MarineSDMs

Marine Species Distribution Models

Ben Best

2023-11-21

Table of contents

1 Introduction

1.1 Background

The best available global distributions are presently AquaMaps (Kaschner et al. 2006; Ready et al. 2010) with supplementation by IUCN RedList range maps[1]. These have been used to calculate the biodiversity within Exclusive Economic Zones (EEZs) (Halpern et al. 2012) as well as beyond in the high seas (Visalli et al. 2020).

1.2 Goals

This book is meant to capture the overview and details of modeling species distributions in the marine environment for the purposes of advancing the status quo of global and U.S. national species distributions along the following dimensions:

1. **Space**
   The current AquaMaps distributions are 1/2º (~55 km at equator), whereas the best available global bathymetry is 1/240º (< 0.5 km).
2. **Time**
   The current AquaMaps distributions are based on static climatic averages over all seasons, which does not capture temporal dynamics: seasonally within a year, nor long-term climate change trends. This will necessitate sampling the environment contemporaneously with species observations before fitting the model and predicting to different environmental snapshots.
3. **Environment**
   Other environmental variables besides the initial physiographic (depth) and oceanographic (temperature, chlorophyll, primary productivity and ice) may elicit an improved statistical fit, related to species' environmental niche. Some candidates include: temperature fronts, eddy kinetic energy, distance from shore, distance from shelf.
4. **Biology**
   Where sufficient observations exist, additional models should be developed highlighting differences between:

[1] IUCN RedList range maps: https://www.iucnredlist.org/resources/spatial-data-download

- **Life stage**, e.g. larval vs adult.
- **Gender** where varies, such as male sperm whales being more cosmopolitan.
- **Subpopulations** for understanding metapopulation dynamics
- **Behavior**, such as migrating, feeding or breeding.

By definition MBONMarine Biodiversity Observation Network; see MarineBON.org is a network, so this is inclusive of and meant for all participants.

1.3 Motivations

- AquaMaps.org
  AquaMaps (Kaschner et al. 2006; Ready et al. 2010) represents a massive amount of work to gather parameters for >33.5K marine species, including areas to mask out.
- OBIS.org
  The Ocean Biogeographic Information System (Klein et al. 2019; Grassle 2000)is the central portal for continuously added observations with extra flags for quality control, all of which makes marine SDMs possible.
- **Modeling** methods have dramatically improved over time and are ripe for fresh application. The R package `dismo` originally came came out with an SDM vignette as a practical supplement to their excellent review of SDMs (Elith and Leathwick 2009) and using the Maxent algorithm (Elith et al. 2011). The raster package furthered that (rastersdm) and now there's `terra` sdm. Alongside these developments has been a boon of cloud-computing, particularly Google Earth Engine (Gorelick et al. 2017; Campos et al. 2023), allowing for dense global raster processing.
- The world is quickly moving towards a future trying to conserve 30% of the oceans by 2030, so called "**30 by 30**". In the U.S., this is America the Beautiful initiative. We need biodiversity indicators to track progress. This push for conservation is driven by increasing impacts of **climate change**, as evidenced by marine heatwaves and shifts in population distributions.

1.4 Contribute

We very much welcome your feedback, contributions and collaboration. Here are a few ways from least to most involved:

1. Email Ben (ben@ecoquants.com) with any suggestions, including suggested revisions of this online book.

> **Note**
>
> Note that you can download this entire book as:
>
> - Adobe Acrobat pdf to add annotations; or
> - Microsoft Word docx to edit with Track Changes on.
>
> These are available in the upper left navigation menu by clicking the download icon .

2. Submit a New Issue on Github.
3. Click on " Edit this Page" in the upper right. If you have a Github account, then you can fork this repository from owner "marinebon" to your username, edit the page(s) and submit a pull request.
4. If you are a regular contributor, you can be added to the collaborators of this repository to push changes directly (without needing a pull request).

