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.

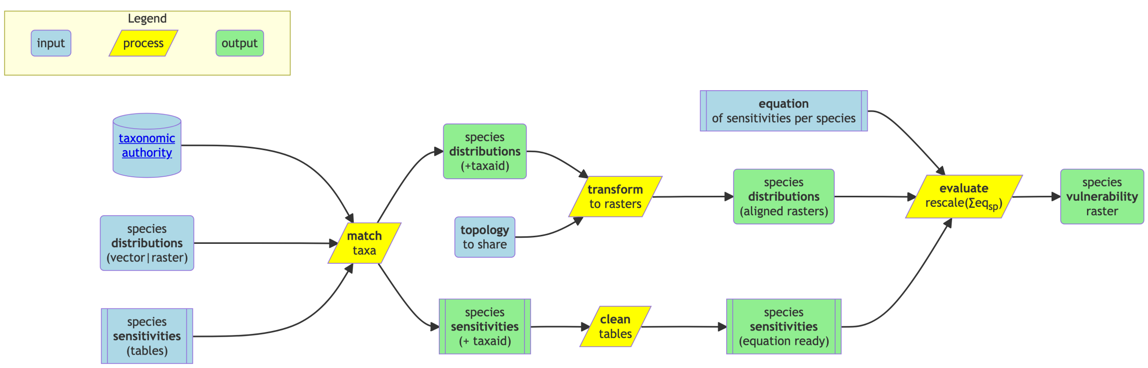


Figure 1.1: Flowchart of process for incorporating marine species sensitivities with distributions and generating a holistic vulnerability map.

Part I

Science

2 Science

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

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

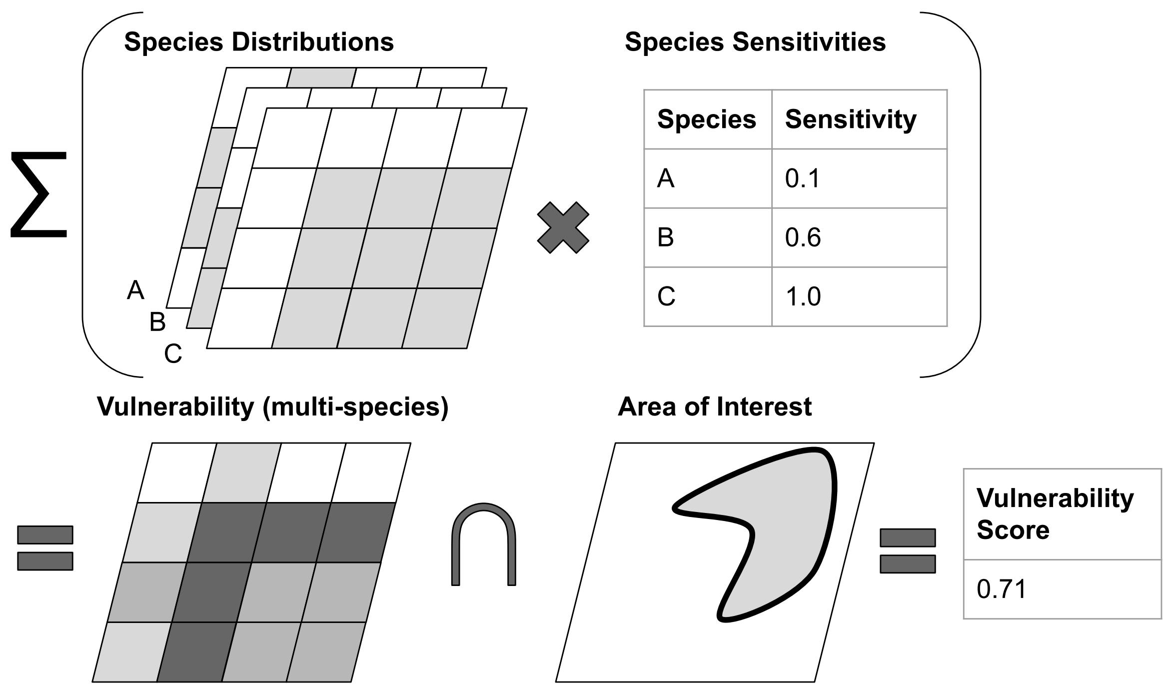


Figure 2.1: Overview of process.

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

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).

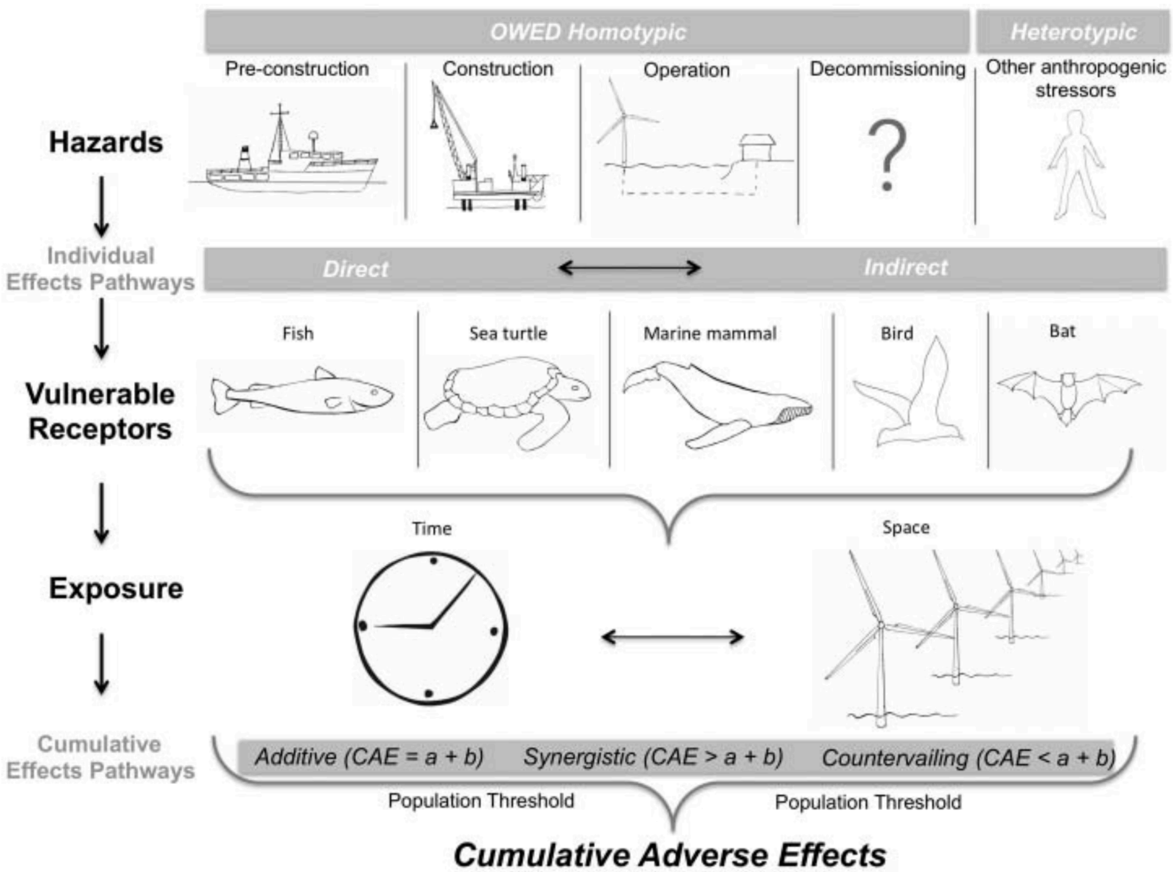


Figure 3.1: Cumulative adverse effects of offshore wind energy development on wildlife (Goodale and Milman 2016).

