Marine Sensitivity

Project Documentation

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Preface

This is a Quarto book.

1 Introduction

This Marine Sensitivity (MS) project of BOEM seeks to assess the sensitivity of marine species to offshore energy development, whether oil & gas or wind. By combining the best available species distributions with known species sensitivities we can map out areas of the ocean that are most vulnerable to human activities. This information can be used to inform decisions about where to place energy infrastructure and/or implement mitigations to minimize impacts on the marine environment.

This is a process, not a product. Information is imperfect, especially given the large expanse of US waters. Distributions and abundance of species change, modified increasingly by climate change and human activities. Knowledge on species sensitivities continues to expand with more research. And finally the methods for both modeling and distributing all this information continue to improve. We aim to provide a transparent and reproducible process that can be regularly updated as new data and methods become available.

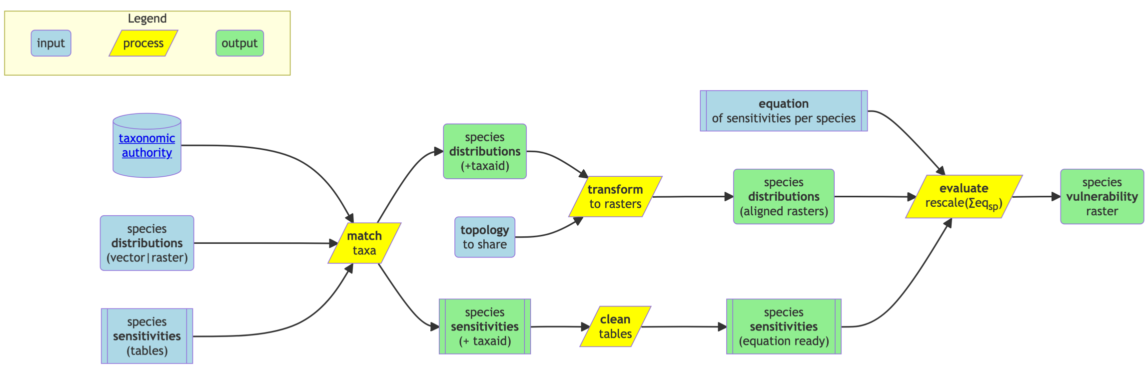


Figure 1.1: Flowchart of process for incorporating marine species sensitivities with distributions and generating a holistic vulnerability map.

Part I

Science

2 Science

The term vulnerability (V) is a function of exposure (E), sensitivity (S) and adaptive capacity (A) (Equation 2.1).

$$V = f(E, S, A) \tag{2.1}$$

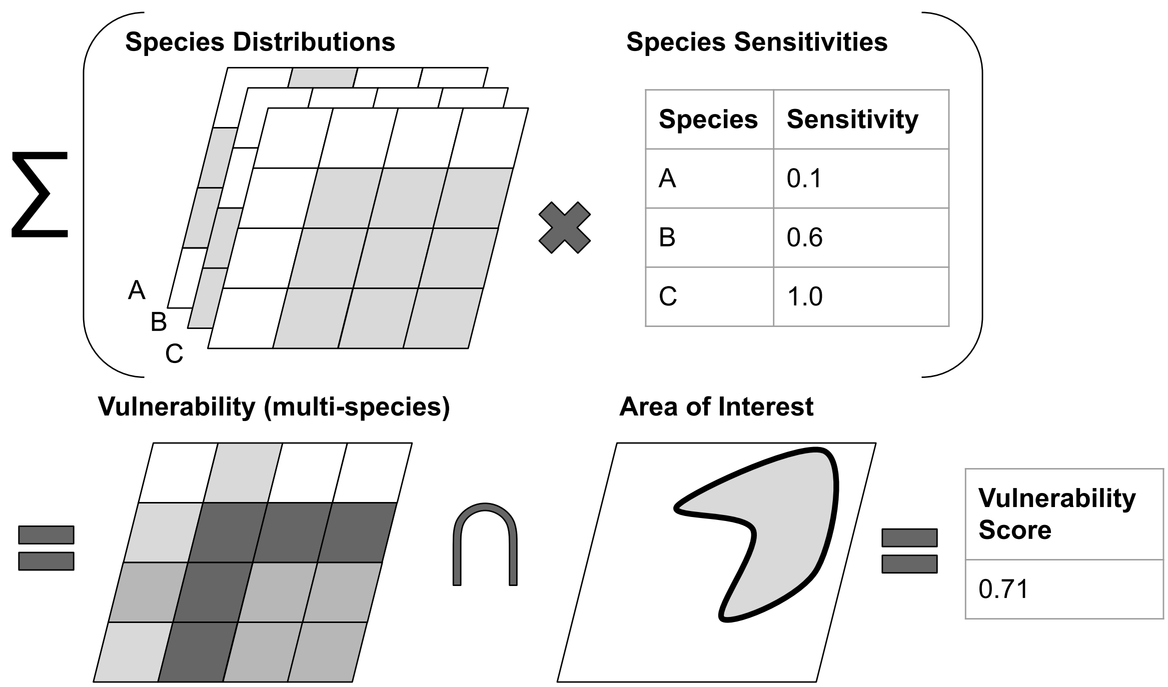


Figure 2.1: Overview of process.

$$cell_V = \sum_{spp} p * w \tag{2.2}$$

The raster of vulnerability (V) contains cells representing a sum across species (spp) of presence (p) multiplied by the sensitivity weight (w) (Equation 2.2).

3 Stressors

3.1 Offshore Wind Energy

Evaluation of stressors from the offshore wind industry needs to be evaluated based on human activities given the phase of development, whether pre-construction, construction, operation or decommissioning (Figure 3.1).