Part I

Create SDM

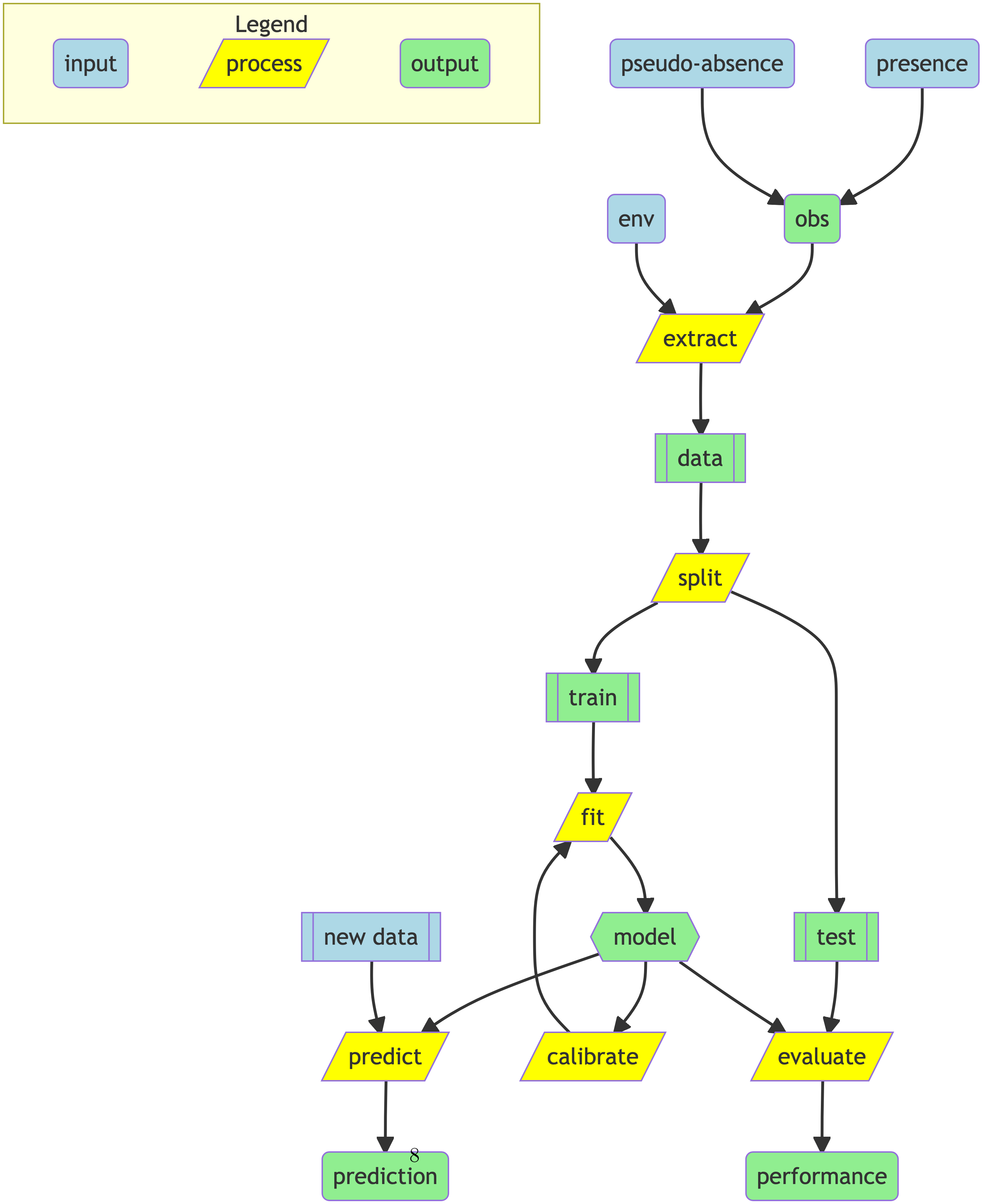


Figure 1.1: Diagram of SDM data preparation and model fitting.