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

Primary productivity is specified in the explicit mandate for BOEM's management, per the Outer Continental Shelf Lands Act (OCSLA), Section 18(a)(2) of the OCSLA Amendments of 1978 specifying 8 factors the USDOI must consider in the timing and location of OCS oil and gas activities, including "the relative environmental sensitivity and marine productivity of different areas of the OCS." (Balcom et al. 2011)

We processed the Vertically Generalized Production Model (VGPM) product from Oregon State's Ocean Productivity Lab (using the script vg.R) (Figure 4.1).

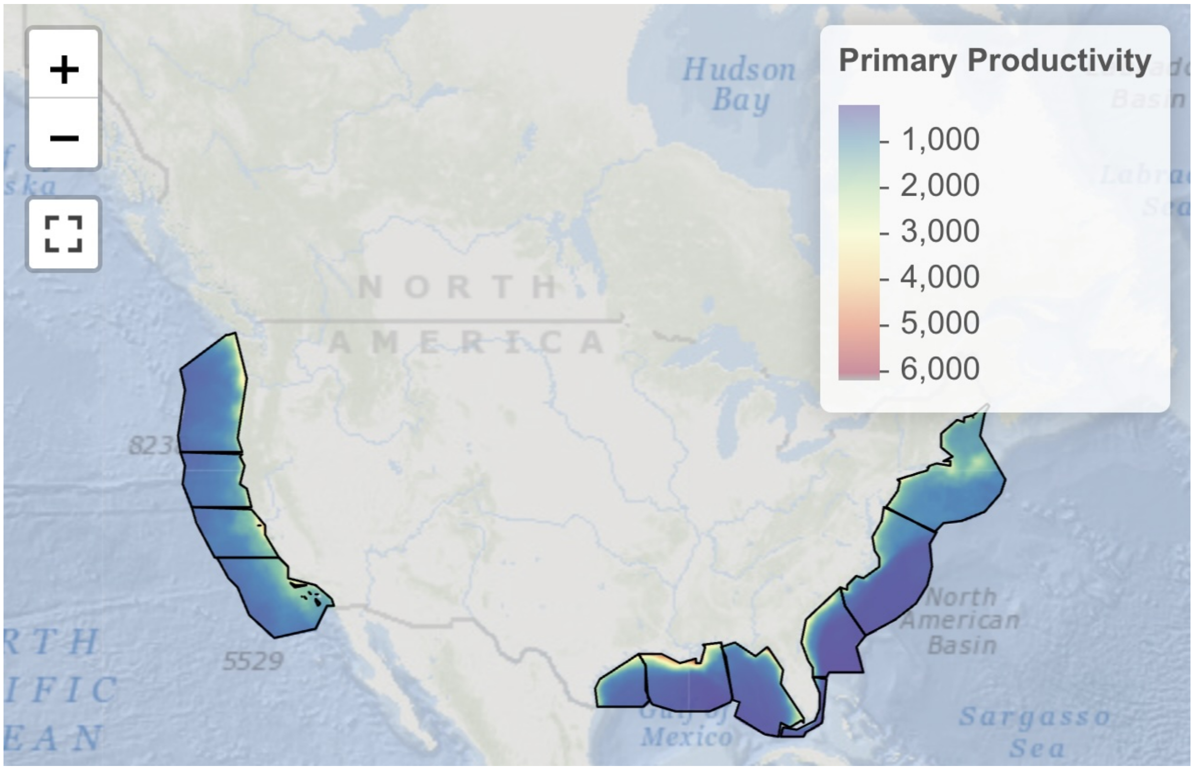


Figure 4.1: Primary productivity throughout the continental United States averaged across months of 2021, as measured by Oregon State's Vertically Generalized Production Model (VGPM). Expansion is anticipated across the entire US EEZ and for more recent years.

5 Exposure

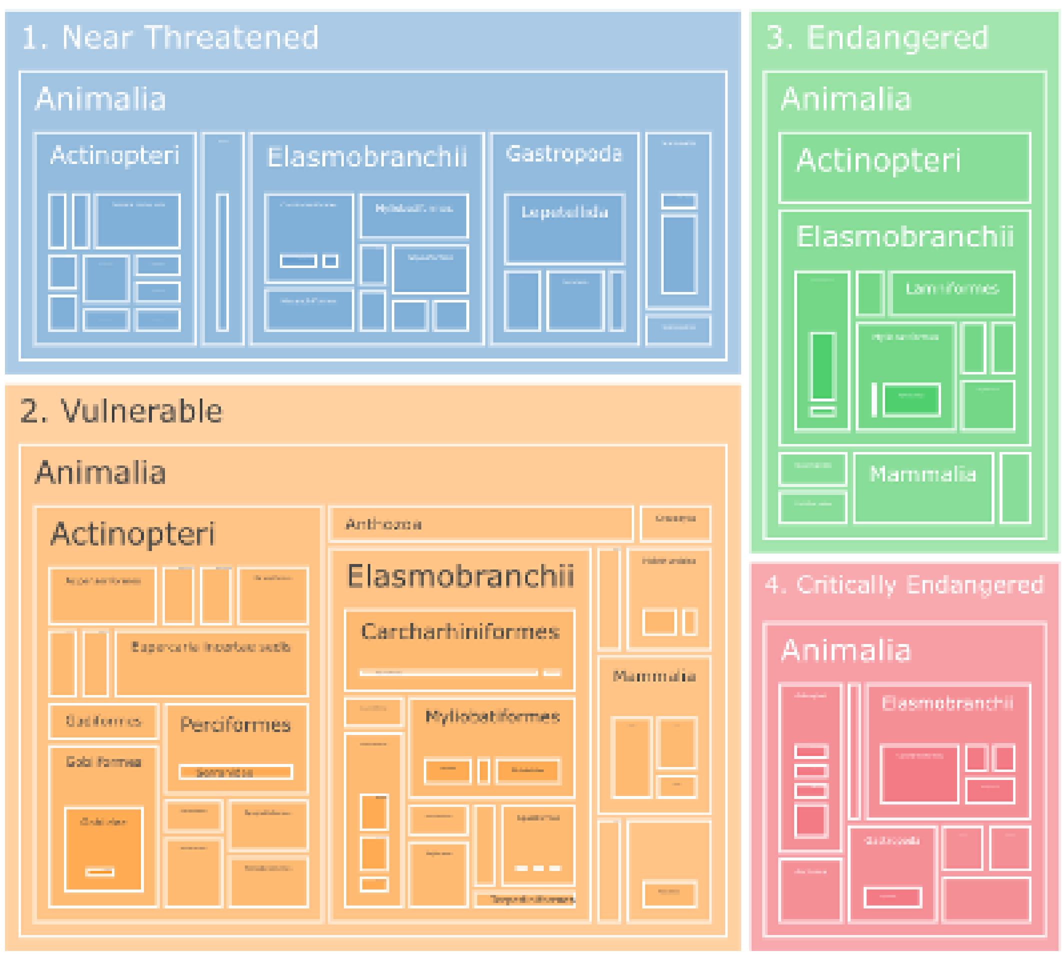
Cumulative exposure (Figure 3.1) is important for understanding impacts to a population.