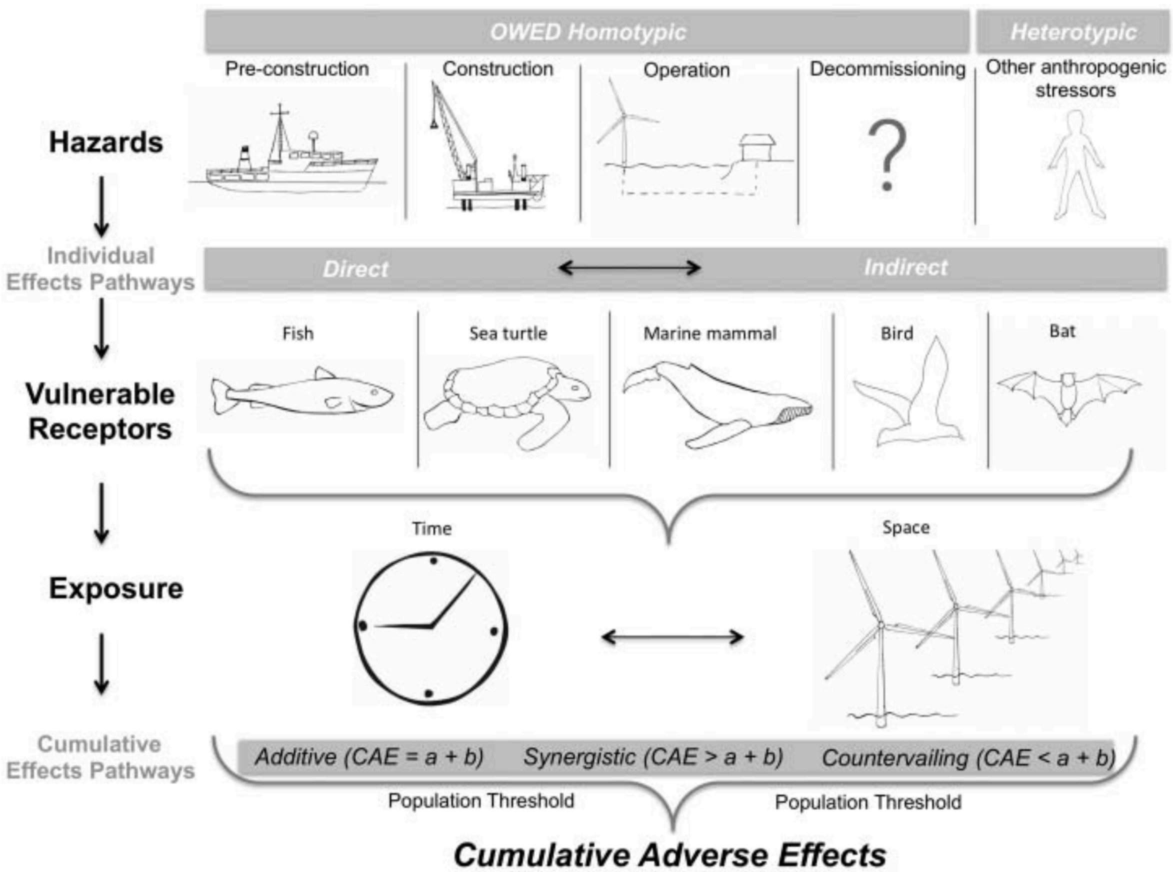


Figure 3.1: Cumulative adverse effects of offshore wind energy development on wildlife (Goodale and Milman 2016).

3.2 Oil & Gas

4 Receptors

Receptors are the species and habitats that are potentially impacted by the human activity.

4.1 Species

4.1.1 Corals

4.1.2 Invertebrates

4.1.3 Fish

4.1.4 Marine Mammals

4.1.5 Seabirds

4.1.6 Sea Turtles

4.2 Habitats

4.2.1 Coral Reefs

4.2.2 Hydrothermal Vents

4.2.3 Kelp Forests

4.2.4 Mangrove Forests

4.2.5 Seamounts

4.3 Primary Productivity

5 Exposure

Cumulative exposure (Figure 3.1) is important for understanding impacts to a population.

Part II

Software

6 Software

6.0.1 Interactive Applications

We have developed a series of interactive applications to explore the data and results of the MS project. These applications allow users to visualize the data, explore the results, and interact with the data in a more intuitive way. The applications are built using the `shiny` package in R, which allows us to easily create a user interface with complex reactivity for an interactive web application easily accessed through a web browser. The applications are designed to be user-friendly and intuitive, with interactive maps, charts, and tables that allow users to explore the data in a more dynamic way.

6.0.2 Overcoming Challenges with Large Spatial Data

The MS project incorporates many large spatial datasets that are problematic to render in a typical interactive application. For instance, the most common interactive mapping R package `leaflet` has a 4MB limitation for displaying rasters (see "Large Raster Warning" in Raster Images • leaflet). Vectors (i.e., points, lines and polygons) get smoothed when containing many vertices, but contiguity gets lost between polygons and rendering degrades to non-usable depending on the internet speed of the user's connection.

To work around these limitations, we have implemented "cloud native" web services and formats (see also Cloud-Optimized Geospatial Formats Guide). Our implementations effectively reduce the size of any given spatial object based on the zoom level of the user's browser. For rasters, we use cloud-optimized GeoTIFFs (COGs) and for vectors, we use Mapbox Vector Tiles (MVT). These formats are designed to be fast and efficient for web mapping applications, and they allow us to display large spatial datasets in an interactive web application without sacrificing performance or usability. Let's take a closer look at implementation of each.