2 Prepare Data

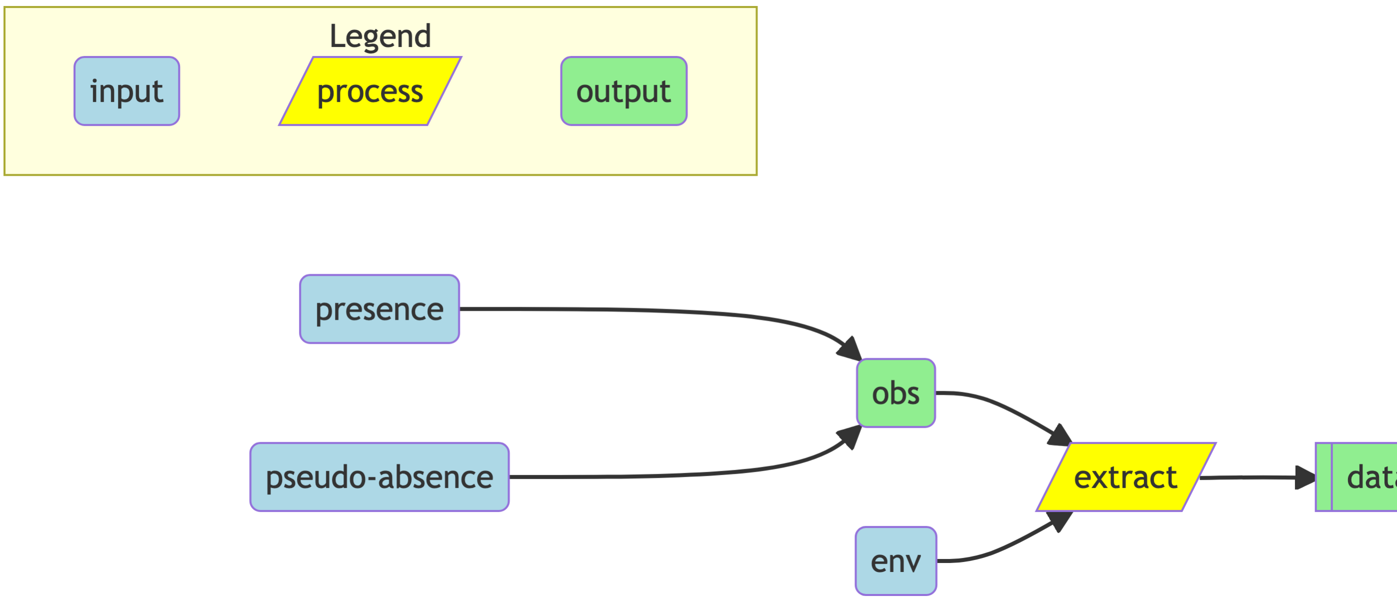


Figure 2.1: Diagram of SDM data preparation for model fitting.

- **obs**
  observations: occurrences from OBIS; masked by FAO regions defined by AquaMaps (Skyttner 2020)
  - **presence**
    OBIS: species occurrence
  - **absence**
    OBIS not-species, but same family
- **env**
  environment
- **tbl**
  table of observations (presence and absence) with environmental values

2.1 Environmental Predictors

2.1.1 Physiographic

- `depth`
  Bathymetric Depth
- `d2coast`
  Distance to Coast
- `d2shelf`
  Distance to Shelf

2.1.2 Time Varying

- `vgpm`
  Vertically integrated primary Productivity model

2.1.3 Depth & Time Varying

- `temp`
  Temperature, either sea-surface temperature (SST) or some modeled product from HyCOM, ROMS or Copernicus
- `salin`
  Salinity

3 Model

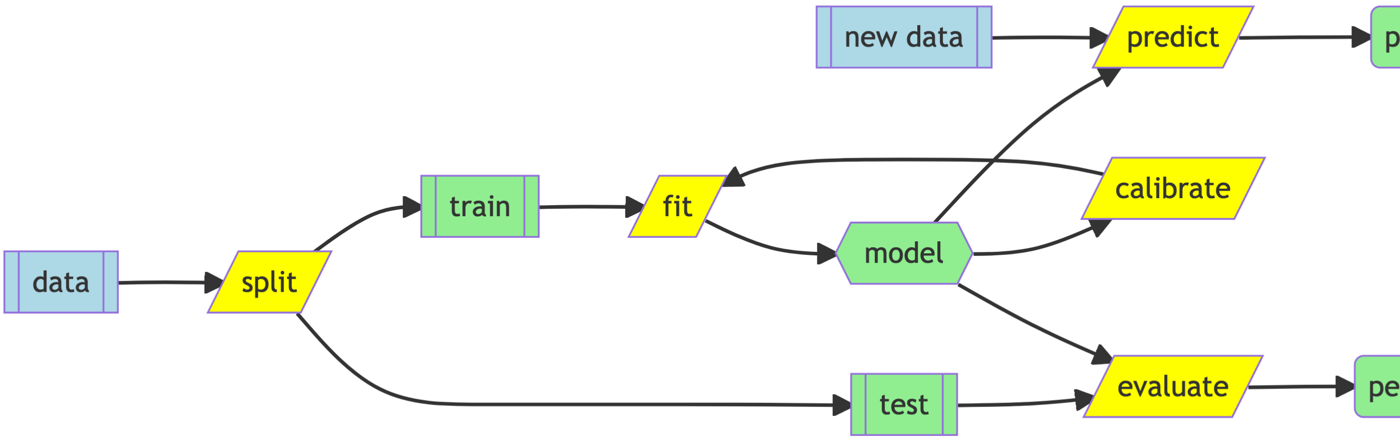
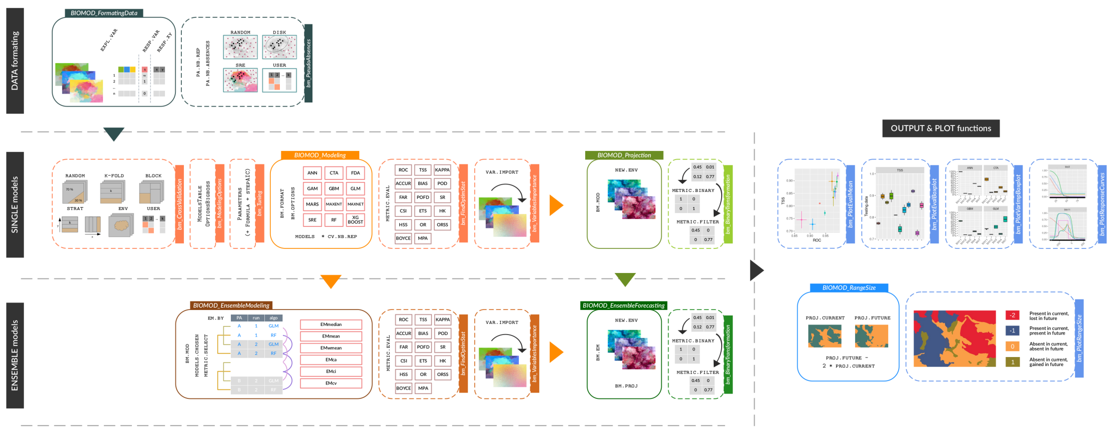


Figure 3.1: Diagram of SDM Modeling processes.

