditions
  - In what conditions is the species more or less likely to be there?
- Data required:
  - Records of species presence/absence/abundance
  - Environmental data that can be matched to species records





Species Distribution Model Basics

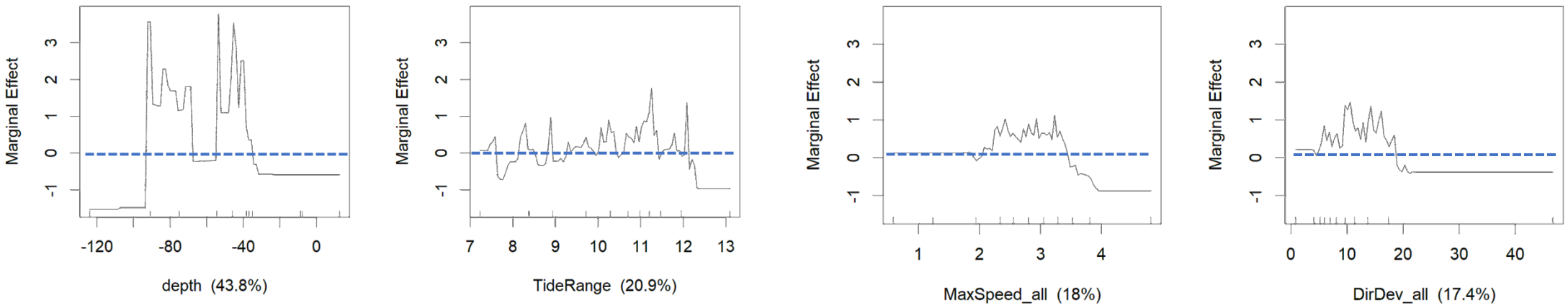
Step 1 – Model training

- This is where the majority of the stats happen
- A ***lot*** of options – choice depends on data quality and availability and research objectives
  - Linear methods – generalized liner models (including mixed)
    - Relatively simple and straightforward
  - Additive methods – generalized additive models (also including mixed)
    - Handles non-linear relationships
  - Machine-learning methods – boosted regression trees, random forest
    - Handles complex relationships and data distributions, but can be demanding of computer resources and tricky to set up and interpret

Species Distribution Model Basics

Step 1 – Model training

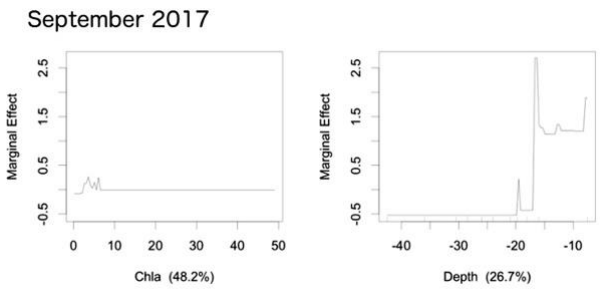
- Sometimes you can stop here
- Species/environmental relationships might be all you need

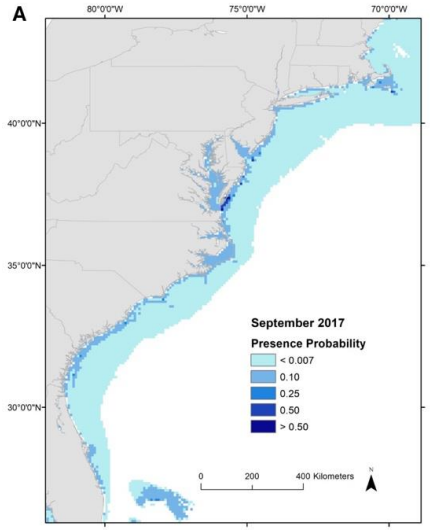


Species Distribution Model Basics

Step 2 – Prediction

- Now that you know the species/environment relationships, calculate presence probability given a set of environmental data
- Usually mapped grid of environmental variables covering area of interest
- Spatial scale and resolution are important considerations
    - Mostly determined by data availability and research objectives





Acoustic Telemetry Data Setup

What is your response variable?

- Binary presence absence (0, 1)
- Abundance (can include absence)
- Temporal resolution (presence/absence or # of animals per time period)
    - Important for matching environmental data, so think about it early

Acoustic Telemetry Data Setup

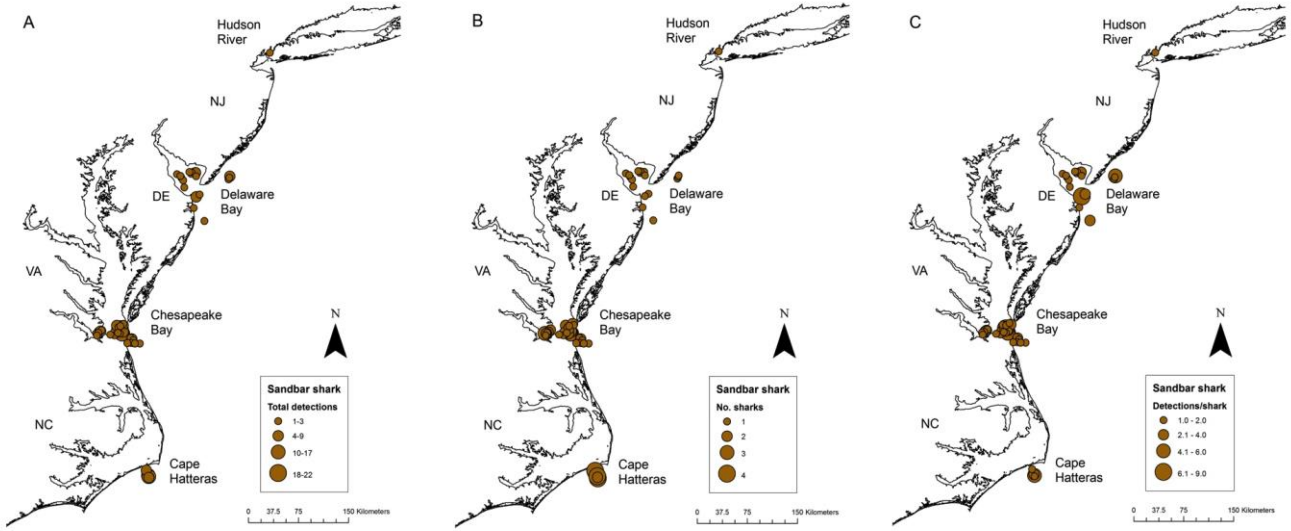
What is your response variable?

- Binary presence absence
  - An acoustic tag detection is an obvious presence record
  - Absence can be trickier
    - Assuming non-detection = absence may not be realistic
    - Detection range vs. environment – are you picking up 100 % of tagged animals?
    - Behavioral consistency – are the animals animals you tagged acting like the rest of the population usually does?
  - Can be accounted for in field study design

Acoustic Telemetry Data Setup

What is your response variable?

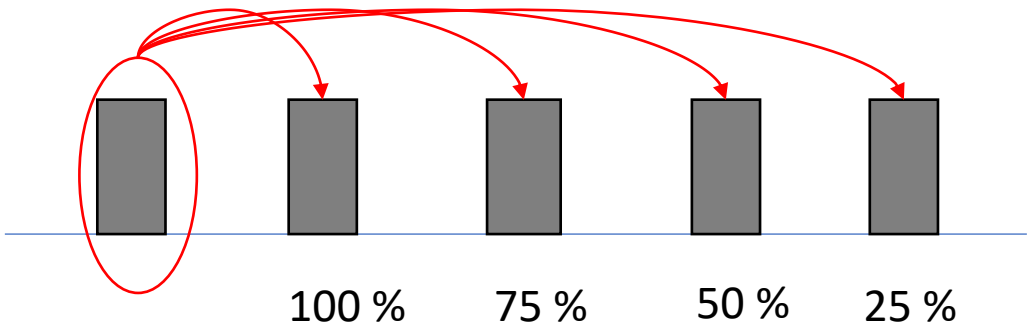
- Abundance and other metrics
  - Abundance
    - Number of individuals
    - Number of tag detections
  - Other metrics that could be treated as abundance
    - Detection events
    - Residence time

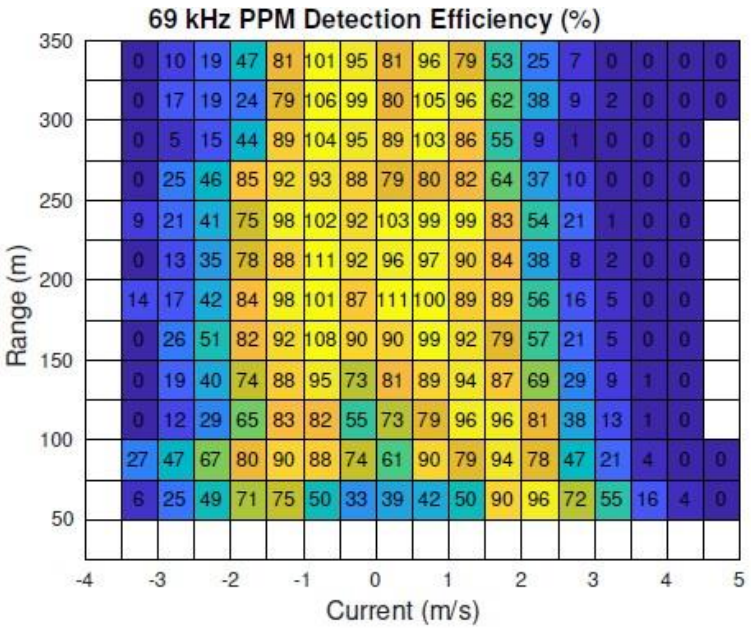


Acoustic Telemetry Data Setup

Addressing tag detection assumptions

- Range testing – DO IT
  - Account for as much environmental variability as possible
  - Use a variety of methods
    - Stationary tags and floating drifters
    - Stationary tags at varying distances
    - Receivers that can hear each other
  - Tag detection efficiency (actual detections/known tag transmissions) also tells you about the probability of a tagged fish passing by a receiver undetected (false absence)