6 Scoring

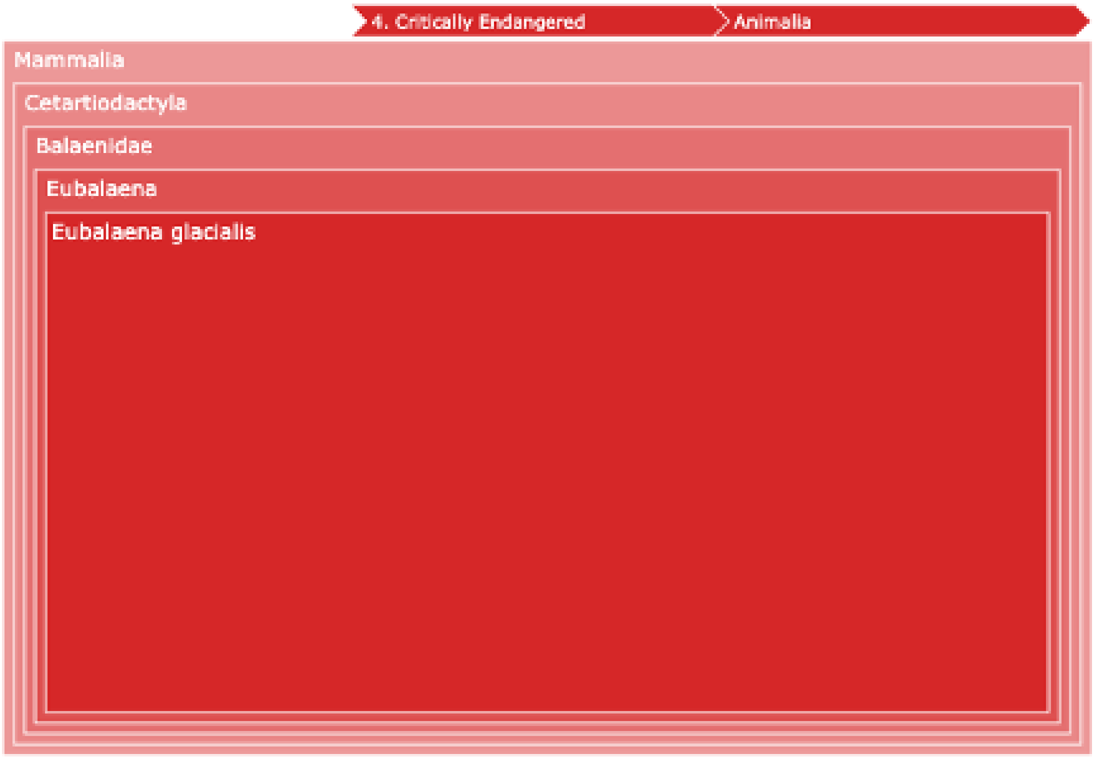
6.1 Visualization

We are in process with sorting the scoring methodology informed by visualization approaches.

6.1.1 Treemap



- Audience: scientists
- Show contribution of each element to a given pixel or area of interest
- Elements can be hierarchical across Sensitivity metrics and/or taxonomy
- Interactively zoom, e.g.: 4. Critically Endangered > Animalia > Mammalia



6.1.2 Flower Plot

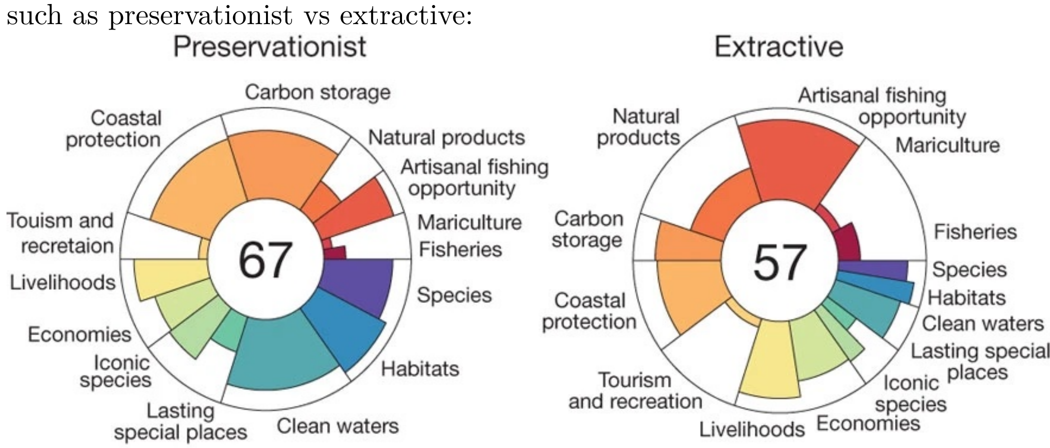
- **Petal Length**
  "One question was about the meaning of the numbers on the pedal plot. I explained that a higher sensitivity score indicates an area that could be susceptible to minor perturbations, while a lower score suggests an area that is more robust to minor changes." - TW

  - **OHI**
    In the original Ocean Health Index (Halpern et al. 2012), the length of the petal reflected the percent towards maximum sustainability of the given goal. The framework is also based on a reference point, either spatially or temporally (Samhouri et al. 2012).

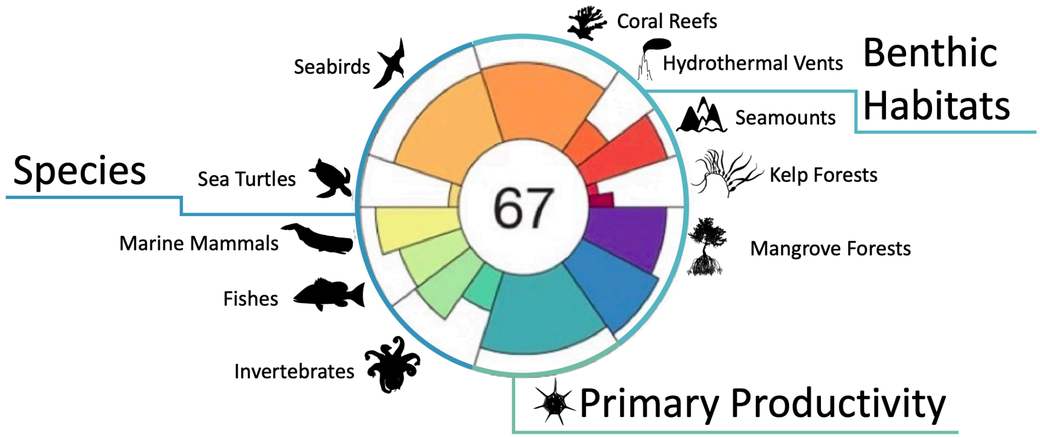
– **RESA ’25**
It makes sense to make the most vulnerable the highest score, so a low score is preferable (versus a preferred high score for sustainability of an OHI goal). We'll need to determine what the "highest" score means as a reference point and consider SMART criteria. (Specific, Measurable, Assignable, Realistic, Time-related). Will the reference point be the same globally or vary based on some regional maximum?

- **Petal Width** (and possiblyvarying weights)
"Another question was about how we manage the weights. I mentioned that we are not currently applying weights, but someone seemed concerned about it. We can discuss this further if needed." - TW

  – **OHI**
  For the OHI flower plot, the width of the petal represents its weight contributing to the weighted average score in the center of the flower. The varying importance of each goal is based on societally held values with potentially different value sets, such as preservationist vs extractive:



  – **RESA ’25**
  For the RESA ’25, when looking at Species, Habitats and Primary Productivity, how shall they be weighted to factor into a final score? Shall species groups be simply weighted based on the number of species within, total biomass, extinction risk, commercial value, etc? And then Species versus less numerous Benthic Habitats and a singular value for Primary Productivity? I will conduct a literature survey to assign sensible value sets, but an App could also apply a user-defined value set to assign weights. That gets messy, but if transparent and easy ideally would lead to scientific consensus with a workshop and/or survey.