6.0.2.1 Raster: Cloud-Optimized GeoTIFFs (COGs) and Titiler

Historically, to read a raster, such as a GeoTIFF, from the web, the client software would have to read the entire file before rendering. Cloud Optimized GeoTIFFs (COGs) take advantage of HTTP GET range requests to read only the part of the file needed for rendering. So a COG stores quadtree simplifications of the original raster at multiple zoom levels and metadata for accessing their byte ranges in the file in the metadata header. This allows the client software to request only the parts of the file needed for rendering, which can greatly reduce the amount of data transferred and speed up rendering. This is for accessing the raw data in pixel values, e.g., for a raster of species distribution then the abundance of a species in each cell. We would want to also apply a color ramp to visualize the data. The open-source (TiTiler software is a lightweight web service that serves up these color ramped tiles on the fly. So COGs can be stored on a simple file server (like Amazon S3 or Azure Blob Storage) and served up as interactive web maps with TiTiler as an intermediary between the COG files and the client accessing the interactive Shiny mapping app (Figure 6.1).

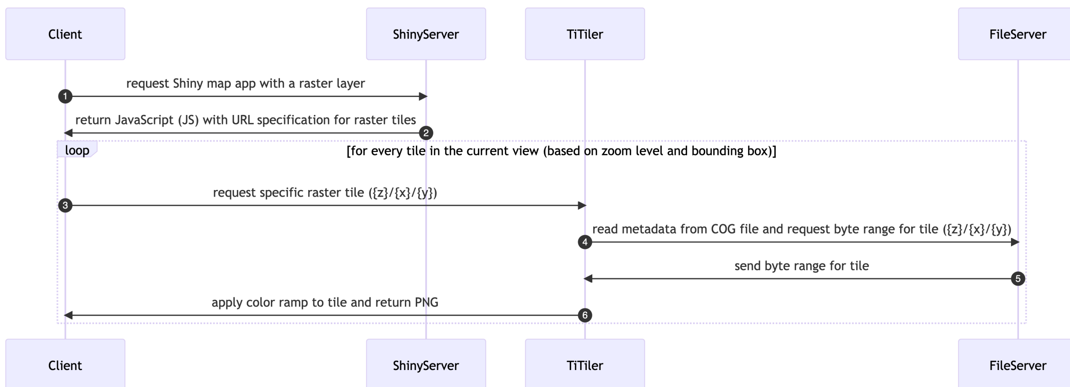


Figure 6.1: Sequence diagram implementing large raster interactive display using Cloud-Optimized GeoTIFFs (COGs) and Titiler in a Shiny mapping app.

6.0.2.2 Vector: Mapbox Vector Tiles (MVTs) and pg_tileserv

Although "cloud native" vector formats exist for simple file storage (see Cloud-Optimized Geospatial Formats Guide), none of these allow for flexible filtering and manipulation. Instead, we use PostgreSQL with the spatial extension (PostGIS) to store the vector data and serve it as Mapbox Vector Tiles (MVTs) using the **pg_tileserv** web service written in the language Go, which is very fast. This means that we don't have to pre-render the MVTs (such as you might do with tippecanoe), but can instead serve the raw vector data directly from the database and let **pg_tileserv** handle the rendering on the fly. Filters (in the form of CQL) can be applied to the request. Symbology is rendered client-side via JavaScript, which allows for interactive hover and click events on vector objects (e.g., BOEM aliquot). Some speed-up is enabled by implementing a Varnish cache service in between. We can even write our own database functions for customized rendering, such as H3 hexagonal summaries. This allows us to serve vector data as web maps with minimal configuration and setup, and it provides a fast and efficient way to display large vector datasets in an interactive web application (Figure 6.2).

6.0.3 Github Repositories

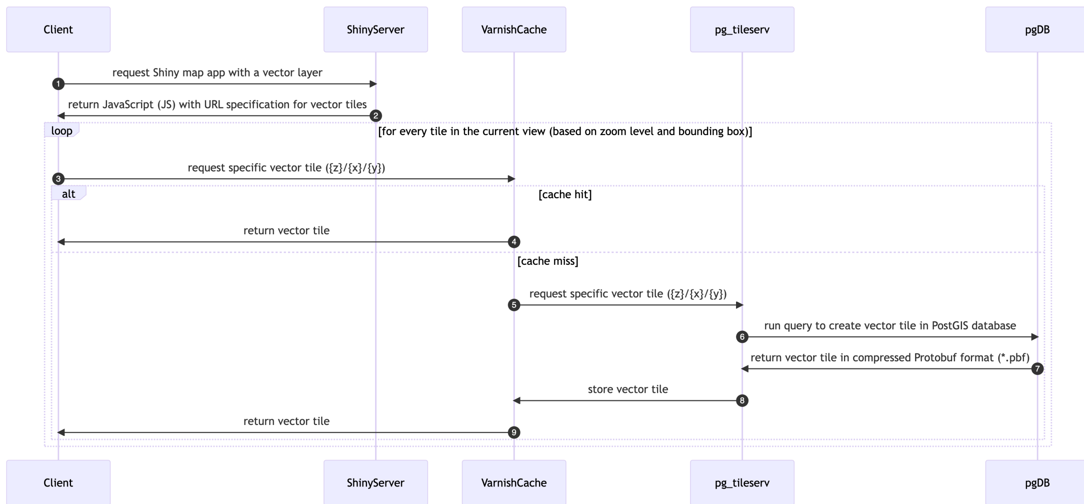


Figure 6.2: Sequence diagram implementing large vector interactive display using Mapbox Vector Tiles (MVTs) and pg_tileserv in a Shiny mapping app.

repo	description
api	application programming interface (API) using R Plumber package
apps	Shiny applications
docs	documentation for BOEM's offshore environmental sensitivity index products
manuscripts	Manuscripts with review of sensitivities by industry and receptors (species, habitats, human uses)
MarineSensitivity.github.io	default website
msens	R library of functions for mapping marine sensitivities, sponsored by BOEM
objectives	repository for issues spanning multiple repositories and doing big picture roadmapping
server	server setup for R Shiny apps, RStudio IDE, R Plumber API, PostGIS database, pg_tileserv
workflows	scripts for testing data analytics and visualization as well as production workflows