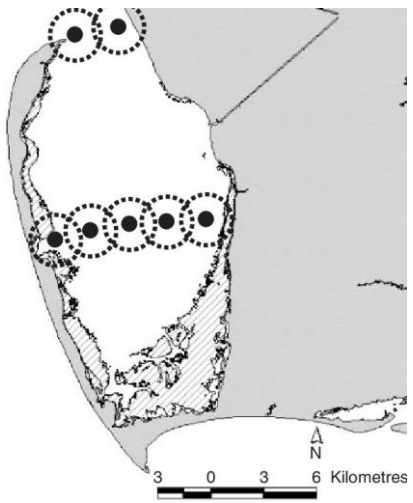


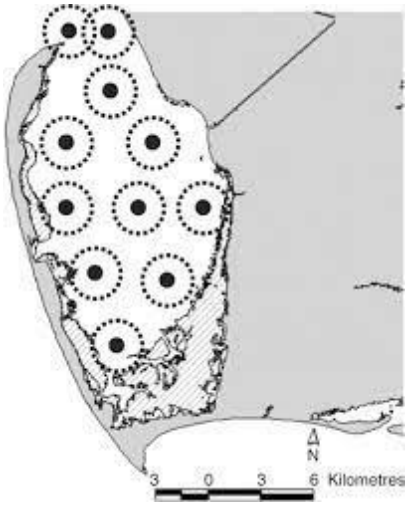


Acoustic Telemetry Data Setup

Addressing environmental assumptions

- Receiver deployment strategy
  - Don’t need to catch everything, just enough to get an idea of the species/environment relationships
  - Cover a wide variety of habitat types and environmental conditions
    - Including places/conditions you *don’t* expect the species to be
    - If you’re accounting for false absences, then zeroes are real (and important!) data





Heupel et al. (2006)

Acoustic Telemetry Data Setup

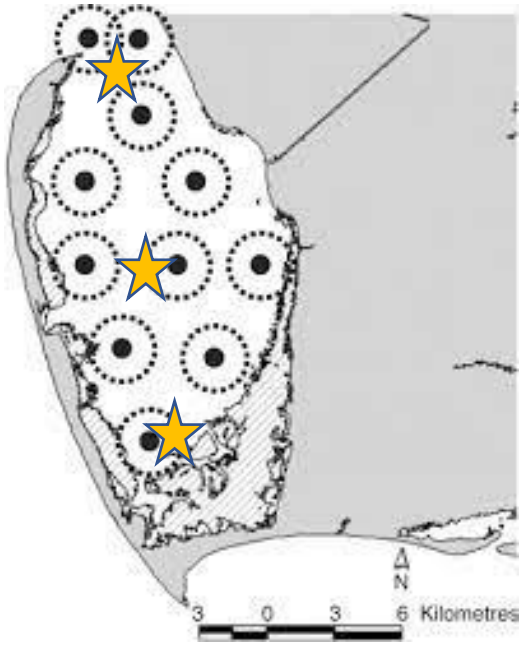
Addressing animal behavior assumptions

- Vary tagging times and locations
  - Avoids putting all tags out on the same subpopulation (unless that's your research goal)
- Follow-up tagging
  - Are more recently-tagged animals showing the same behavior and/or environmental associations as older ones?
- Hit the literature
  - Have behaviors and environmental associations been documented elsewhere?

Getting and Using Environmental Data

Matching environmental data to tag detections

- Crucial for model training
- Sensors carried by animals
- Sensors at receiver sites/in area of interest
    - Nice variety of sensors available, some built into receivers
    - Have an idea which environmental variables are of interest
    - Cover as much environmental variability as possible
        - Don’t need a sensor in every habitat area, but try to represent every habitat type

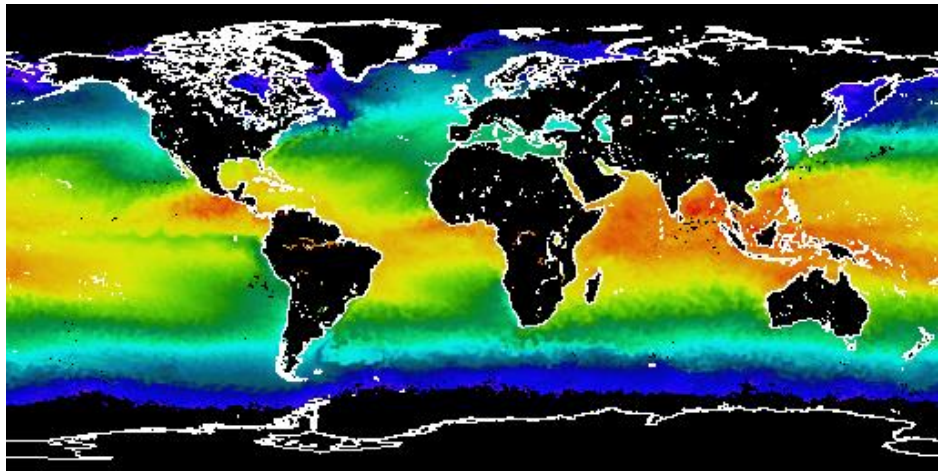


Heupel et al. (2006)

Getting and Using Environmental Data

Matching environmental data to tag detections

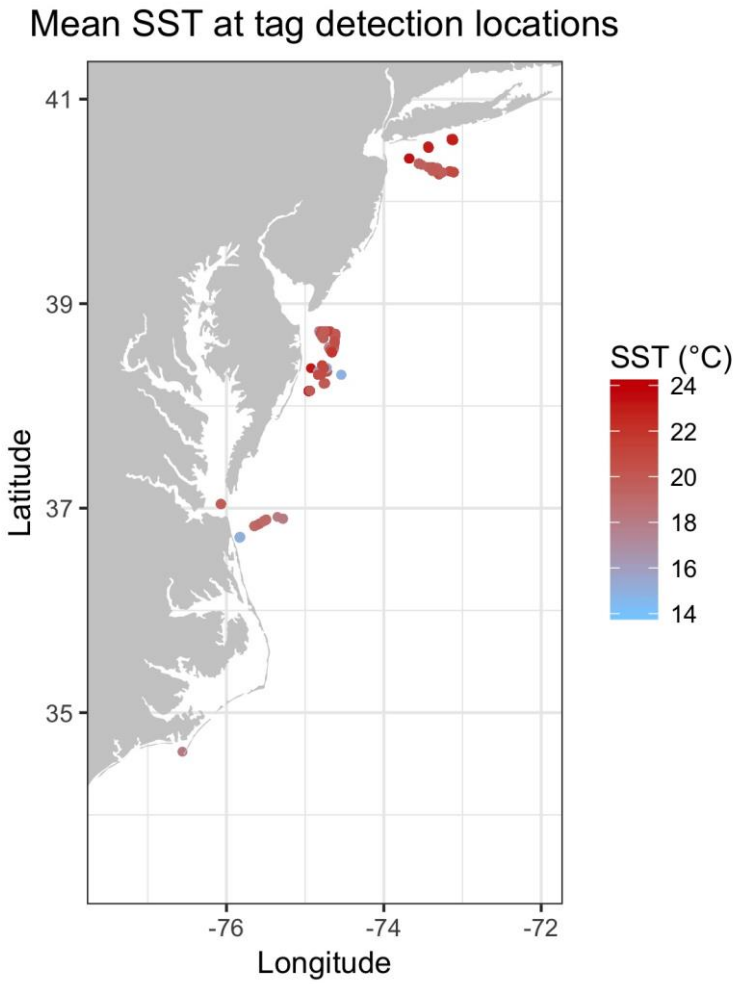
- Environmental data you didn’t collect
  - Variety of publicly-available point-collected, remotely-sensed/satellite, and modeled data
  - Consider spatial and temporal coverage and resolution, scale, proximity to receiver sites
    - Local coverage may vary even for large-scale satellite data



Getting and Using Environmental Data

Matching environmental data to tag detections

- Doing the matching
  - Remember when you thought about temporal resolution?
  - Presence/absence (and abundance if zeroes are included):
    - Time intervals – determined by data availability and research goals
      - Hourly – presence/absence or # animals per hour
    - Make sure to only include times the receiver was actually in the water!