4 Ensemble

- biomod2
  Species distribution modeling, calibration and evaluation, ensemble modeling



Part II

Combine SDMs

We look at combining SDMs to calculate biodiversity based on addressing questions of interest and relevance.

5 Mosaic

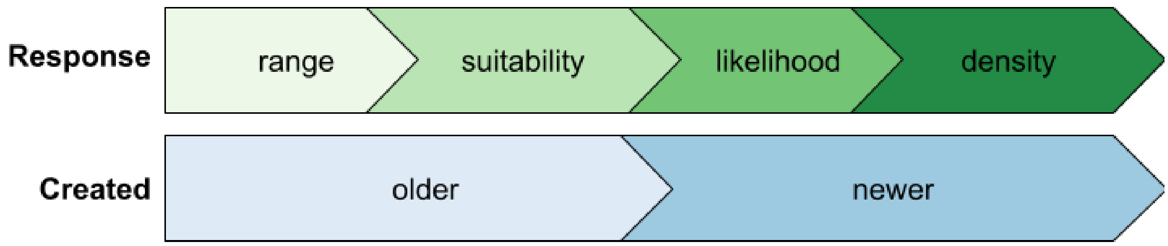


Figure 5.1: Hierarchy of preferred model outputs based on response type and age.

This is illustrated well by Figure 5.1.

6 Group Taxa

Taxonomic groups (Tittensor et al. 2010) in the high seas (Visalli et al. 2020) were packaged with simple query statements in the draft R package gmbi (global marine biodiversity indicators).

7 Indicators

7.1 Diversity

Here are the classic diversity indices from the R package `vegan`:

$$
\begin{aligned}
H &= -\sum_{i=1}^{S} p_i \log_b p_i && \text{Shannon-Weaver} \\
D_1 &= 1 - \sum_{i=1}^{S} p_i^2 && \text{Simpson} \\
D_2 &= \frac{1}{\sum_{i=1}^{S} p_i^2} && \text{inverse Simpson}
\end{aligned}
$$

where p_i is the proportion of species i, and S is the number of species so that $\sum_{i=1}^{S} p_i = 1$, and b is the base of the logarithm.

7.2 Endemism

Endemism could be measured as a function of the presence or average of the species range, given by either a global SDM converted to a binary range or using the existing IUCN range maps.

7.3 Extinction Risk

This is provided by IUCN RedList, as well as sometimes at a national level, such as NatureServe's Conservation Status Ranks for the U.S.

7.4 Functional Importance

7.5 Habitat Forming

Habitat forming species, such as coral, mangrove, seagrasses and kelp are especially important for biodiversity and ecosystem services.

7.6 Phylogenetic Uniqueness

7.7 Richness

7.8 Sensitivity

Sensitivity to specific human activities, such as shipping or fishing. Some activities may have different stages of development, such as construction versus operation of offshore wind energy.

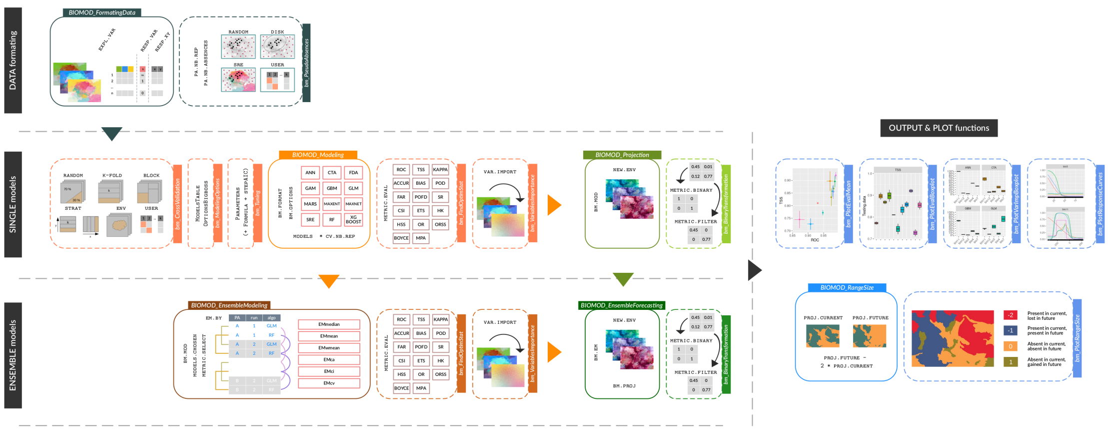
7.9 Trophic Index

8 Software

8.1 R

Most packages have not yet migrated from using the deprecated `raster` R package to the new `terra` package, except for `biomod2` (ref?).