6.0.4 Software Components

APIs
application programming interfaces (APIs)

Apps
interactive applications using Shiny

Database
PostgreSQL database extended spatially with PostGIS

Docs
technical documentation

Libraries
documented functions as an R package

Server
server software configuration using Docker

Workflows
scripts for exploring plus production workflows

7 Server

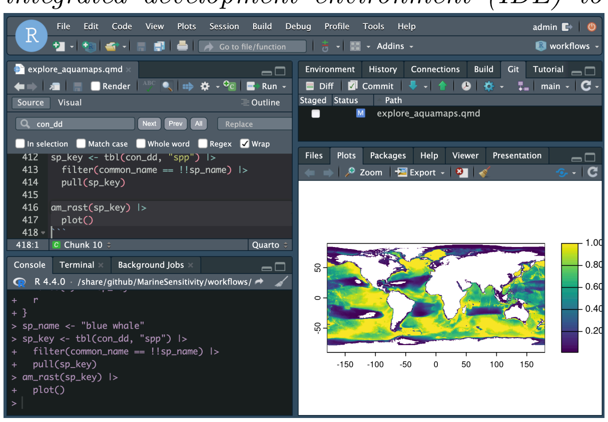
The server is for serving up any web services outside those of Github (e.g., website, docs and R package msens) using Docker (see the docker-compose.yml; with reverse proxying from subdomains to ports by Caddy).

7.1 Setup

For instructions on launching an Amazon instance and installing the server software, see Server Setup · MarineSensitivity/server Wiki.

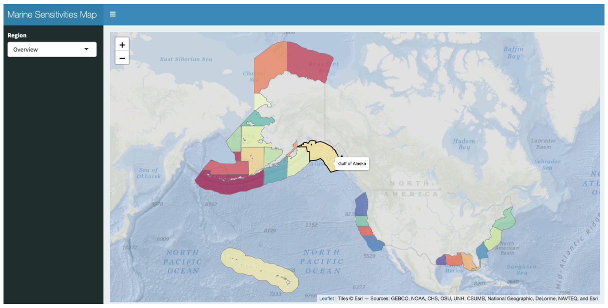
7.2 Services

The server is running the following services:

- **RStudio**
  integrated development environment (IDE) to code and debug directly on the server
  

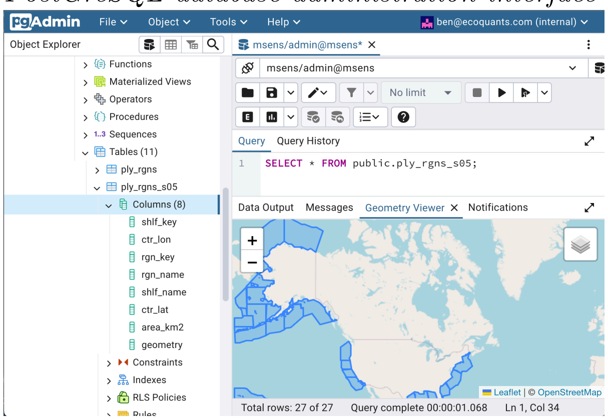
  More info..

- **Shiny**
  interactive applications
  e.g., **shiny**.marinesensitivity.org/**map**



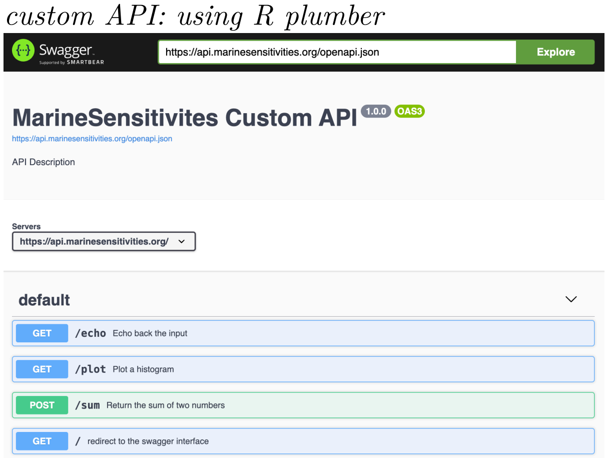
More info..

- **PGadmin**
  PostGreSQL database administration interface



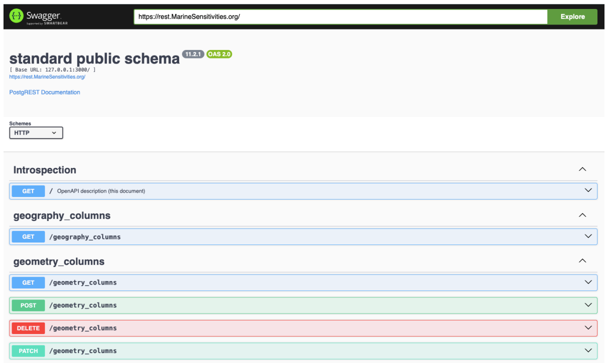
More info..

- **api**
  custom API: using R plumber



More info..

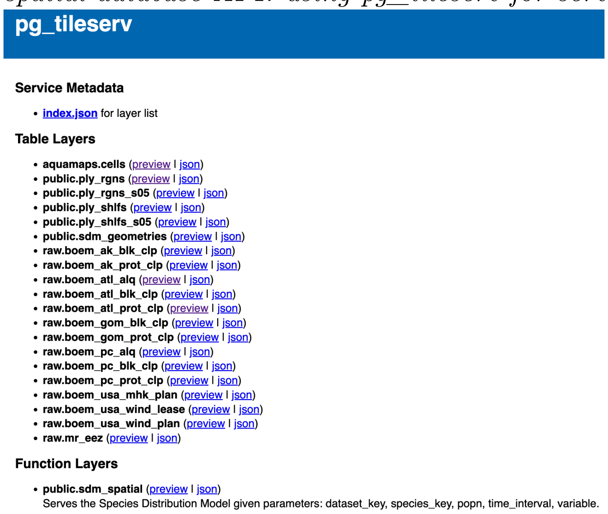
- **swagger**
  generic database API: using PostGREST



More info..