Getting and Using Environmental Data

Matching environmental data to tag detections

- Doing the matching
  - Matching your own environmental data based on date, time, location
    - Pay attention to time zones
  - Example R code:

```
FishEnvCombo <- merge(TagDetections,
                      EnvData[,c("temp", "chla", "depth", "datetime", "station)],
                      by = c("datetime", "station"))
```

Getting and Using Environmental Data

Matching environmental data to tag detections

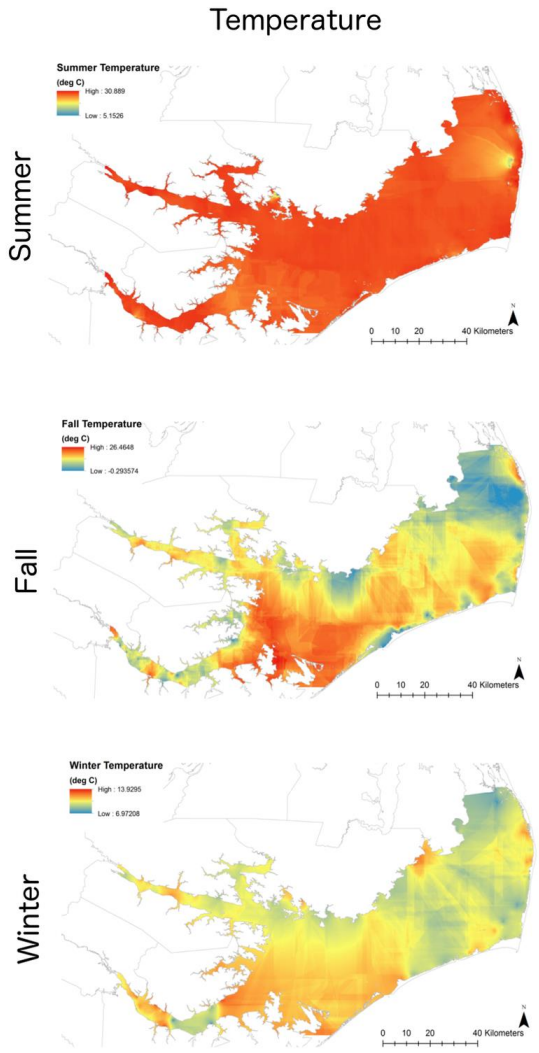
- Doing the matching
  - Matching someone else's environmental data
  - R package rerddapXtracto – pulls data from public ERDDAP servers based on lat/lon location, date
  - Most satellite data are only available on a daily basis
  - Example R code (thanks Beth Bowers!):

```
TagData<-yourfish
xpos<-TagData$x #longitude
ypos<-TagData$y #latitude
tpos<-TagData$date #detection or receiver dates
zpos <- rep(0., length(xpos)) #if elevation or other data are relevant, put here instead

urlBase <- "https://upwell.pfeg.noaa.gov/erddap/"
sstInfo <- rerddap::info('erdMBsstd3day', url = urlBase)
YourDataEnv <- rxtracto(sstInfo, parameter = 'sst', xcoord=xpos, ycoord=ypos, tcoord=tpos, zcoord=zpos, xlen=0.05, ylen=0.05)

yourfish$meanerdMBsstd3day=YourDataEnv$mean
```

Getting and Using Environmental Data

Environmental data to predict against

- Site-based predictions
  - Data covering a certain time period at a specific location
- Spatial mapping
  - Data covering time period and spatial extent of interest
  - Multiple maps may be necessary – one for each month, season, etc.

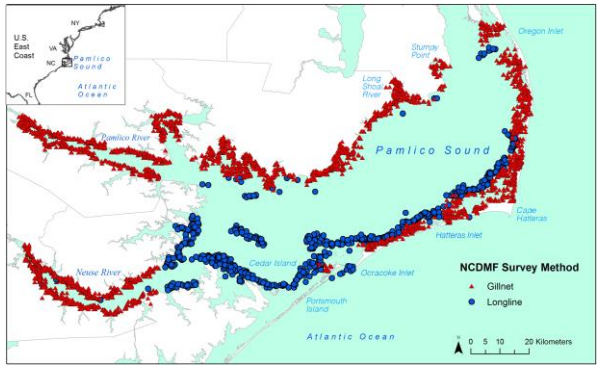


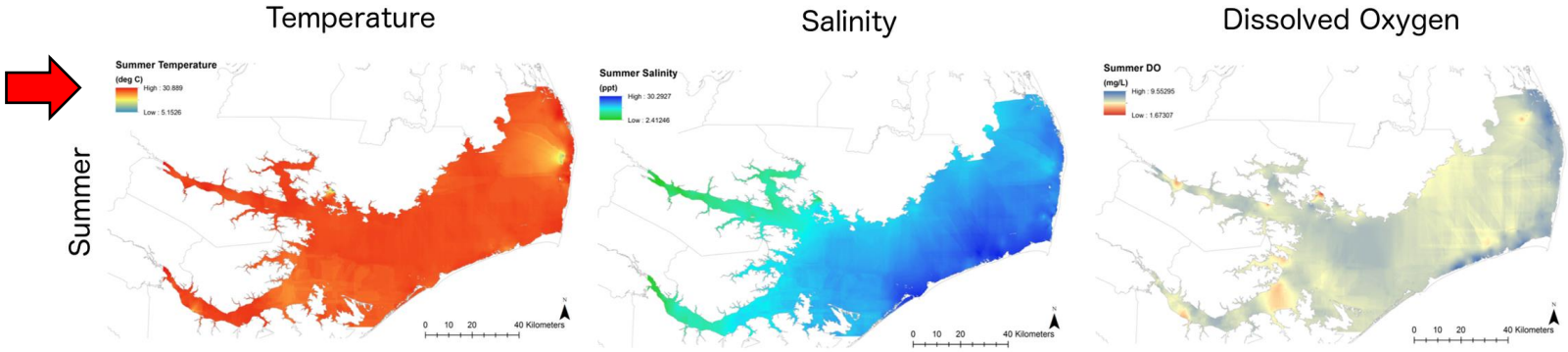
Bangley et al. (2018)

Getting and Using Environmental Data

Environmental data to predict against

- Spatial mapping
  - Your own data – interpolate across area of interest
    - Works best if your data cover as much of the area of interest as possible
    - Can be finer-scale than satellite data – good for small, local areas
    - Variety of methods available in R, ArcGIS, QGIS…
      - Consult you friendly local spatial statistician!



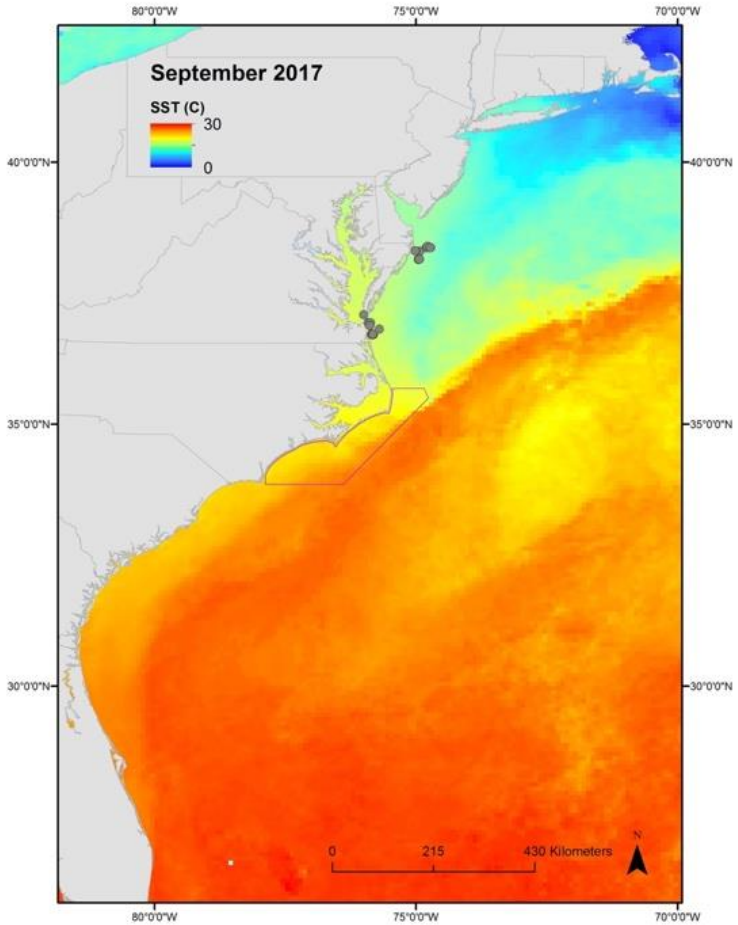


Bangley et al. (2018)

Getting and Using Environmental Data

Environmental data to predict against

- Spatial mapping
  - Remotely-sensed data
    - Usually already mapped – just download maps covering your area and time period of interest
      - Ocean Color website: https://oceancolor.gsfc.nasa.gov/
      - Can also be extracted at regularly-spaced points if you want a resolution different than standard downloads



Case Study: Northwest Atlantic Dusky Sharks

Bangley, C. W., T. H. Curtis, D. H. Secor, R. J. Latour, and M. B. Ogburn. 2020. Identifying important juvenile dusky shark habitat in the Northwest Atlantic Ocean using acoustic telemetry and spatial modeling. Marine and Coastal Fisheries 12: 348-363

Danielle Hall

Smithsonian Environmental Research Center

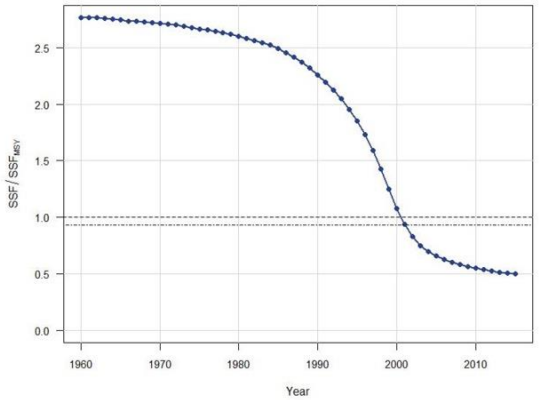
Case Study: Northwest Atlantic Dusky Sharks

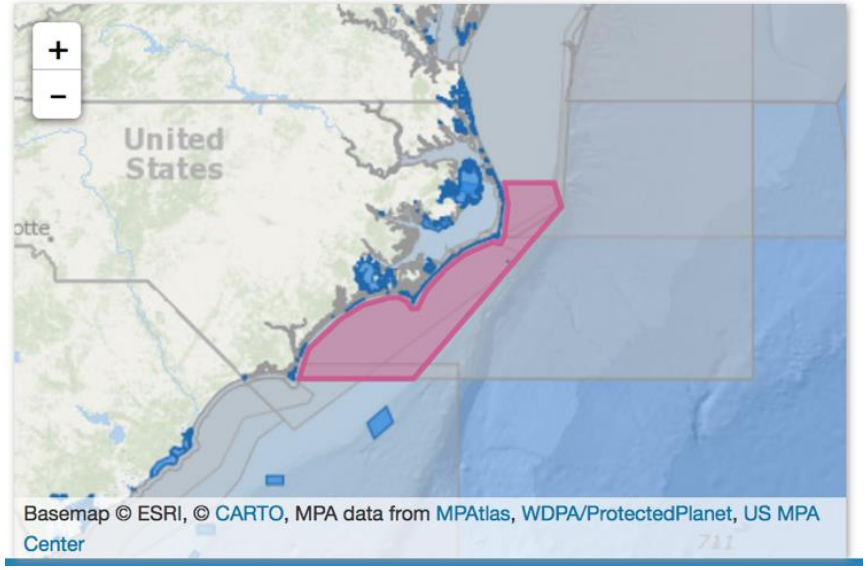
Dusky Shark (*Carcharhinus obscurus*)

VULNERABLE VU — Worldwide

ENDANGERED EN — Northwest Atlantic

NMFS – overfished with overfishing occurring (SEDAR 2016)





Case Study: Northwest Atlantic Dusky Sharks

Objectives

Develop spatial models of Dusky Shark presence probability based on telemetry detections and environmental data.