Coral Reefs
Hydrothermal Vents
Benthic Habitats
Seabirds
Seamounts
Species
Sea Turtles
67
Kelp Forests
Marine Mammals
Mangrove Forests
Fishes
Invertebrates
Primary Productivity

Part II

Software

7 Software

The **Marine Sensitivity Toolkit** (MST) is a stack of software components for reproducibly, interactively and hierarchically generating environmental vulnerability maps and scores. Tabular data is collated across studies evaluating sensitivity of species to oil & gas and offshore wind energy development. The best available species and benthic habitat distributions are being mosaicked across the US EEZ. Scores will be summarized according to subgroups within Species, Benthic Habitats and Primary Productivity. These scores will be averaged into an overall score and visualized as a flower plot, applicable to various levels of BOEM relevancy: regional, ecoregions, protraction diagrams, blocks and aliquots. The software components for achieving this interactively are: 1) server — a Docker configuration to spin up all the software; 2) database — a spatially enabled database (PostgreSQL with PostGIS extension); 3) workflows — scripts (as Quarto notebooks) to explore, ingest and update the database and output files; 4) APIs — application programming interfaces for rendering vector (using pg_tileserv) or raster (using TiTiler) tile services for interactive mapping as well as a custom API (using R plumber); 5) libraries — re-usable documented functions as an R package for import, analysis and visualization using the APIs; 6) applications — interactive apps using the R Shiny framework for rendering vulnerability maps; and 7) documentation — as a Quarto notebook with figures, tables, glossary and references in interactive html or static docx/pdf output formats. This toolbox is intended to primarily serve BOEM needs internally, but by being open-source and fully reproducible the hope is to enlist buy-in and even contributions from external partners, whether from other government agencies, academia, NGOs or industry.

We ascribe to the philosophy of sharing all code for the sake of reproducibility, transparency and efficiency (Maitner et al. 2024; Lowndes et al. 2017); i.e. the FAIR principles of Findability, Accessibility, Interoperability, and Reusability (Wilkinson et al. 2016).

7.0.1 Interactive Applications

We have developed a series of interactive applications to explore the data and results of the MST 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 (Chang et al. 2024), 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.

7.0.2 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.

7.0.2.1 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 7.1).

7.0.2.2 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

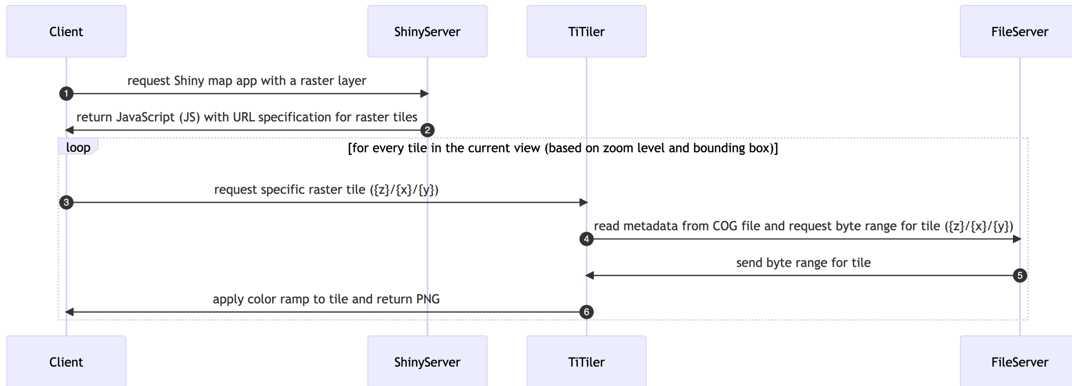


Figure 7.1: Sequence diagram implementing large raster interactive display using Cloud-Optimized GeoTIFFs (COGs) and Titiler in a Shiny mapping app.

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 7.2).

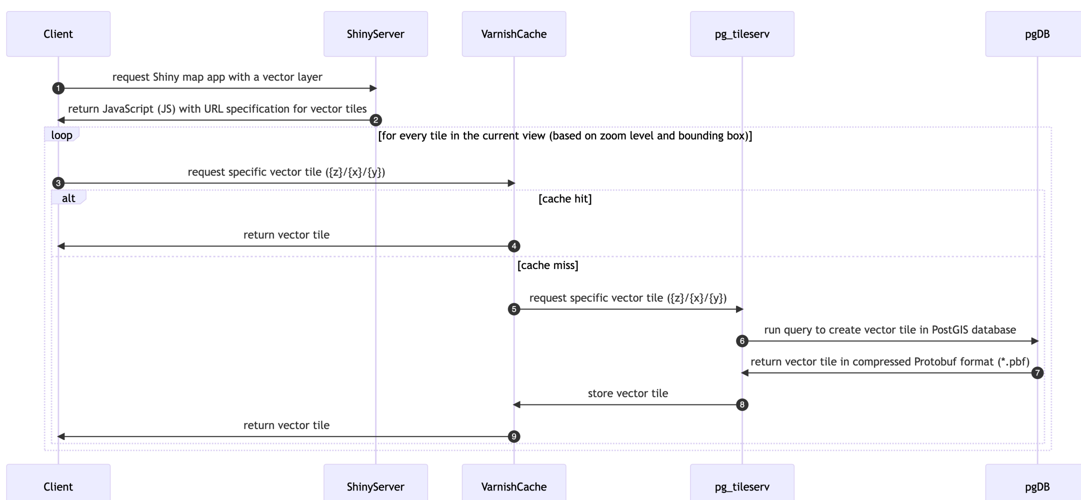


Figure 7.2: Sequence diagram implementing large vector interactive display using Mapbox Vector Tiles (MVTs) and pg_tileserv in a Shiny mapping app.

7.0.3 Github Repositories

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

7.0.4 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

8 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).

8.1 Setup

For the latest instructions on launching an Amazon instance and installing the server software, see Server Setup · MarineSensitivity/server Wiki, which is pasted below for convenience…

on AWS as EC2 instance using Docker

8.1.1 launch instance

name: **msens1**:

- Software Image (AMI)
  Canonical, **Ubuntu**, 22.04 LTS, amd64 jammy image build on 2023-09-19 ami-0fc5d935ebf8bc3bc
- Virtual server type (instance type)
  t2.xlarge (4 vCPU, 16 GB memory)

- Firewall (security group)
  New security group
- Storage (volumes)
  2 volume(s)
  - **20 GB**
    `/` server software, disposable
  - **60 GB**
    `/share` for all data, persistent and to be backed up

8.1.1.1 allocate IP address

- Elastic IP addresses | EC2 | us-east-1 for persistent IP address
- Allocated IPv4 address: `100.25.173.0`
- Associate Elastic IP address

8.1.2 ssh to server

```
pem='/Users/bbest/My Drive/private/msens_key_pair.pem'
ssh -i $pem ubuntu@msens1.marinesensitivity.org
```

8.1.2.1 set hostname

- Change the hostname of your Amazon Linux instance - Amazon Elastic Compute Cloud

```
sudo vi /etc/cloud/cloud.cfg
# preserve_hostname: true
sudo hostnamectl set-hostname msens1.marinesensitivity.org
sudo reboot
```

8.1.2.2 mount volume

The extra volume (60 GB for `/share`) was added during EC2 launch instance wizard, but needs to be mounted before available for use.