- **tile**

  spatial database API: using pg_tileserv for serving vector tiles



More info..

8 Database

8.1 Table and Column Naming Conventions

- Table names are plural and use all lower case.
- Unique identifiers are suffixed with:
  - `*_id` for unique integer keys;
  - `*_key` for unique string keys;
  - `*_seq` for auto-incrementing sequence integer keys.
- Column names are singular and use snake_case.
- Foreign keys are named with the singular form of the table they reference, followed by _id.
- Primary keys are named id.

8.2 Species Distribution Models

See entity relationship diagram (ERD) for the species distribution models (SDM) database tables in this workflow:

- Create SDM Tables

And example of ingesting SDM outputs into the database in this workflow:

- Ingest GoMex cetacean & sea turtle SDMs

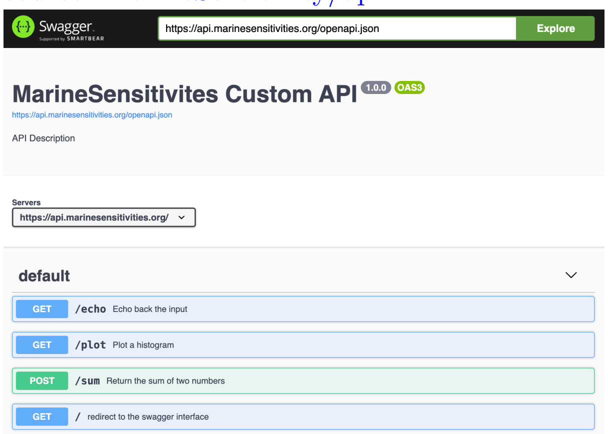
9 Workflows

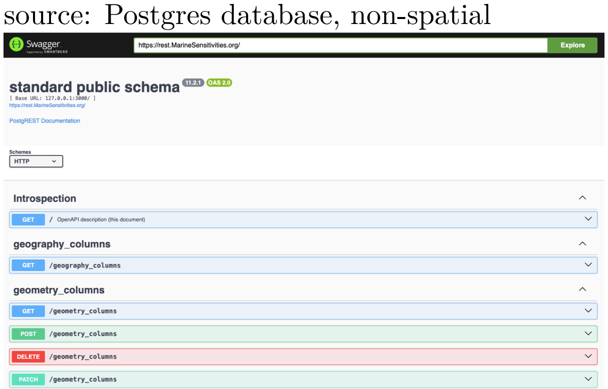
Workflows are scripts for testing data analytics and visualization as well as production workflows for ingesting data. See:

- marinesensitivity.org/workflows
  rendered html pages from the scripts (as Quarto notebooks)
- github.com/MarineSensitivity/workflows
  source code in the Github repository

10 APIs

There three APIs, each used for different purposes:

1. **api**
   custom API: using R plumber
   source: MarineSensitivity/api
   

2. **swagger**
   generic database API: using PostGREST
   source: Postgres database, non-spatial
   

3. **tile**
   spatial database API: using pg_tileserv for serving vector tiles

source: Postgres database, spatial

pg_tileserv

Service Metadata

- **index.json** for layer list

Table Layers

- **aquamaps.cells** (preview | json)
- **public.ply_rgns** (preview | json)
- **public.ply_rgns_s05** (preview | json)
- **public.ply_shlfs** (preview | json)
- **public.ply_shlfs_s05** (preview | json)
- **public.sdm_geometries** (preview | json)
- **raw.boem_ak_blk_clp** (preview | json)
- **raw.boem_ak_prot_clp** (preview | json)
- **raw.boem_atl_alq** (preview | json)
- **raw.boem_atl_blk_clp** (preview | json)
- **raw.boem_atl_prot_clp** (preview | json)
- **raw.boem_gom_blk_clp** (preview | json)
- **raw.boem_gom_prot_clp** (preview | json)
- **raw.boem_pc_alq** (preview | json)
- **raw.boem_pc_blk_clp** (preview | json)
- **raw.boem_pc_prot_clp** (preview | json)
- **raw.boem_usa_mhk_plan** (preview | json)
- **raw.boem_usa_wind_lease** (preview | json)
- **raw.boem_usa_wind_plan** (preview | json)
- **raw.mr_eez** (preview | json)

Function Layers

- **public.sdm_spatial** (preview | json)
  Serves the Species Distribution Model given parameters: dataset_key, species_key, popn, time_interval, variable.

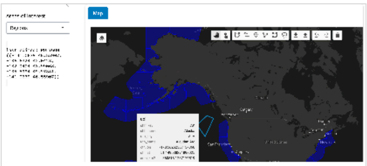
11 Libraries

By creating an R package, we can document functions and make them easily available to other users.

- `msens`
  R library of functions for mapping marine sensitivities, sponsored by BOEM

Functions can ***read*** data from the one APIs (which communicate with the Database), ***analyze*** the data, ***visualize*** the results and store some smaller ***data***.

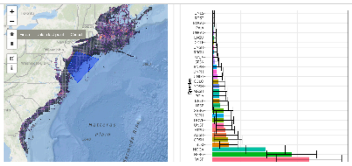
12 Apps



Areas of Interest

AREAS VECTOR

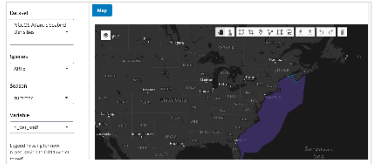
Map high resolution Areas of Interest (using vector tiles) for visualization (and later summarization).