Account for seasonal/migratory changes in distribution.

Use spatial models to predict distribution during periods of low/no tag detection.

Case Study: Northwest Atlantic Dusky Sharks

Danielle Hall

Methods - Telemetry

23 Dusky Sharks

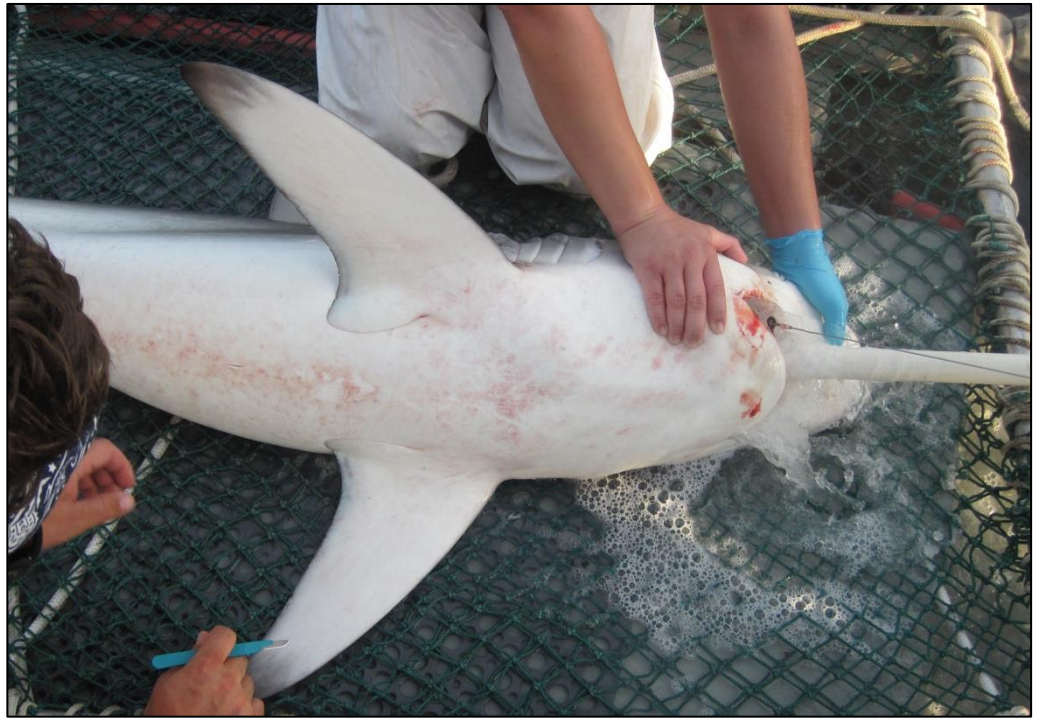
- 5 by VIMS off VA – Sept 2016, Aug 2017
- 3 by Tobey Curtis/OCEARCH off NY Bight – Sept 2016
- 15 off Ocean City, MD – Sept 2017
- 1067-2200 mm total length

The Atlantic Cooperative Telemetry Network

FACT Fish Move.

Case Study: Northwest Atlantic Dusky Sharks

Methods - Mapping, Modeling, and Mapping



VIMS

Daily environmental data extracted at receiver locations from ERDDAP products:
Depth (m) – ETOPO1
SST (°C) – MODIS Aqua
Chl a (mg/m^3) – MODIS Aqua
Sal (psu) - SMAP

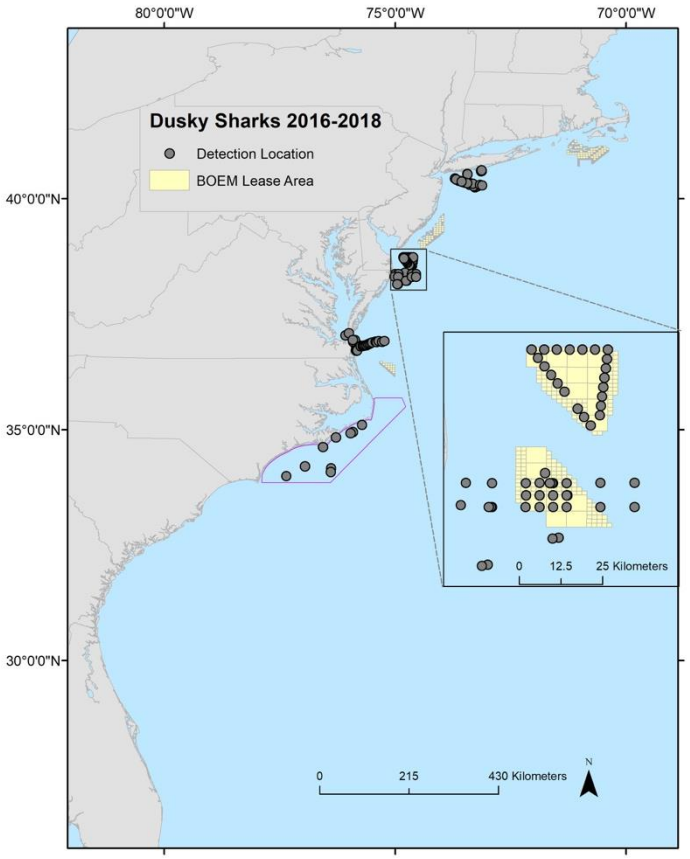
Daily presence/absence of tagged dusky sharks at each receiver – matches environmental data temporal resolution