- Make an Amazon EBS volume available for use on Linux - Amazon Elastic Compute Cloud

```
df -H
```

```
Filesystem      Size  Used Avail Use% Mounted on
/dev/root        21G  2.3G   19G  11% /
tmpfs           8.4G     0  8.4G   0% /dev/shm
tmpfs           3.4G  898k  3.4G   1% /run
tmpfs           5.3M     0  5.3M   0% /run/lock
/dev/xvda15     110M  6.4M  104M   6% /boot/efi
tmpfs           1.7G  4.1k  1.7G   1% /run/user/1000
```

```
lsblk
```

```
NAME     MAJ:MIN RM   SIZE RO TYPE MOUNTPOINTS
loop0      7:0    0  24.6M  1 loop /snap/amazon-ssm-agent/7528
loop1      7:1    0  55.7M  1 loop /snap/core18/2790
loop2      7:2    0  63.5M  1 loop /snap/core20/2015
loop3      7:3    0 111.9M  1 loop /snap/lxd/24322
loop4      7:4    0  40.8M  1 loop /snap/snapd/20092
xvda     202:0    0    20G  0 disk
 xvda1  202:1    0  19.9G  0 part /
 xvda14 202:14   0     4M  0 part
 xvda15 202:15   0   106M  0 part /boot/efi
xvdb     202:16   0    60G  0 disk
```

```
sudo file -s /dev/xvdb
# /dev/xvdb: data
```

So no file system on `/dev/xvdb` yet.

```
sudo mkfs -t xfs /dev/xvdb
sudo mkdir /share
sudo mount /dev/xvdb /share
```

```
sudo cp /etc/fstab /etc/fstab.orig
sudo blkid
# /dev/xvdb: UUID="bc766dfb-1c42-49cf-9320-2242a2d48a2e" BLOCK_SIZE="512" TYPE="xfs"
sudo vim /etc/fstab
# UUID=bc766dfb-1c42-49cf-9320-2242a2d48a2e  /share  xfs  defaults,nofail  0  2

df -h
sudo umount /share ; df -h
sudo mount -a      ; df -h
```

8.1.3 install docker

Following:

- Step-by-Step Guide to Install Docker on Ubuntu in AWS | by Srija Anaparthy | Medium

```
sudo apt-get update
#OLD: sudo apt-get install docker.io -y
```

NEW: [[Migrate to `docker compose`]]

```
sudo systemctl start docker
sudo docker run hello-world
sudo systemctl enable docker
docker --version
# Docker version 24.0.6, build ed223bc
sudo usermod -a -G docker $(whoami)
```

8.1.3.1 run docker compose

- /Users/bbest/My Drive/private/`msens_server_env-password.txt`

```
sudo chown -R ubuntu:ubuntu /share
mkdir -p /share/github/MarineSensitivity
cd /share/github/MarineSensitivity
# clone server repo
git clone https://github.com/MarineSensitivity/server.git
cd server

# add password, used as $PASSWORD in docker-compose.yml
echo 'PASSWORD=******' > .env

# launch docker instances
sudo docker-compose up -d
```

8.1.4 Backup `/share` with snapshots

Per Automate snapshot lifecycles - Amazon Elastic Compute Cloud, created two policies:

- **bkup__msens-share__daily** every 24 hrs at 09:00 UTC, max of 7
- **bkup__msens-share__weekly** every Monday 09:00 UTC, max of 8

8.2 Docker compose

The Docker compose file is used to define and run multi-container Docker applications. Here is the `docker-compose.yml` file for the server pasted for convenience …

```yaml
version: "3.9"

services:
  caddy:
    container_name: caddy
    image: caddy:latest
    ports:
      - 80:80
      - 443:443
    restart: unless-stopped
    volumes:
      - ./caddy/Caddyfile:/etc/caddy/Caddyfile
      - /share:/share
      - /share/caddy/data:/data
      - /share/caddy/config:/config

  rstudio:
    container_name: rstudio
    build: ./rstudio
    environment:
      ROOT: 'true'
      USER: admin
      PASSWORD: ${PASSWORD}
      ADD: shiny
    ports:
      - 8787:8787  # rstudio
      - 3838:3838  # shiny
    restart: unless-stopped
    volumes:
      - /share:/share
      - /share/shiny_apps:/srv/shiny-server

  plumber:
    container_name: plumber
    build: ./plumber
    ports:
      - 8888:8888  # api
```

```yaml
    restart: unless-stopped
    volumes:
      - /share:/share
    depends_on:
      - postgis

  postgis:
    container_name: postgis
    image: postgis/postgis:latest
    environment:
      POSTGRES_DB: msens
      POSTGRES_USER: admin
      POSTGRES_PASSWORD: ${PASSWORD}
      ANON_PASSWORD: ${ANON_PASSWORD}
      PGDATA: /share/postgis/data
    volumes:
      # all files in /docker-entrypoint-initdb.dare automatically executed
      #  in alphabetical order on container creation
      - ./postgis/init.sh:/docker-entrypoint-initdb.d/init.sh  # add user anon
      - /share:/share
      - /share/postgis:/var/lib/postgresql
    restart: unless-stopped
    healthcheck:
      test: 'exit 0'
    ports:
      - 5432:5432

  pgadmin:
    container_name: pgadmin
    image: dpage/pgadmin4:latest
    restart: always
    environment:
      PGADMIN_DEFAULT_EMAIL: ben@ecoquants.com
      PGADMIN_DEFAULT_PASSWORD: ${PASSWORD}
      PGADMIN_LISTEN_PORT: 8088
      # PGADMIN_CONFIG_CONFIG_DATABASE_URI: "'postgresql://admin:$PASSWORD@postgis:5432/msens
    ports:
      - 8088:8088
    volumes:
      - /share/pgadmin:/var/lib/pgadmin
    depends_on:
      - postgis
```

```yaml
pgbkups:
  container_name: pgbkups
  image: prodrigestivill/postgres-backup-local
  restart: always
  user: postgres:postgres # Optional: see below
  volumes:
    - /share/postgis_backups:/backups
    # sudo mkdir /share/postgis_backups; sudo chown -R 999:999 /share/postgis_backups
  links:
    - postgis
  depends_on:
    - postgis
  environment:
    - POSTGRES_HOST=postgis
    - POSTGRES_DB=msens
    - POSTGRES_USER=admin
    - POSTGRES_PASSWORD=${PASSWORD}
    - POSTGRES_EXTRA_OPTS=-Z6 --blobs
    - SCHEDULE=@daily
    - BACKUP_KEEP_DAYS=7
    - BACKUP_KEEP_WEEKS=4
    - BACKUP_KEEP_MONTHS=6
    - HEALTHCHECK_PORT=8088

tile:
  container_name: tile
  environment:
    DATABASE_URL: 'postgresql://admin:${PASSWORD}@postgis:5432/msens'
  image: pramsey/pg_tileserv:latest
  depends_on:
    - postgis
  ports:
    - 7800:7800

tilecache:
  container_name: tilecache
  image: varnish:latest # 7.4.2  # last updated: 2023-12-26
  volumes:
    - /share:/share
    # - "./varnish/default.vcl:/etc/varnish/default.vcl"
  ports:
    - 6081:6081
```

```yaml
    environment:
      # VARNISH_SIZE: '2G'
      VARNISH_BACKEND_HOST: tile # .marinesensitivity.org
      VARNISH_BACKEND_PORT: 7800
      VARNISH_HTTP_PORT: 6081  # VARNISH_PROXY_PORT: '6081'
    #command: "-p default_keep=43200" # 60*60*12 = 43200 sec = 12 hrs
    restart: always
    depends_on:
      - "tile"

  rest:
    container_name: rest
    environment:
      PGRST_DB_URI: 'postgresql://anon:${ANON_PASSWORD}@postgis:5432/msens'
      PGRST_OPENAPI_SERVER_PROXY_URI: http://127.0.0.1:3000
      PGRST_DB_ANON_ROLE: anon  # db-anon-role
    image: postgrest/postgrest
    depends_on:
      - postgis
    ports:
      - "3000:3000"

  swagger:
    container_name: swagger
    image: swaggerapi/swagger-ui
    depends_on:
      - rest
    ports:
      - "8080:8080"
    expose:
      - "8080"
    environment:
      API_URL: https://rest.MarineSensitivity.org/

  titiler:
    container_name: titiler
    image: ghcr.io/developmentseed/titiler:latest
    environment:
      PORT: 8000
      # WORKERS_PER_CORE: 1
    ports:
      - "8000:8000"
```

8.3 DNS

The domain name server (DNS) records are managed by SquareSpace. The subdomains point to the server on Amazon at `100.25.173.0`, whereas the main website is hosted by Github servers, per Managing a custom domain for your GitHub Pages site - GitHub Docs.