- `biomod2`
  Species distribution modeling, calibration and evaluation, ensemble modeling



- `eks`
  Tidy and Geospatial Kernel Smoothing for spatially filtering outlier observations
- `predicts`
  New R library using terra for predicting from fitted model

8.2 Python

- Xarray
  Xarray makes working with labelled multi-dimensional arrays in Python simple, efficient, and fun!

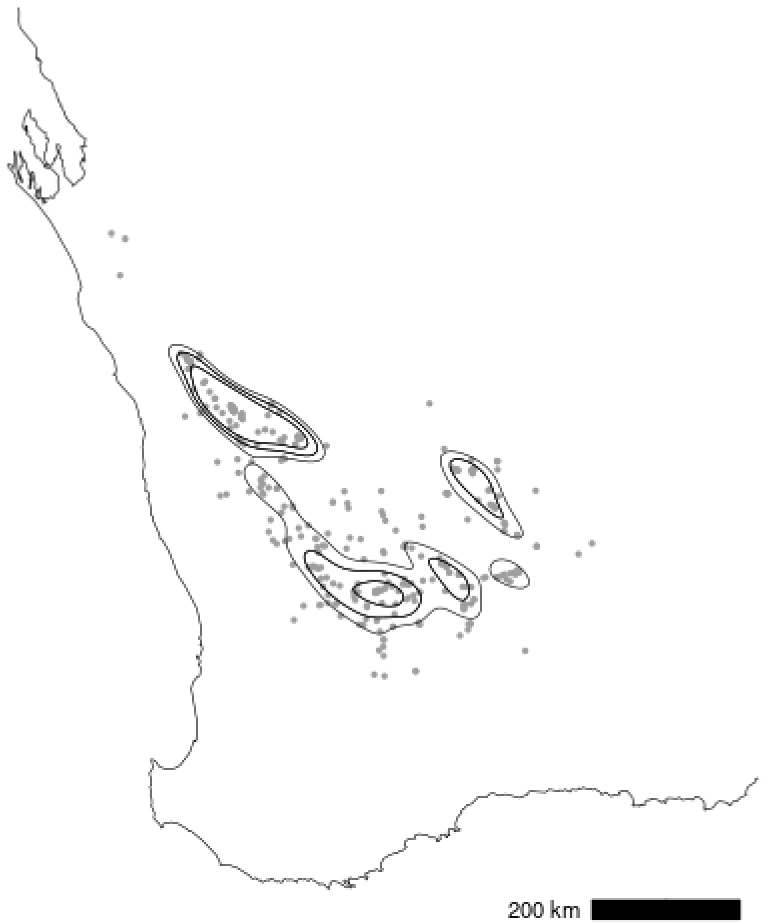


Figure 8.1: Source: Kernel density estimates for tidy and geospatial data in the eks package

8.3 Google Earth Engine

- XEE
  XEE is a new Python package for Earth Engine that provides a set of functions to facilitate the use of Earth Engine API. It is designed to be used in Jupyter notebooks and Google Colab. Documentation

9 Organize

9.1 Partners

- ***Confirmed***
  - **AquaMaps**
    distribution maps for over 33,500 species of fishes, marine mammals and invertebrates
    contacts:
    * Gabriel Reygondeau (g.reygondeau@oceans.ubc.ca)
  - **DisMAP**
    Distribution Mapping and Analysis Portal (NOAA)
    contacts:
    * Melissa Karp (melissa.karp@noaa.gov)
    * Roger Griffis (roger.b.griffis@noaa.gov)
  - **MBON**
    Marine Biodiversity Observation Network (NOAA, NASA)
    contacts:
    * Ben Best
    * Tylar Murray
    * Dan Otis
    * Frank Muller-Karger
  - **OBIS**
    Ocean Biodiversity Information System (UNESCO)
    contacts:
    * Candido Principe De Souza, Silas (s.principe@unesco.org)
    * Ward Appeltans (w.appeltans@unesco.org)
- ***Proposed***

  - **FishGLOB**
    fish biodiversity under global change (global bottom trawl)
    contacts:
    * Malin Pinsky
  - **MGEL**
    Marine Geospatial Ecology Lab, Duke
    contacts:
    * Jason Roberts
    * Patrick Halpin
  - **PMEL**
    Pacific Marine Environmental Lab, NOAA
    contacts:
    * Heather Welch
    * Elliot Hazen

9.2 Portal

- Candidate website:
  MarineSpeciesMaps.org (BDB registered domain)
  - similar to:
    * MarineRegions.org
      spatial authority
    * MarineSpecies.org
      taxonomic authority

9.3 Timeline

9.3.1 Meetings

- **2024-01-23**
  Marine Biodiversity Summit in DC
  (organized by Gabrielle, Emmett)
- **2024-03-21**
  SDM meeting in New Orleans
  (organized by BDB; so far AquaMaps)

9.3.2 Sequence

1.