Bird Hotspots

DISTRIBUTIONS HOTSPOTS

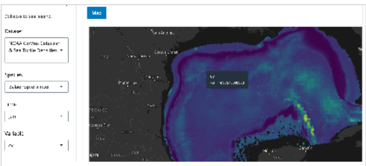
Bird hotspots application showing hotspot probability for species present given drawn Area of Interest.



Distributions, Raster

DISTRIBUTIONS RASTER

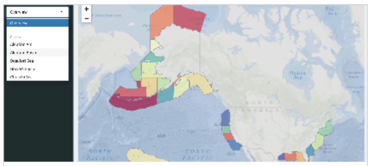
Show species distributions with high resolution rasters as cloud-optimized GeoTIFFs (COGs).



Distributions, Vector

DISTRIBUTIONS VECTOR

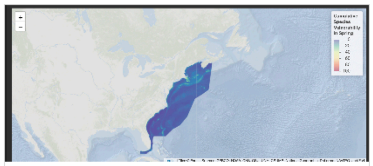
Show species distributions with high resolution vectors (as vector tiles).



Regional Map

AREAS

Basic interactive map of BOEM regions.



Vulnerability Mapper

DISTRIBUTIONS VULNERABILITIES RASTER

Combine species distribution models (raster) and vulnerability metrics (tables) to identify areas of high conservation concern.

See also details of individual applications in the Appendix.

13 Docs

Technical documentation is principally in this book:

- marinesensitivity.org/docs
  the main documentation site
- github.com/MarineSensitivity/docs
  source code in the Github repository

But there are also some other self-documenting resources:

- marinesensitivity.org/`msens`
  documented R functions

14 Summary

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References

Goodale, M. Wing, and Anita Milman. 2016. “Cumulative Adverse Effects of Offshore Wind Energy Development on Wildlife.” *Journal of Environmental Planning and Management* 0 (0): 1–21. https://doi.org/10.1080/09640568.2014.973483.

Ross, Pauline M., Elliot Scanes, Maria Byrne, Tracy D. Ainsworth, Jennifer M. Donelson, Shawna A. Foo, Pat Hutchings, Vengatesen Thiyagarajan, and Laura M. Parker. 2023. “Surviving the Anthropocene: The Resilience of Marine Animals to Climate Change.” In. CRC Press.

Glossary

acclimatisation the adjustment of an organism to environmental conditions in the field or environment rather than the laboratory without an adjustment in their genetics. Acclimatisation has been used to describe phenotypically plastic responses in natural conditions. Source: Ross et al. (2023).

adaptation the evolutionary mechanism where natural selection of traits is genetically passed on, typically over many generations, to create an organism suited to the environment. Source: [rossRoss et al. (2023)

adaptive capacity the capacity of the ecosystem or organism to improve and reorganise in response to stress such as climate change through phenotypic plasticity (acclimation, acclimatisation) or adaptation, distributional shifts, and rapid evolution of traits suited to new conditions. Source: Ross et al. (2023).

epigenetics the modification of phenotype plasticity of an organism through altered gene expression without an alteration to the DNA sequence. 'Epi' means above the DNA and includes DNA methylation, modification of histones, and non-coding RNA. Source: Ross et al. (2023).

exposure the magnitude of the change in the environment

fecundity the maximum physiological potential reproductive output of an organism to produce offspring (reproductive output). This differs from fertility, which is the number of offspring born. Source: Ross et al. (2023)

MBON Marine Biodiversity Observation Network; see MarineBON.org

resilience the capacity of an ecosystem, society, or organism to absorb disturbance and reorganise while undergoing change so as to retain essentially the same function, structure, identity, and feedbacks. Resilience reflects the degree to which a complex adaptive system is determined by its capacity to reorganise and adapt in order to avoid being disturbed again. Source: Ross et al. (2023).

sensitivity the magnitude of response to the change

stressor the stimulus that causes stress to an organism

vulnerability combination of exposure and sensitivity

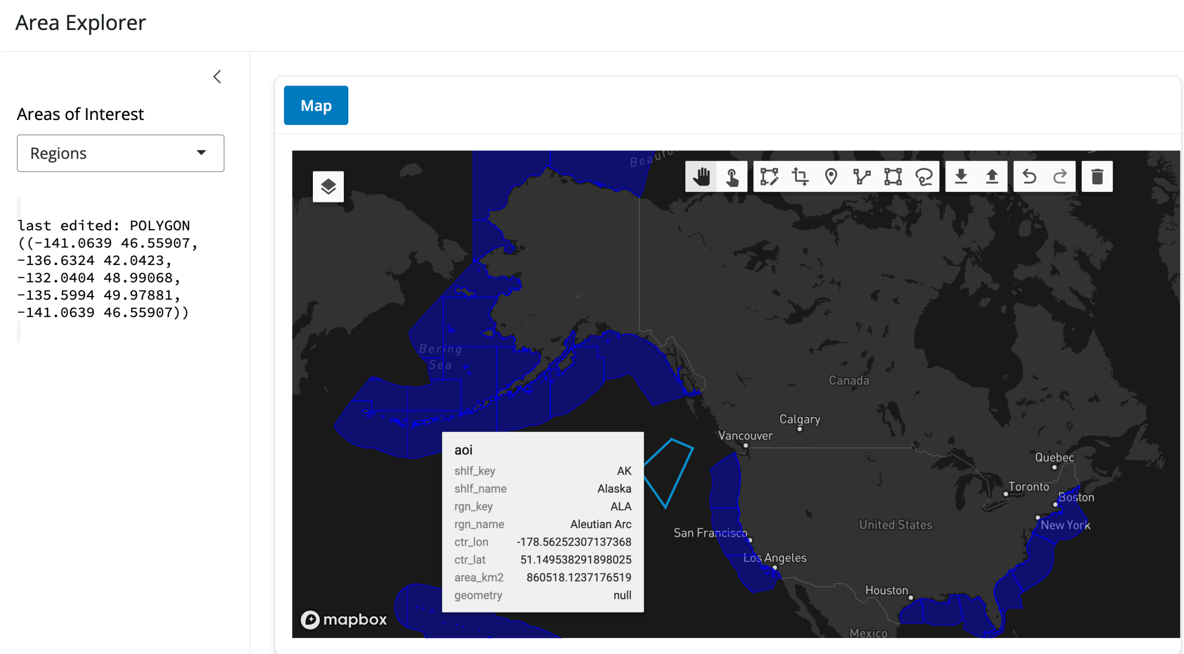
Part III

Applications

Areas of Interest

Map high resolution Areas of Interest (using vector tiles) for visualization (and later summarization).