Host	Type	Data
@	A	185.199.111.153
@	A	185.199.110.153
@	A	185.199.109.153
@	A	185.199.108.153
api	A	100.25.173.0
file	A	100.25.173.0
msens1	A	100.25.173.0
pgadmin	A	100.25.173.0
rest	A	100.25.173.0
rstudio	A	100.25.173.0
shiny	A	100.25.173.0
swagger	A	100.25.173.0
tile	A	100.25.173.0
tilecache	A	100.25.173.0
titiler	A	100.25.173.0
www	CNAME	marinesensitivity.org

8.4 Caddyfile

The Caddyfile parameterizes the reverse proxying between the external subdomains and the Docker's internal ports. Here is the `Caddyfile` pasted for convenience …

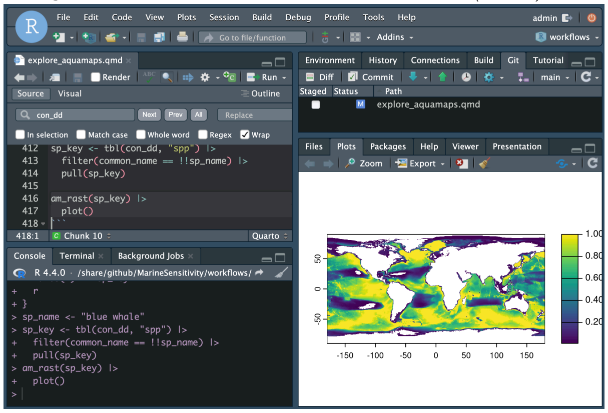
```
api.marinesensitivity.org {
  reverse_proxy plumber:8888
}

file.marinesensitivity.org {
  root * /share/public
  file_server browse {
    # serve *.zst, *.br or *.gz if file exists and client supports precompressed files
```

```
    precompressed zstd br gzip
  }
}

pgadmin.marinesensitivity.org {
  reverse_proxy pgadmin:8088
}

rest.marinesensitivity.org {
  reverse_proxy rest:3000
}

rstudio.marinesensitivity.org {
  reverse_proxy rstudio:8787
}

shiny.marinesensitivity.org {
  reverse_proxy rstudio:3838
}

swagger.marinesensitivity.org {
  reverse_proxy swagger:8080
}

tile.marinesensitivity.org {
  reverse_proxy tile:7800
}

tilecache.marinesensitivity.org {
  reverse_proxy tilecache:6081
}

titiler.marinesensitivity.org {
  reverse_proxy titiler:8000
}
```

8.5 Services

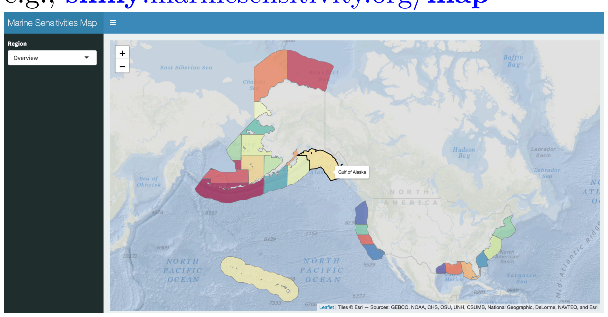
The server is running the following services:

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

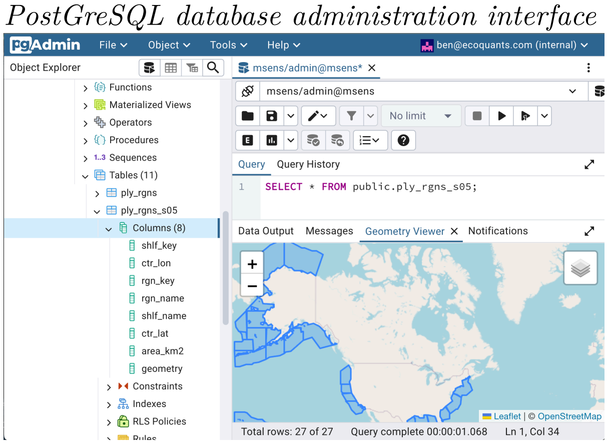
  More info..

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

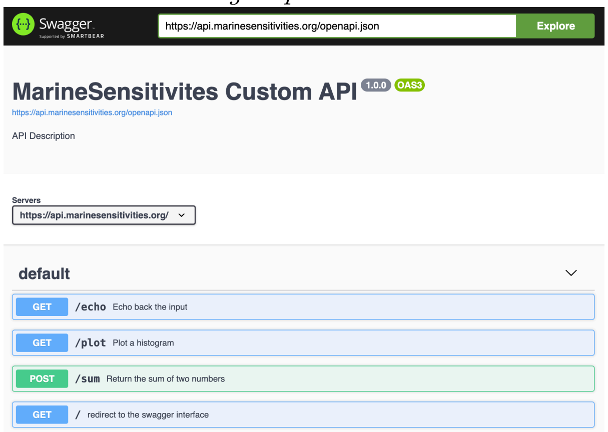
  

  More info..

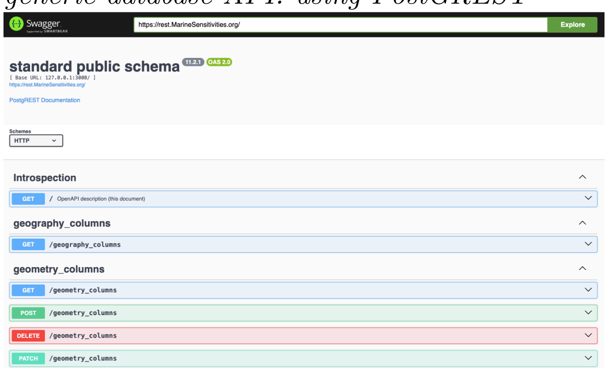
- **PGadmin**
  PostGreSQL database administration interface

  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

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.

More info..

•••

9 Database

9.1 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.

9.2 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

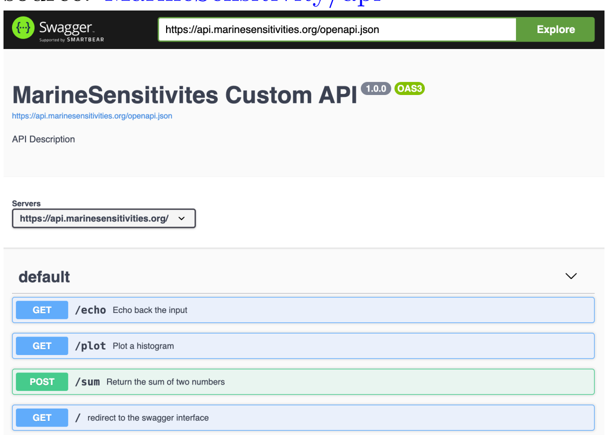
10 Workflows

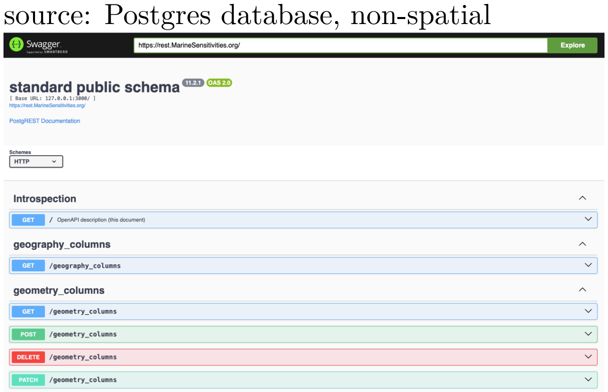
Workflows are scripts for testing data analytics and visualization as well as production workflows for ingesting data. See:

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

11 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)
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- **raw.boem_pc_prot_clp** (preview | json)
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Function Layers

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

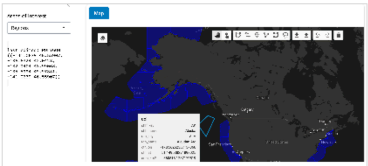
12 Libraries

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***.