References

Campos, João C., Nuno Garcia, João Alírio, Salvador Arenas-Castro, Ana C. Teodoro, and Neftalí Sillero. 2023. "Ecological Niche Models Using MaxEnt in Google Earth Engine: Evaluation, Guidelines and Recommendations." *Ecological Informatics* 76 (September): 102147. https://doi.org/10.1016/j.ecoinf.2023.102147.

Elith, Jane, and John R. Leathwick. 2009. "Species Distribution Models: Ecological Explanation and Prediction Across Space and Time." *Annual Review of Ecology, Evolution, and Systematics* 40 (1): 677–97. https://doi.org/10.1146/annurev.ecolsys.110308.120159.

Elith, Jane, Steven J. Phillips, Trevor Hastie, Miroslav Dudík, Yung En Chee, and Colin J. Yates. 2011. "A Statistical Explanation of MaxEnt for Ecologists." *Diversity and Distributions* 17 (1): 43–57. http://dx.doi.org/10.1111/j.1472-4642.2010.00725.x.

Gorelick, Noel, Matt Hancher, Mike Dixon, Simon Ilyushchenko, David Thau, and Rebecca Moore. 2017. "Google Earth Engine: Planetary-Scale Geospatial Analysis for Everyone." *Remote Sensing of Environment*, Big remotely sensed data: Tools, applications and experiences, 202 (December): 18–27. https://doi.org/10.1016/j.rse.2017.06.031.

Grassle, J. Frederick. 2000. "The Ocean Biogeographic Information System (OBIS): An on-Line, Worldwide Atlas for Accessing, Modeling and Mapping Marine Biological Data in a Multidimensional Geographic Context." *Oceanography* 13 (3): 5–7. https://www.jstor.org/stable/43924357.

Halpern, Benjamin S., Catherine Longo, Darren Hardy, Karen L. McLeod, Jameal F. Samhouri, Steven K. Katona, Kristin Kleisner, et al. 2012. "An Index to Assess the Health and Benefits of the Global Ocean." *Nature*. https://doi.org/10.1038/nature11397.

Kaschner, K., R. Watson, A. W. Trites, and D. Pauly. 2006. "Mapping World-Wide Distributions of Marine Mammal Species Using a Relative Environmental Suitability (RES) Model." *Marine Ecology Progress Series* 316 (July): 285–310. https://doi.org/10.3354/meps316285.

Klein, Eduardo, Ward Appeltans, Pieter Provoost, Hanieh Saeedi, Abigail Benson, Lenore Bajona, Ana Carolina Peralta, and R. Sky Bristol. 2019. "OBIS Infrastructure, Lessons Learned, and Vision for the Future." *Frontiers in Marine Science* 6. https://www.frontiersin.org/articles/10.3389/fmars.2019.00588.

Ready, Jonathan, Kristin Kaschner, Andy B. South, Paul D. Eastwood, Tony Rees, Josephine Rius, Eli Agbayani, Sven Kullander, and Rainer Froese. 2010. "Predicting the Distributions of Marine Organisms at the Global Scale." *Ecological Modelling* 221 (3): 467–78. https://doi.org/10.1016/j.ecolmodel.2009.10.025.

Skyttner, Markus. 2020. "Aquamapsdata: Curated Data from AquaMaps.org." https://github.com/raquamaps/aquamapsdata.

Tittensor, Derek P., Camilo Mora, Walter Jetz, Heike K. Lotze, Daniel Ricard, Edward Vanden Berghe, and Boris Worm. 2010. "Global Patterns and Predictors of Marine Biodiversity Across Taxa." *Nature* 466 (7310): 1098–1101. https://doi.org/10.1038/nature09329.

Visalli, Morgan E., Benjamin D. Best, Reniel B. Cabral, William W. L. Cheung, Nichola A. Clark, Cristina Garilao, Kristin Kaschner, et al. 2020. "Data-Driven Approach for Highlighting Priority Areas for Protection in Marine Areas Beyond National Jurisdiction." *Marine Policy*, March, 103927. https://doi.org/10.1016/j.marpol.2020.103927.