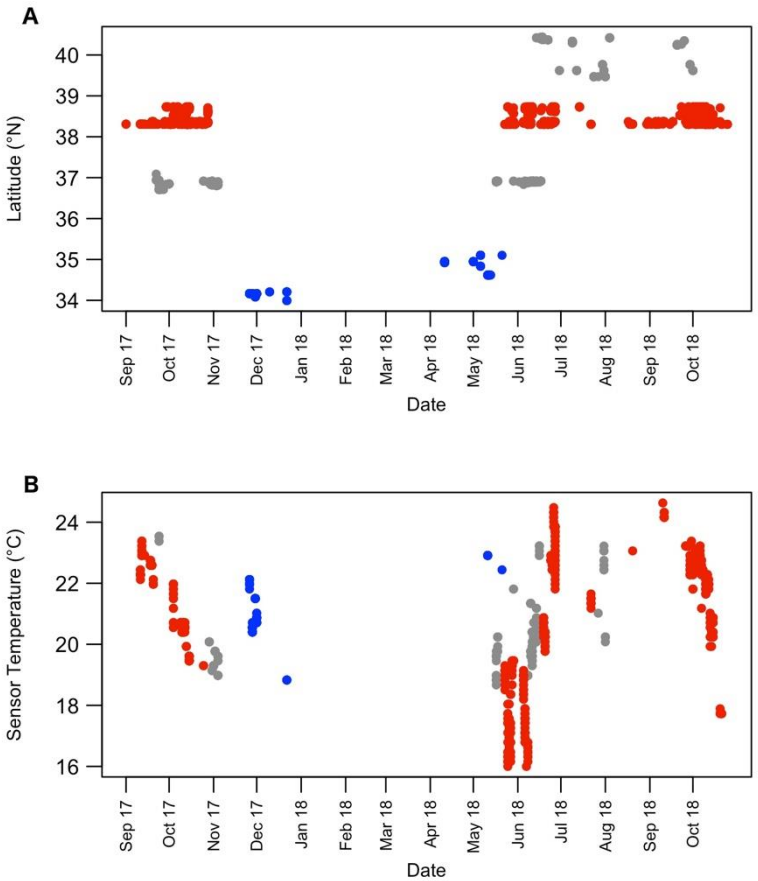
Seasonal and monthly (fall 2017) models

R Packages:
rerddapXtracto – data extraction
gbm.auto – BRT modeling

Case Study: Northwest Atlantic Dusky Sharks

Results – Tag Detections



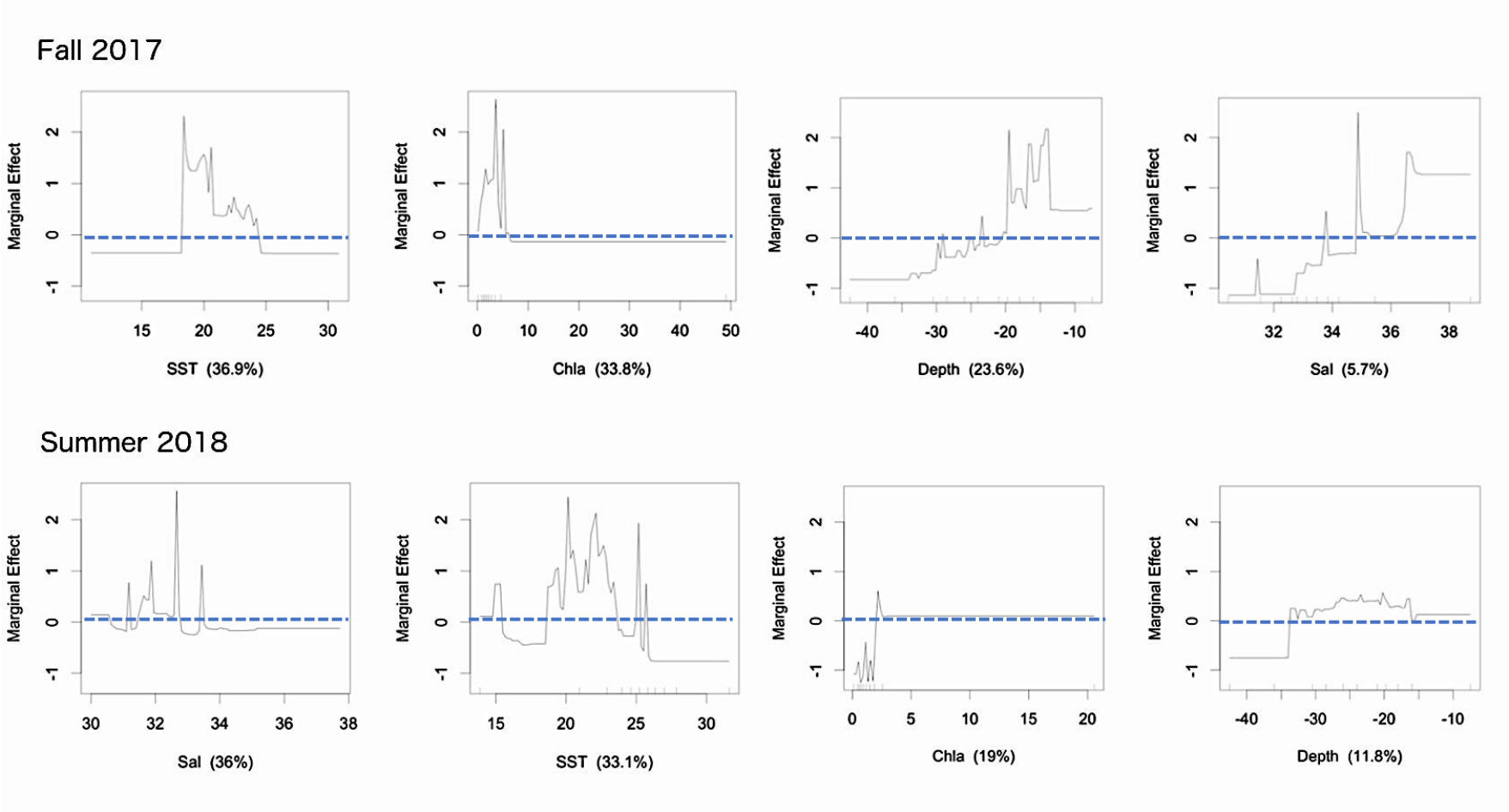


Within BOEM Lease Areas

Within Shark Closure

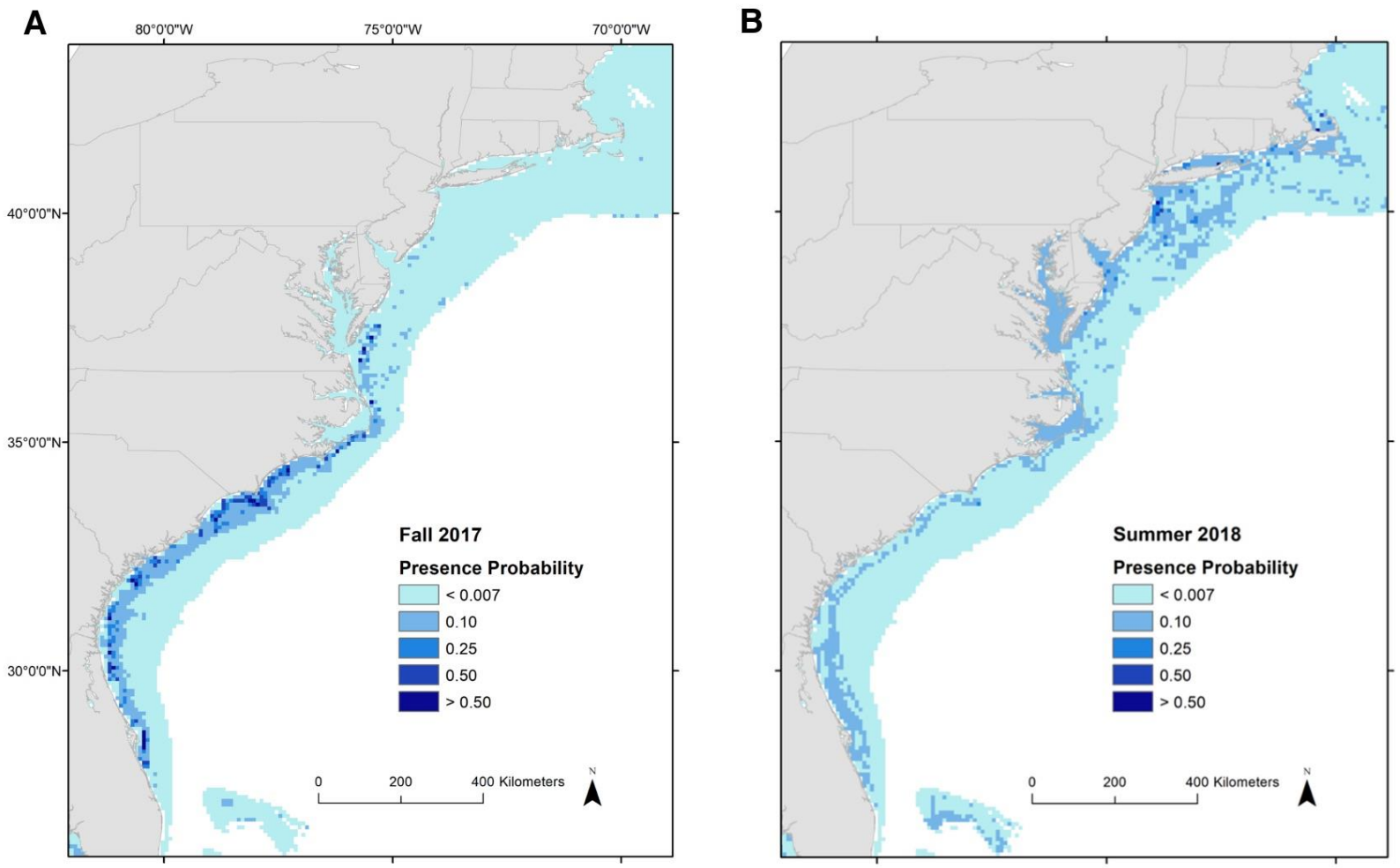
Case Study: Northwest Atlantic Dusky Sharks

Marginal effect plots – seasonal models



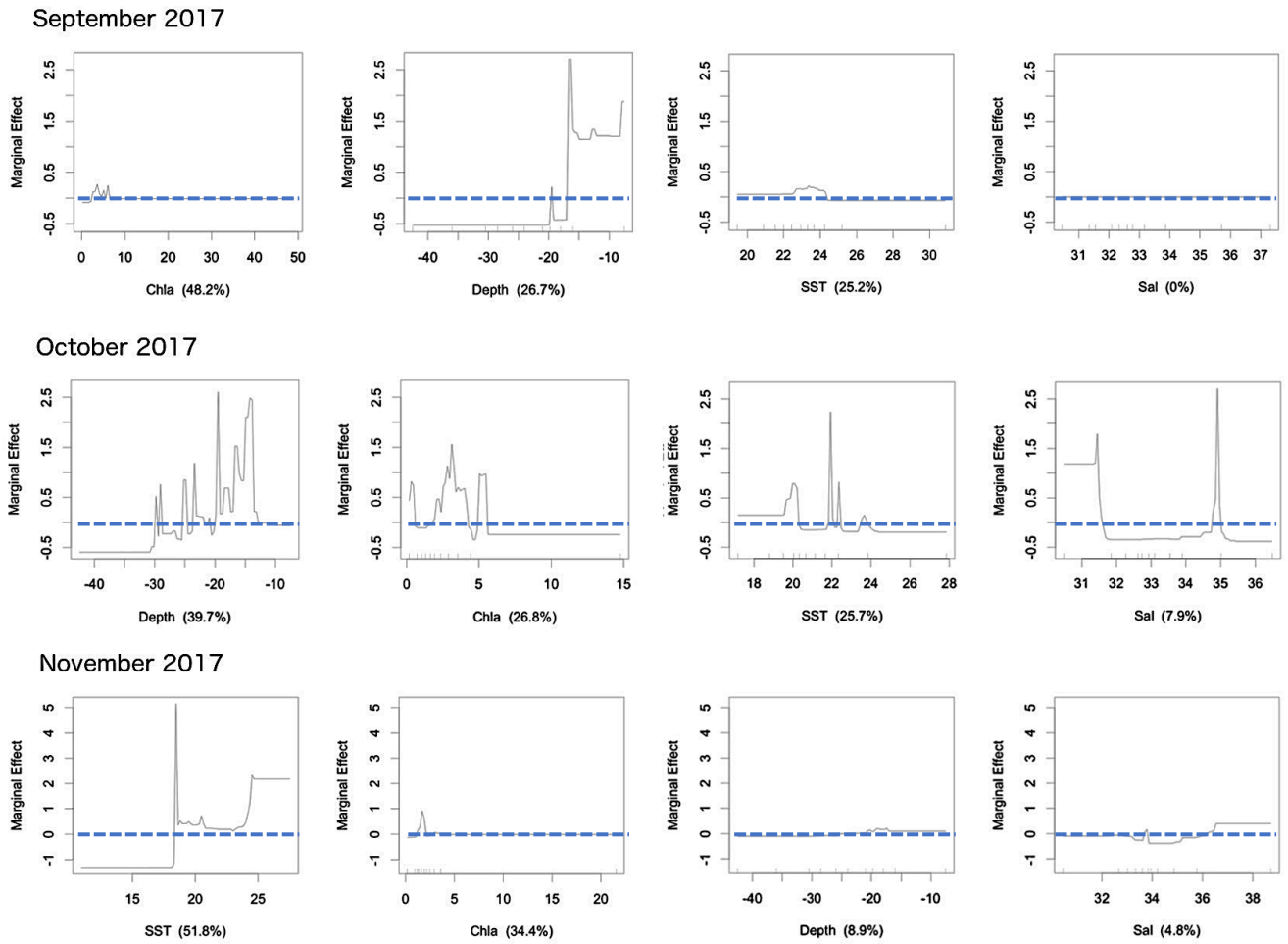
Case Study: Northwest Atlantic Dusky Sharks