- website
- code



Bird Hotspots

Bird hotspots application showing hotspot probability for species present given drawn Area of Interest.

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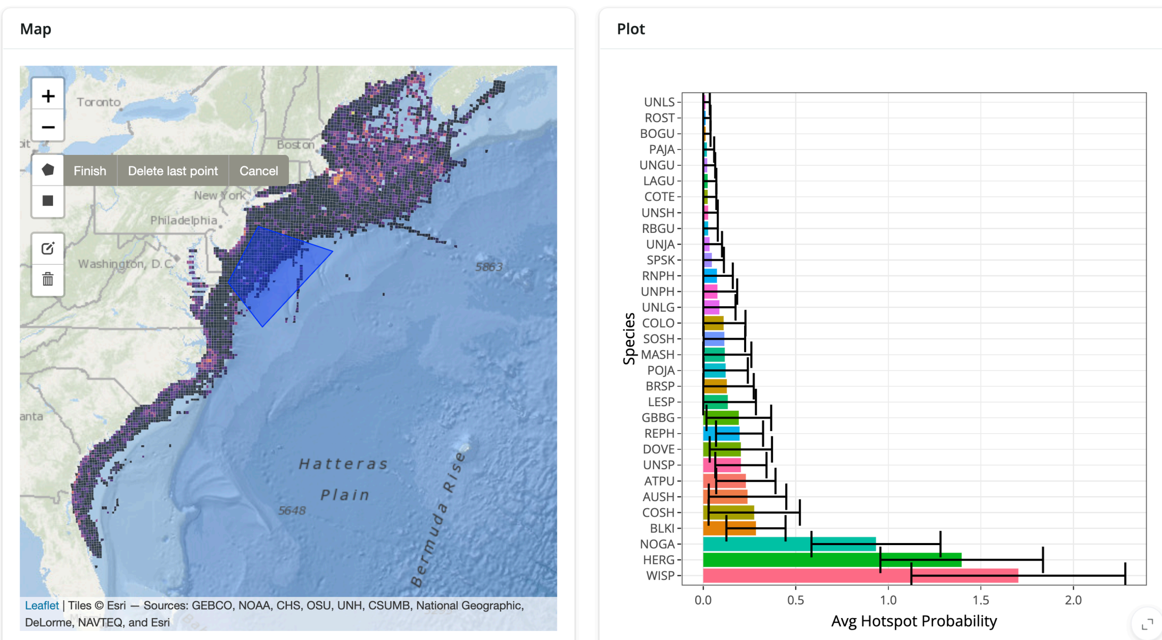

Regional Map

Basic interactive map of BOEM regions.