A Glossary

```r
glossary::glossary_table(as_kable=F) |>
  knitr::kable("pipe", escape = F, row.names = F)
```

term	definition
MBON	Marine Biodiversity Observation Network; see MarineBON.org

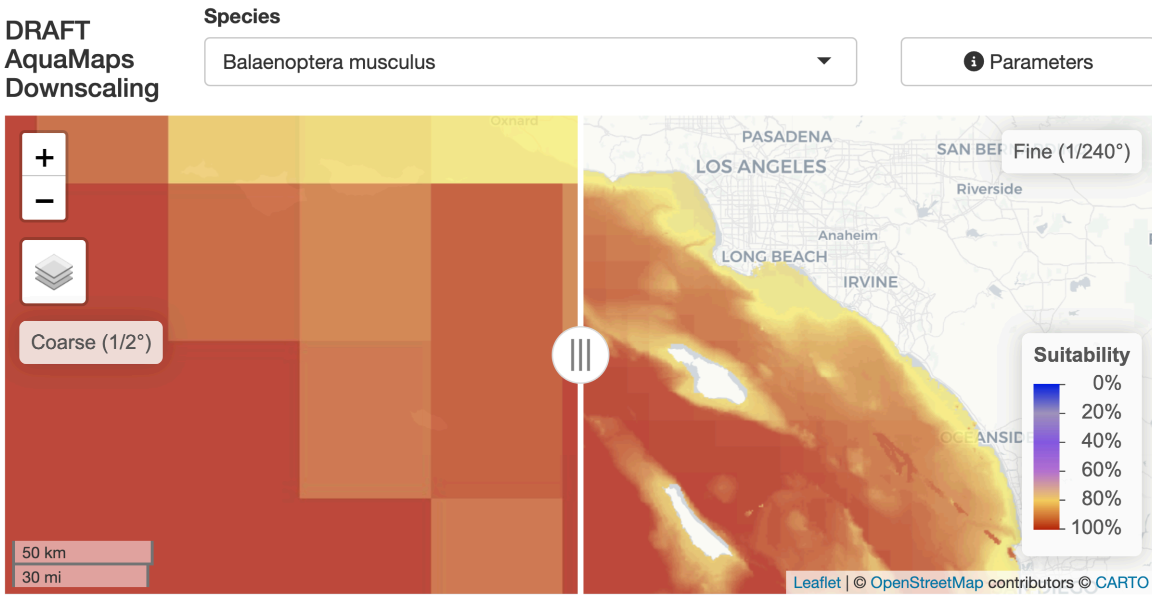
Part III

Explorations

AquaMaps Downscaled

Downscale AquaMaps from 1/2º to GEBCO 1/240º using Google Earth Engine and Shiny.