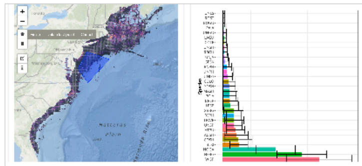
13 Apps



Areas of Interest

AREAS VECTOR

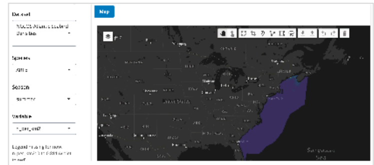
Map high resolution Areas of Interest (using vector tiles) for visualization (and later summarization).



Bird Hotspots

DISTRIBUTIONS HOTSPOTS

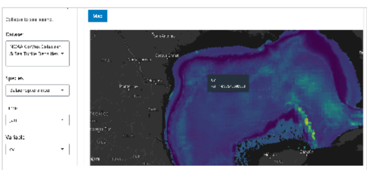
Bird hotspots application showing hotspot probability for species present given drawn Area of Interest.



Distributions, Raster

DISTRIBUTIONS RASTER

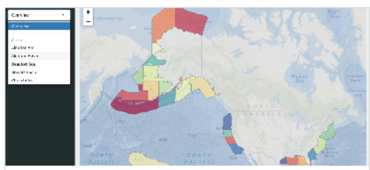
Show species distributions with high resolution rasters as cloud-optimized GeoTIFFs (COGs).



Distributions, Vector

DISTRIBUTIONS VECTOR

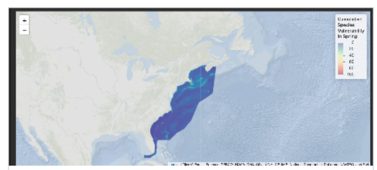
Show species distributions with high resolution vectors (as vector tiles).



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.

14 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

15 Summary

...

References

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Wilkinson, Mark D., Michel Dumontier, IJsbrand Jan Aalbersberg, Gabrielle Appleton, Myles Axton, Arie Baak, Niklas Blomberg, et al. 2016. "The FAIR Guiding Principles for Scientific Data Management and Stewardship." *Scientific Data* 3 (1): 160018. https://doi.org/10.1038/sdata.2016.18.

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

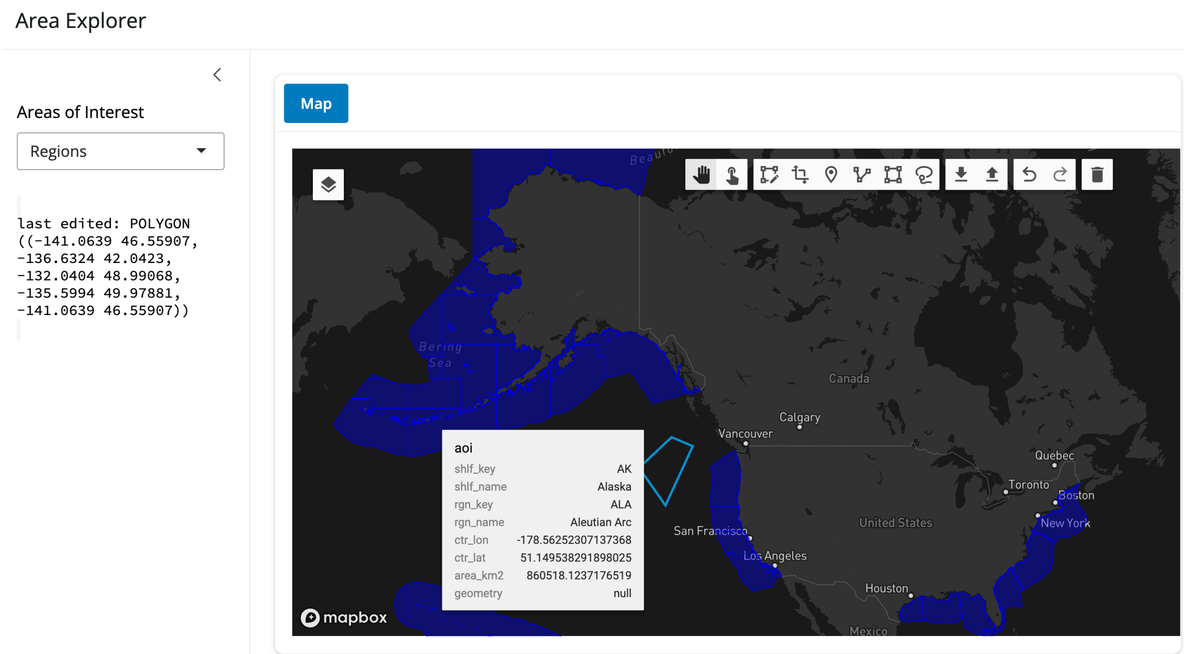
Part III

Applications

Areas of Interest

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

- website
- code



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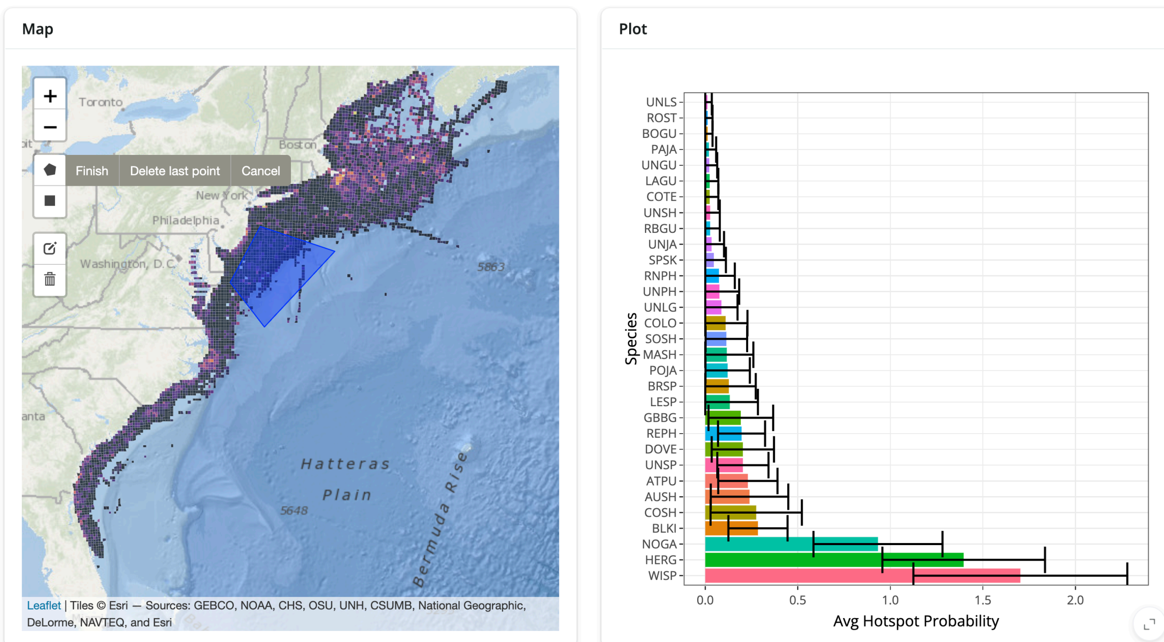
Bird hotspots application showing hotspot probability for species present given drawn Area of Interest.