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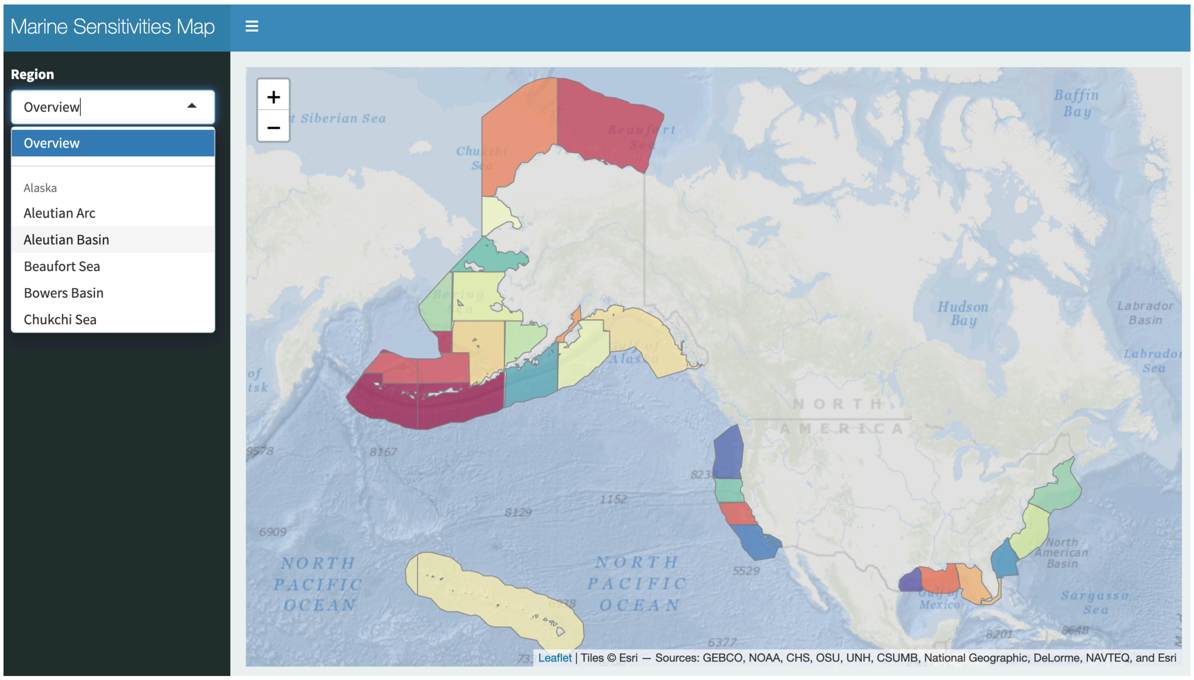
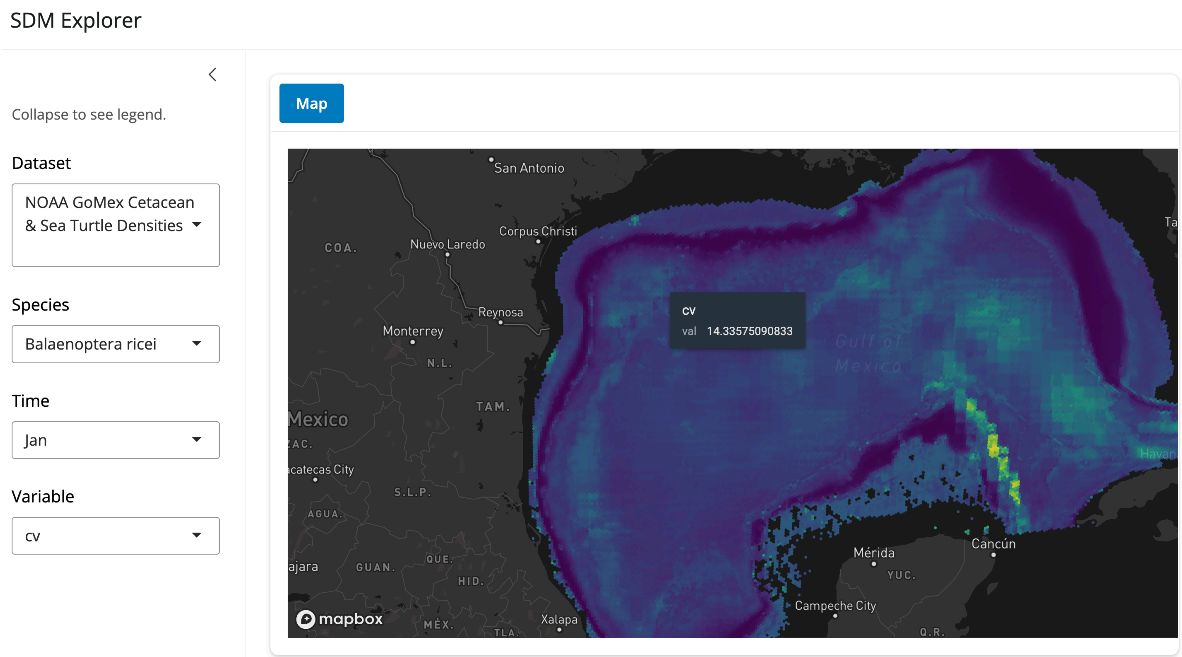


Distributions, Vector

Show species distributions with high resolution vectors (as vector tiles).

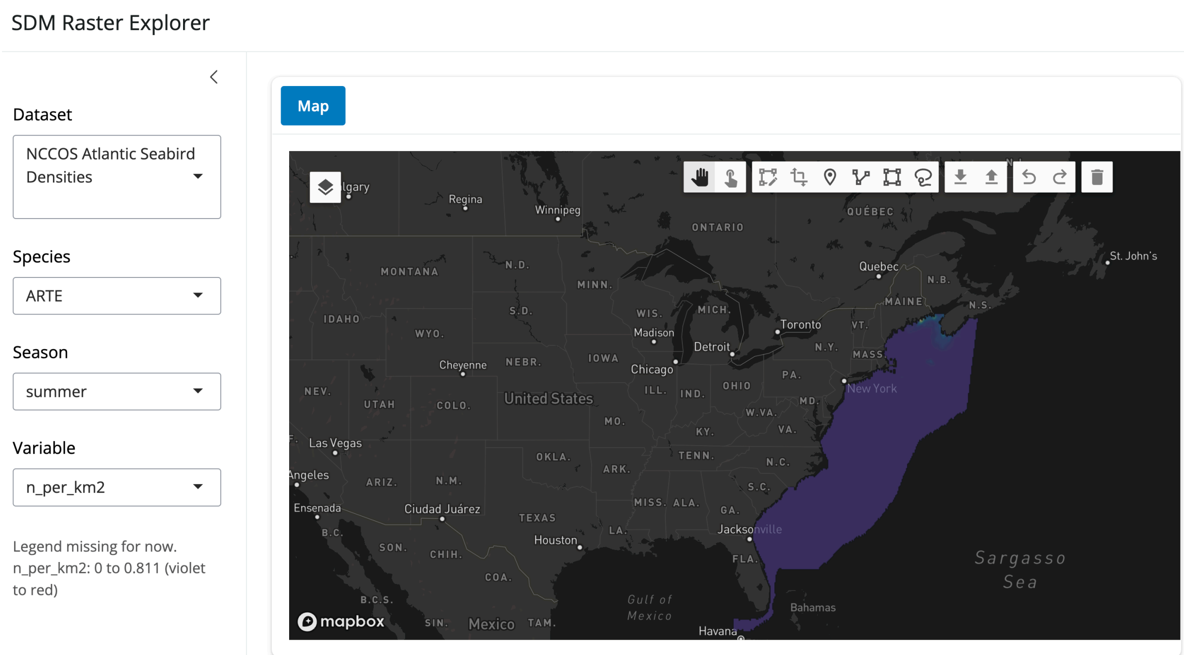
- website
- code



Distributions, Raster

Show species distributions with high resolution rasters as cloud-optimized GeoTIFFs (COGs).

- website
- code



Vulnerability Mapper

Combine species distribution models (raster) and vulnerability metrics (tables) to identify areas of high conservation concern.

- website
- `code`