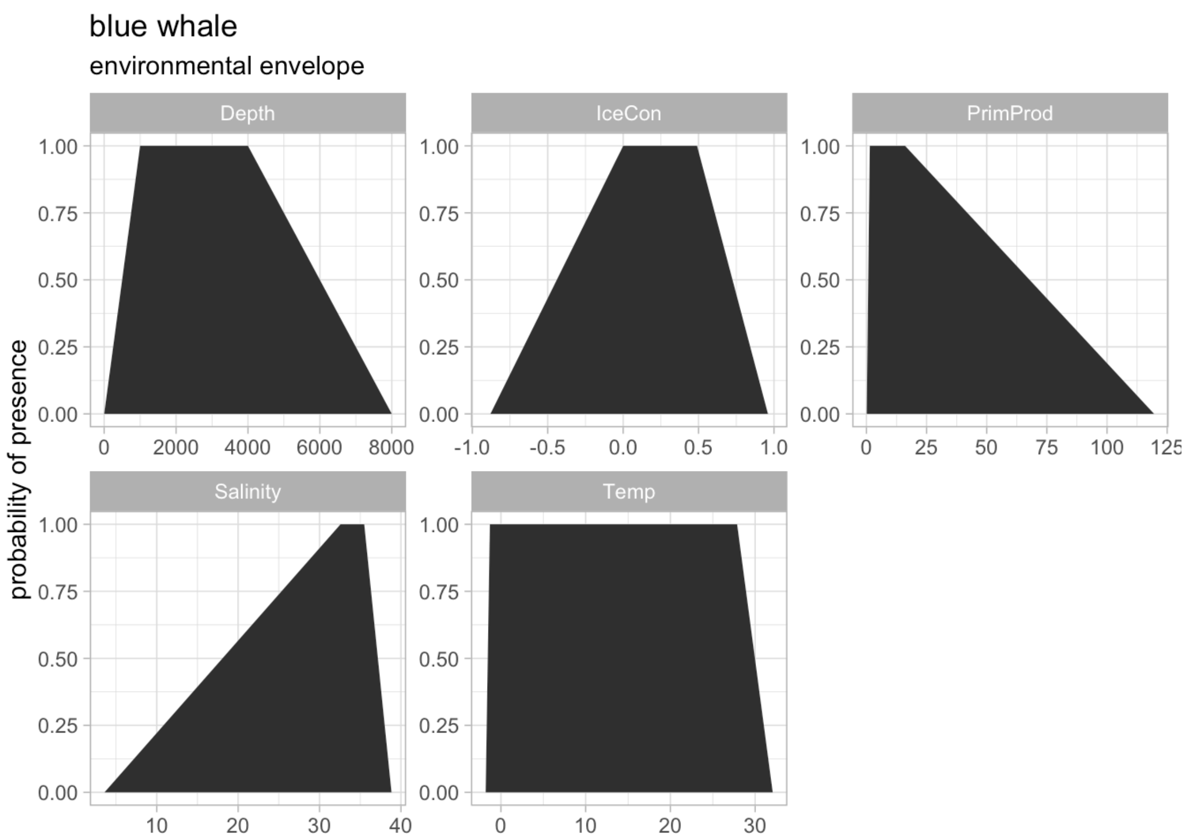
- website
- code



AquaMaps Envelope

Extract and plot AquaMaps environmental envelope, ramp rasters, using R.

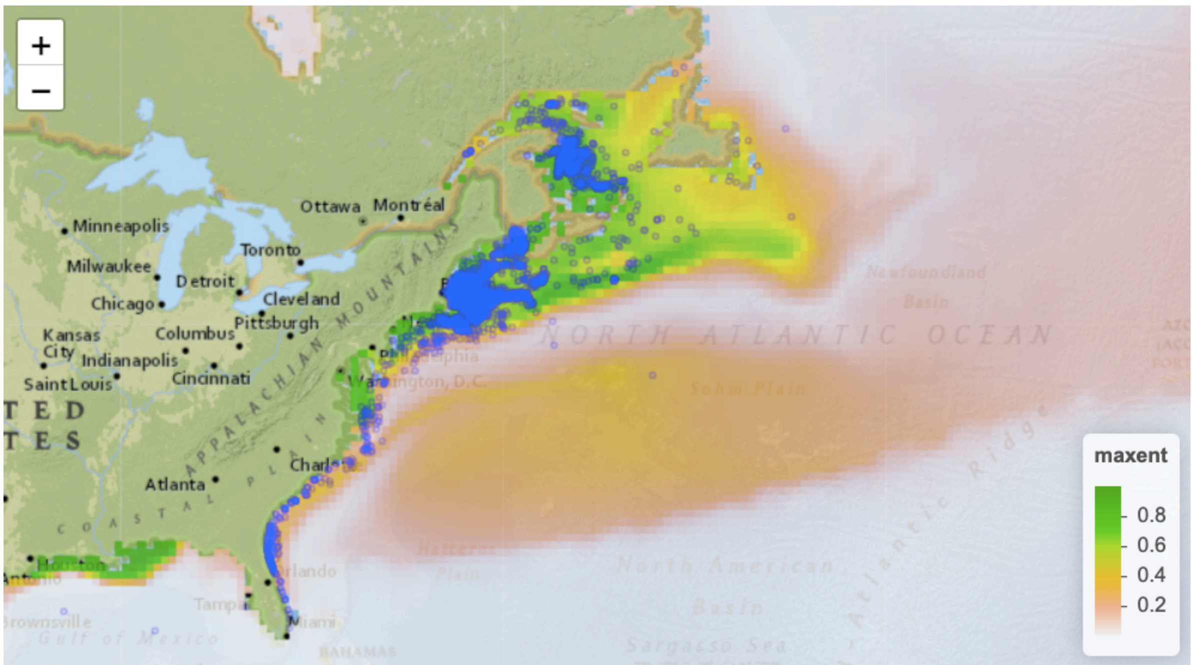
- website
- `code`



SDM using `predicts` in R

Predict species distribution of N Atlantic right whale using OBIS occcurrences and `predicts` package in R.

- website
- `code`



OBIS Top Species by Class

Extract the species with the most numerous observations by unique Class from the OBIS parquet archive in R.

- website
- `code`

	phylum	class	scientificName	AphiaID	date_min	date_max	r
76	Chordata	Aves	Larus fuscus	137142	1758-07-02	2021-12-31	2
88	Chordata	Teleostei	Clupea pallasii	151159	1867-07-21	2022-09-06	1
85	Chordata	Mammalia	Mirounga leonina	231413	1758-07-02	2019-12-02	1
19	Arthropoda	Malacostraca	Pandalus jordani	515469	1937-10-28	2022-09-13	
160	Mollusca	Cephalopoda	Loligo reynaudii	220316	1960-04-16	2006-05-11	
81	Chordata	Elasmobranchii	Carcharhinus melanopterus	105795	1824-07-01	2021-09-28	
15	Arthropoda	Copepoda	Calanus finmarchicus	104464	1872-09-14	2020-12-14	
90	Chordata		Chelonia mydas	137206	1758-07-02	2023-06-14	
169	Myzozoa	Dinophyceae	Tripos fusus	840626	1834-07-02	2022-09-08	
187	Ochrophyta	Phaeophyceae	Macrocystis pyrifera	232231	1885-12-01	2020-10-16	