Mapped model results – seasonal models



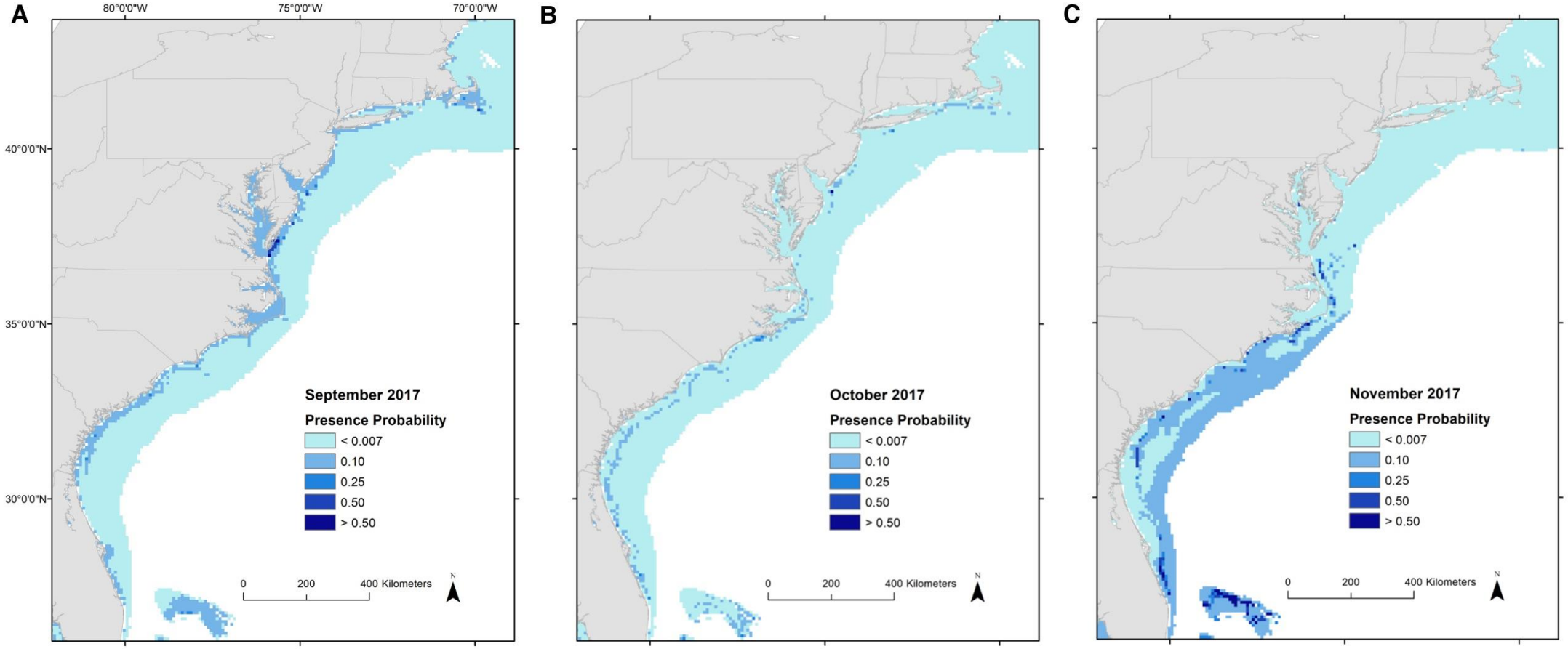
Case Study: Northwest Atlantic Dusky Sharks

Marginal effect plots – monthly models



Case Study: Northwest Atlantic Dusky Sharks

Mapped model results – monthly models



Case Study: Setting up an SDM in Minas Passage

Bangley, C. W., D. Hasselman, J. Mills Flemming, F. Whoriskey, J. Culina, L. Enders, and R. Bradford. Accepted. Modeling the Probability of Overlap Between Marine Fish Distributions and Marine Renewable Energy Infrastructure Using Acoustic Telemetry Data. Frontiers in Marine Science

force | Fundy Ocean Research Centre for Energy

Case Study: Setting up an SDM in Minas Passage

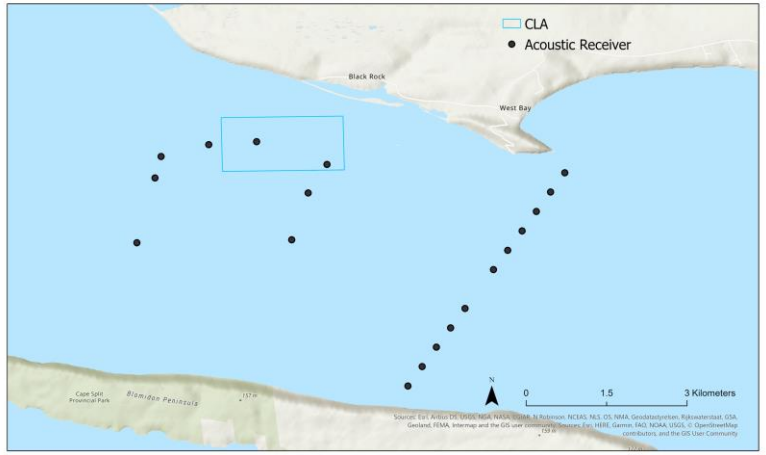
Minas Passage, Nova Scotia

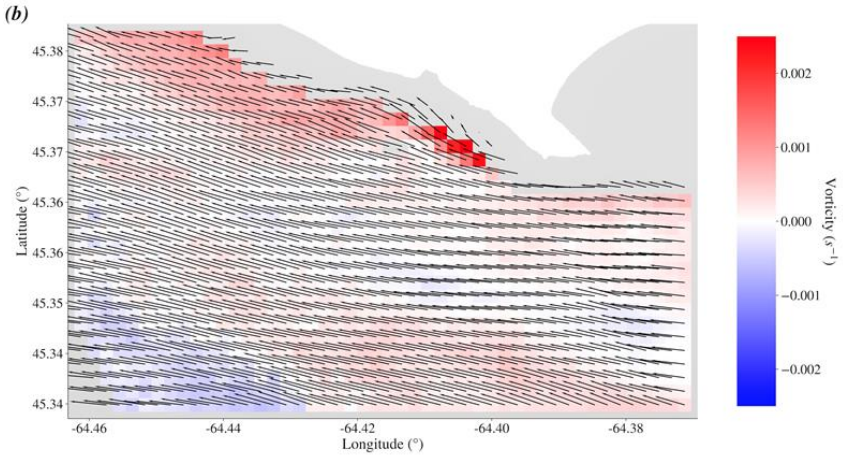
- Up to 15-m tide range, current speeds up to 5 m/s
- Site of active tidal power feasibility studies

Case Study: Setting up an SDM in Minas Passage

Model setup

- Acoustic tag detections – species presence/absence
  - 1-hour temporal resolution
- Environmental data – derived from FORCE radar and hydrodynamic model
  - 150 x 150-m spatial resolution
- Modeling by tide stage (slack high/low, early/mid/late flood and ebb)