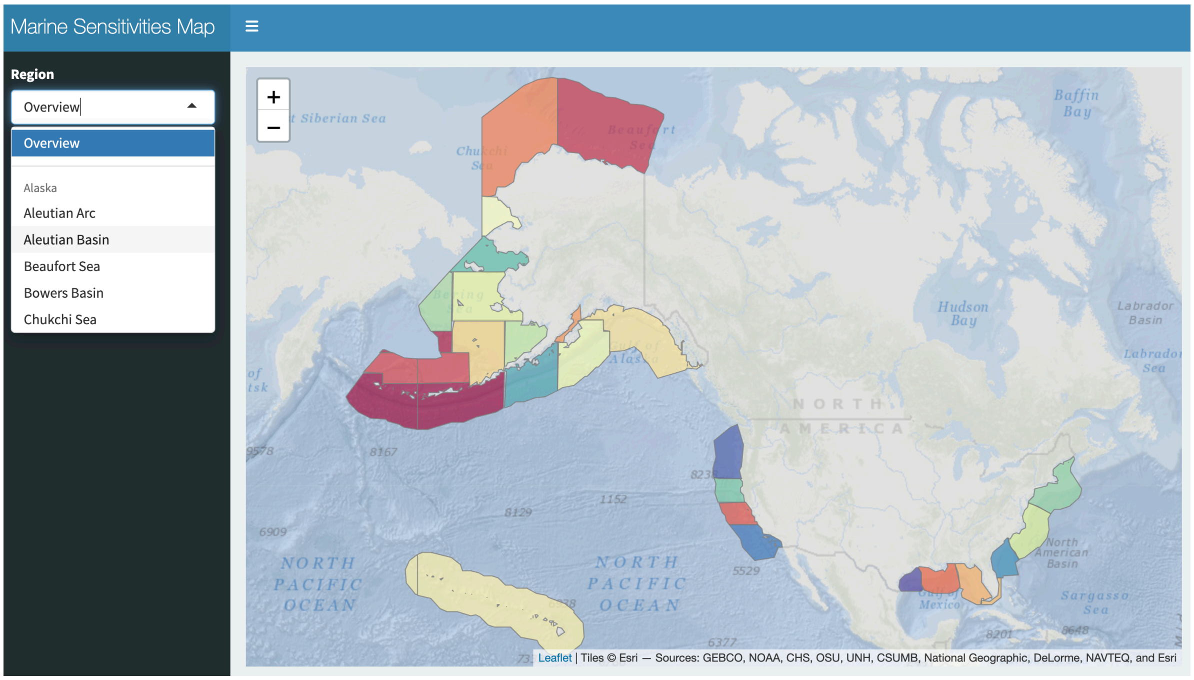
- website
- code



Regional Map

Basic interactive map of BOEM regions.

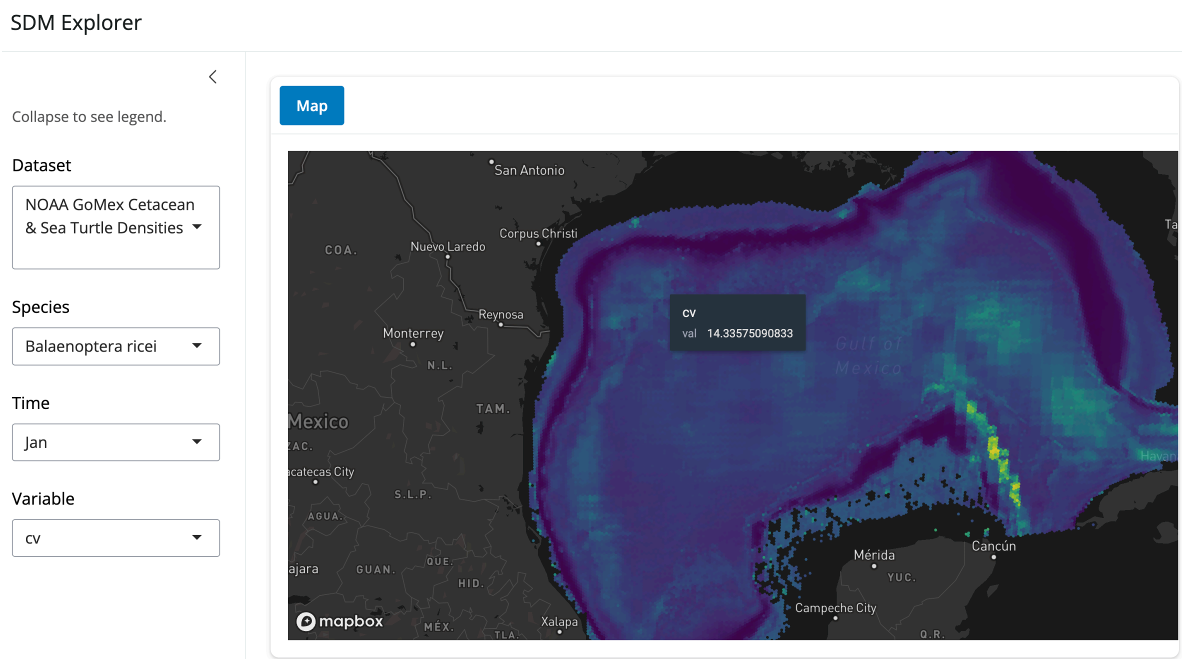
- website
- `code`



Distributions, Vector

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

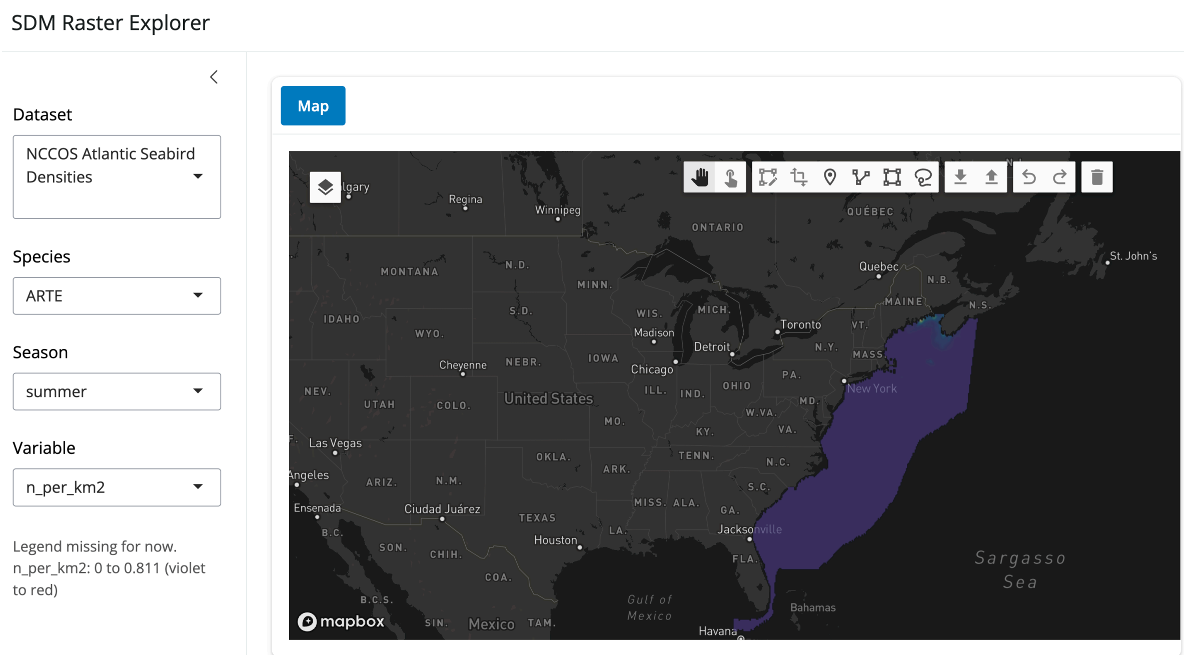
- website
- code



Distributions, Raster

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

- website
- code



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

- website
- code