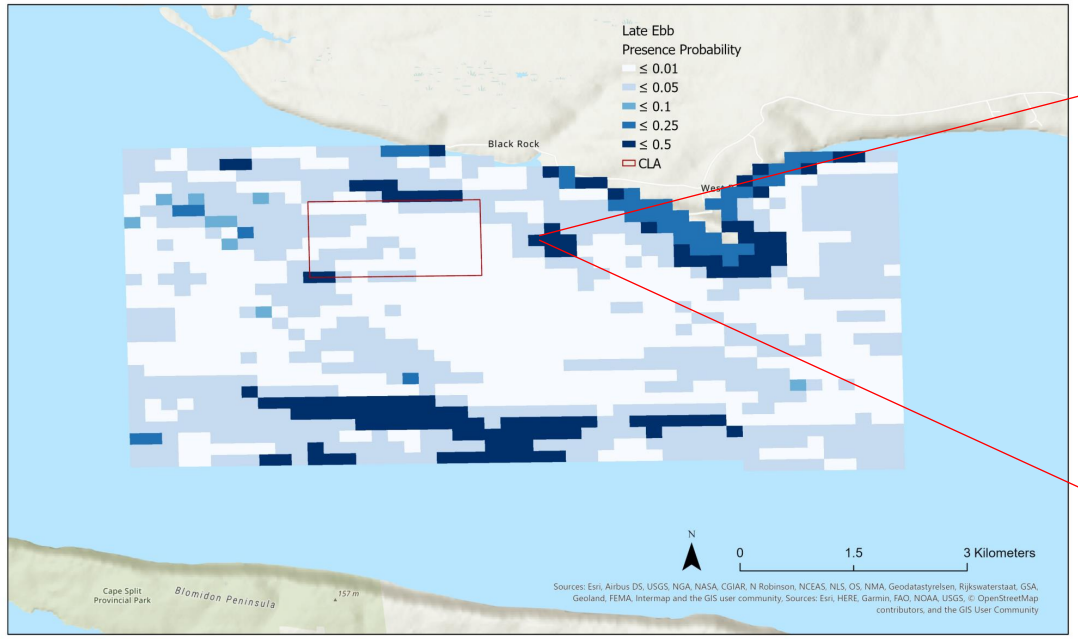


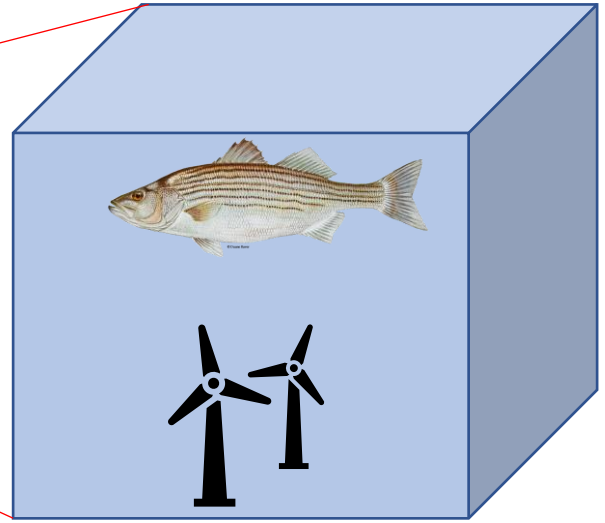


Case Study: Setting up an SDM in Minas Passage

Model goal - illustrate probability of fish “being there in the first place.”

- Also shows changes over time and conditions
- Next step is adding fish and turbine characteristics to individual grid cells for finer-scale encounter risk assessment





High probability

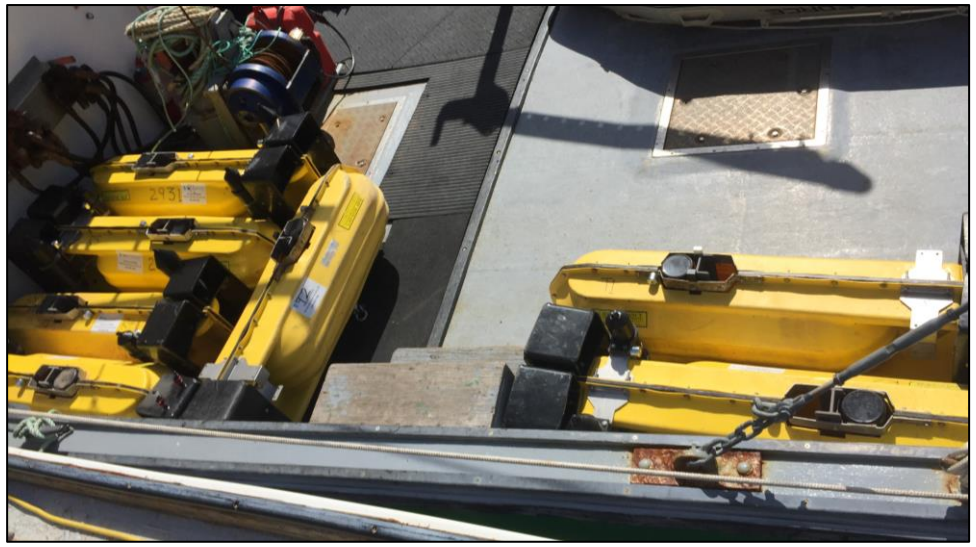
Low probability

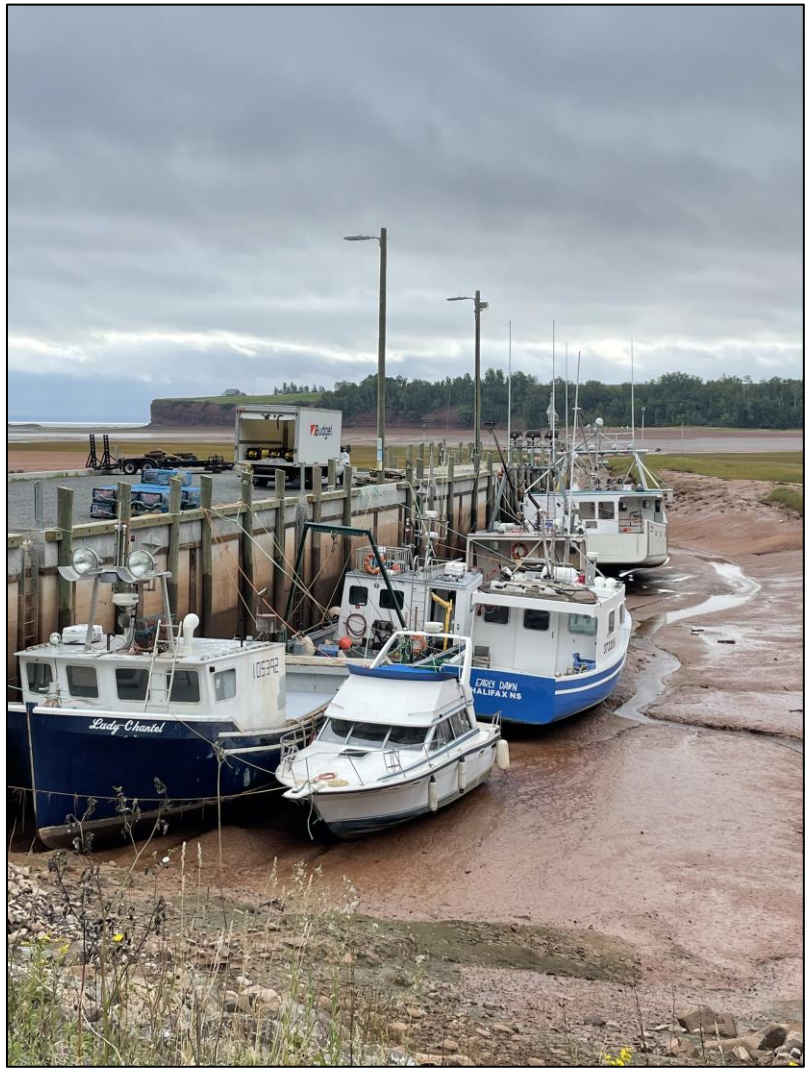
High/Low encounter risk

Case Study: Setting up an SDM in Minas Passage

Challenges

- Acquiring tag detection and environmental data
- Extreme tidal environment
  - Field deployment logistics
  - Effects on tag detection efficiency

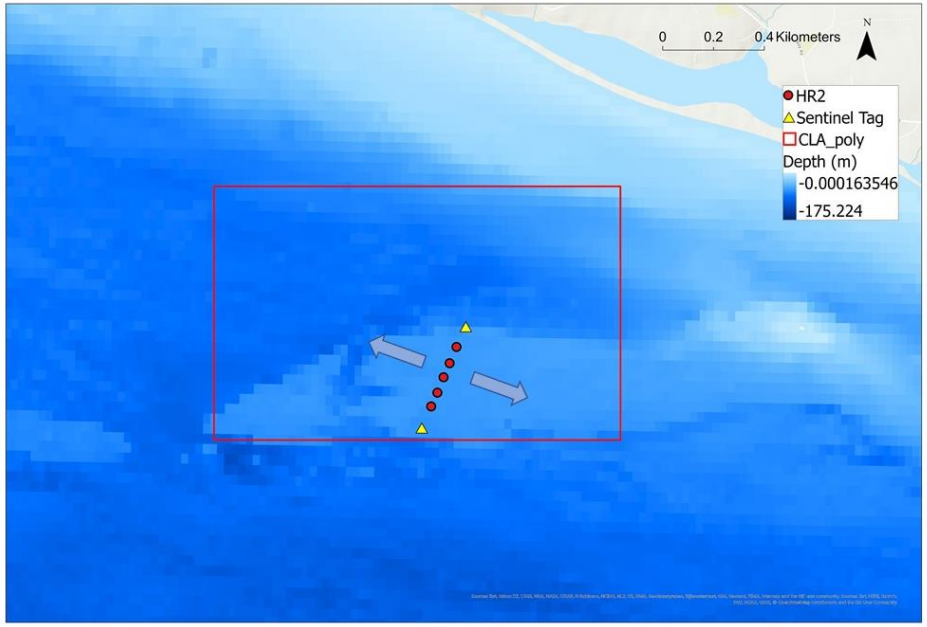


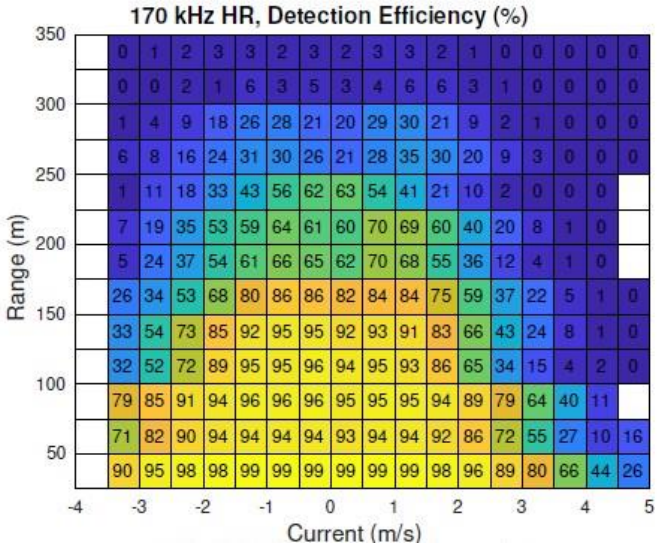


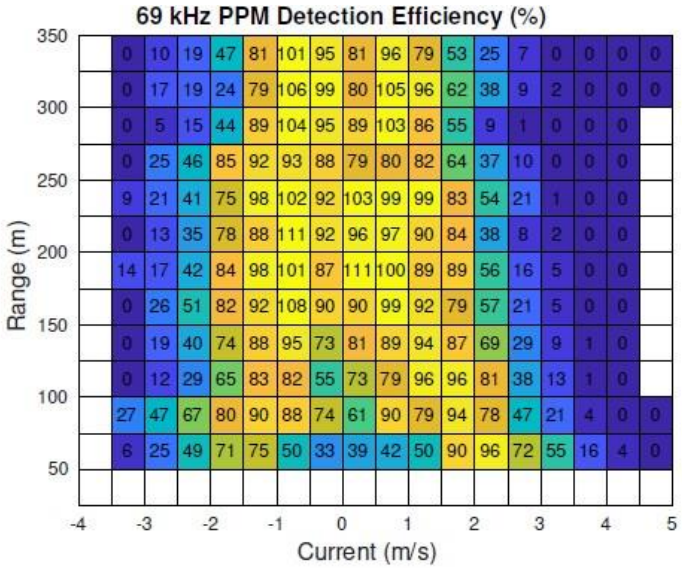
Case Study: Setting up an SDM in Minas Passage

Testing tag detection assumptions

- Range testing using both 69-kHz and HR receivers
- Effects of distance and current velocity



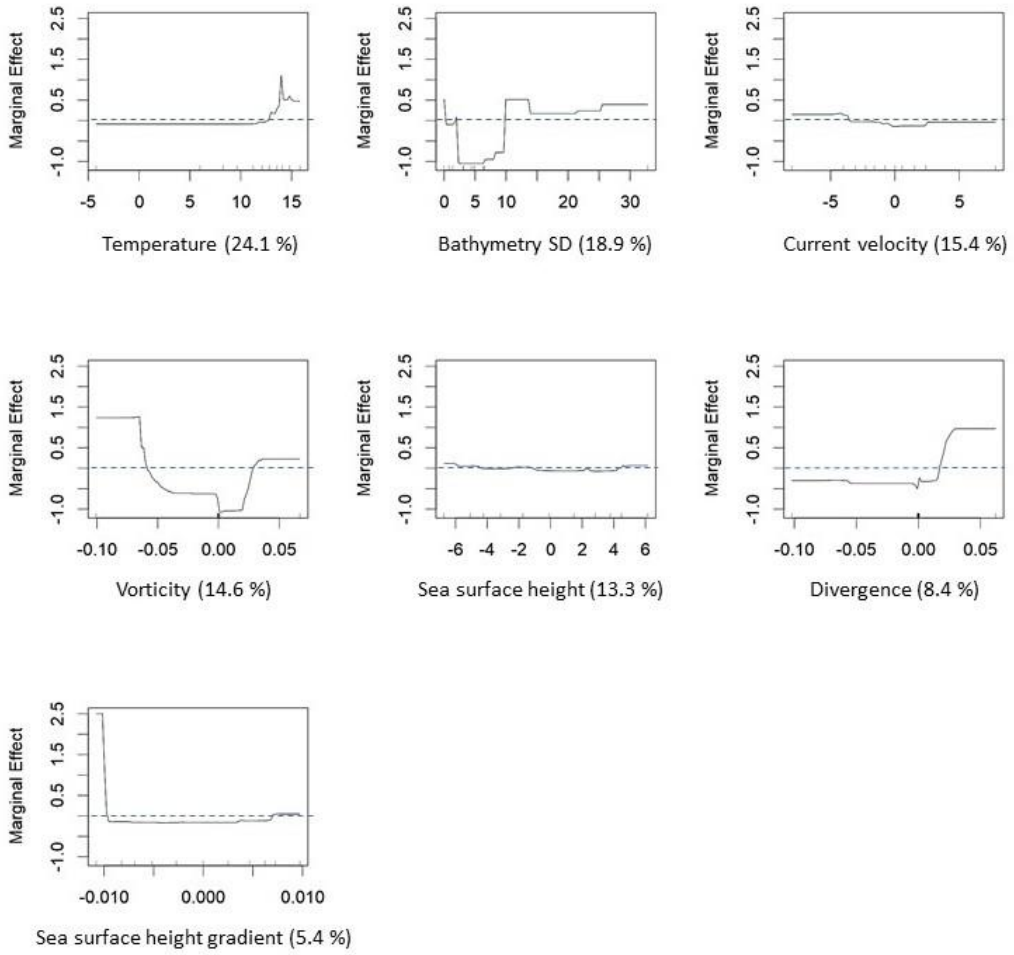




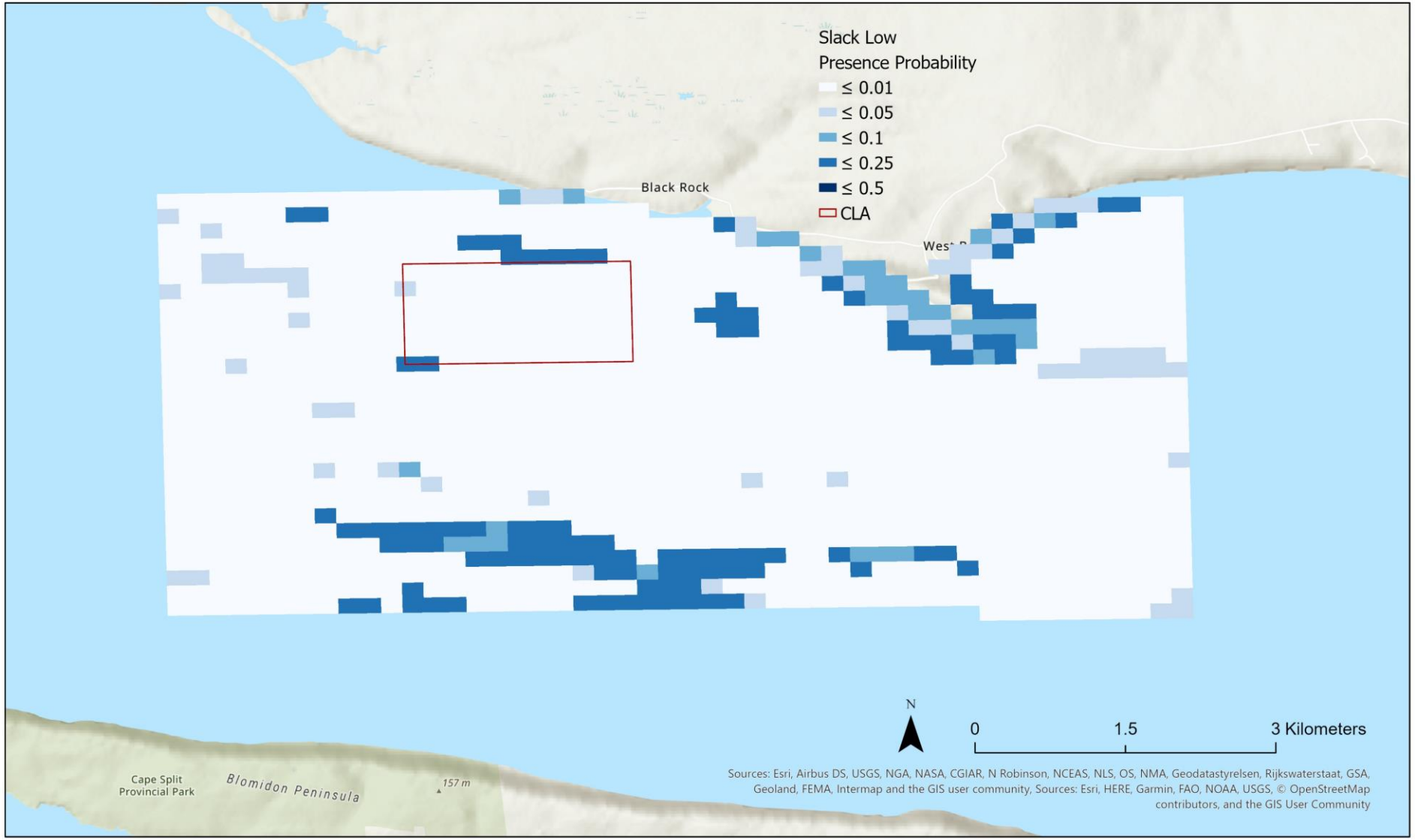
Case Study: Setting up an SDM in Minas Passage

The model

- Boosted regression tree of striped bass in fall 2017-2020
- Response variable – presence/absence
- Predicted against grids representing average conditions during each tide stage



Case Study: Setting up an SDM in Minas Passage



Case Study: Setting up an SDM in Minas Passage

Testing animal behavior assumptions

- Follow-up tagging
  - Are newly-tagged fish showing up in areas of high predicted probability?
  - Does model performance improve with new tag detections added?

Questions and Discussion