Technical Quotation

EcoQuants Proposal for Offshore Environmental Sensitivity Indices

Benjamin D. Best

2023-08-18

Table of contents

1 Abstract

EcoQuants LLC proposes to develop offshore Environmental Sensitivity Indices (ESIs) by producing fine resolution species distribution maps and a framework for applying weights to species and habitats reflecting sensitivity to specific stressors from oil & gas or wind energy.

2 Framework for Environmental Sensitivity Indices

As the solicitation points out, existing methods for calculating environmental sensitivity indices (ESIs) (Niedoroda et al. 2014) only produced results for very broad areas and mostly based on shoreline data. With distance from shore, observational data becomes increasingly sparse. And observation data is generally only applicable to the time and place of occurrence, unless a relationship is modeled between the environment and the observations. In which case, species distribution models can be applied across the seascape (Elith and Leathwick 2009). Ideally, these are resolved in terms of climatic seasons and projected into climate future scenarios.

Once species and habitats are mapped out, weights can be applied based on sensitivity to specific stressors from industry activities and these layers can be summed and scored.

Excellent data portals exist, but do not currently fully meet the solicited need of mapped weighted approach (Davies, Watret, and Gubbins 2014). MarineCadastre.gov has authoritative datasets, but is still lacking in species, and does not integrate these data meaningfully into indicators for decision-making. OceanReports does a beautiful job gleaning basic indicators across many of the datasets but does not summarize species densities in detail, nor provide a system for applying weights or an API for programmatically accessing information.

2.1 Atlas of Species and Habitats

As part of a recent contract with Resources Legacy Foundation, EcoQuants LLC developed an offshore habitat assessment for wind energy in the contiguous United States (Best in review). BOEM's Outer Continental Shelf (OCS) Planning Areas were clipped to the US Exclusive Economic Zone and reported as "zones". Although the website and report are currently password protected while review is underway, relevant sample outputs are worth sharing (and interactive maps viewable for the online version of this report at ecoquants.com/boem-esi).

Species and habitat distributions for the US vary in the spatial resolution, spatial footprint and response. The highest quality species distribution models (SDMs) predict **density** (e.g., numbers of animals per unit area). This is especially useful for complying with the Marine Mammal Protection Act by reporting Potential Biological Removal. Other models predict only the **probability** (or likelihood of encounter), or even only a **range** defined by an expert. Some physiographic habitats, such as seamounts or hydrothermal vents, might only have point **occurrences** to which ecologically meaningful distances are buffered. (Table 1)

Table 1: Summary of datasets used for species and habitats (Best in review).

# Species	Name	Year
9,639	AquaMaps Global Probabilities	2021
342	IUCN Global RedList Ranges	2022
79	NCCOS Atlantic & Pacific Seabird Densities	2021
48	Duke Atlantic Marine Mammal Densities	2022
13	SWFSC Pacific Cetacean Densities	2020
11	NOAA GoMex Cetacean & Sea Turtle Densities	2022
	InterRidge Pacific Hydrothermal Vent Occurrences	2020
	SOEST Pacific Seamount Occurrences	2011
	OregonState Global Productivity	2021

Where the same species overlap between different datasets Table 1 can be further combined by preferring the response (density > probability > range) and year (newer > older) as a mosaic by region (i.e., Pacific, Atlantic and Gulf of Mexico). Presence of species can then be added to produce species richness (Figure 1).

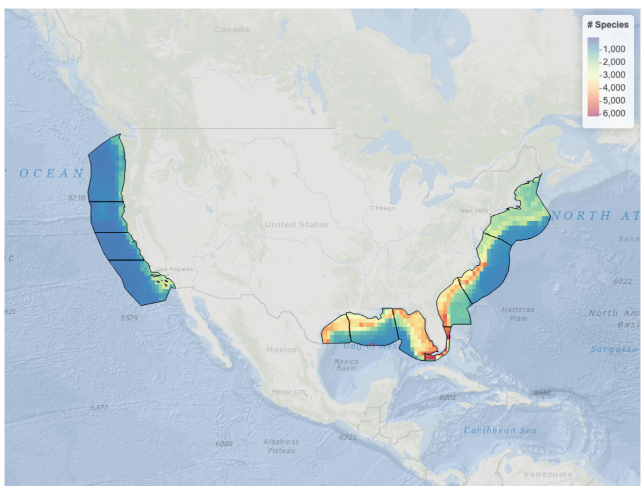


Figure 1: Screenshot of interactive map of species richness by pixel across federal waters for the contiguous United States (Best in review).

Beyond counting species, breaking them up into taxonomic groups and running optimal siting algorithms is something we have experience doing for the high seas (Visalli et al. 2020). For the high seas analysis we additionally used distributions predicted under future climate change scenarios. EcoQuants also worked on developing the original Duke Atlantic Marine Mammal Densities (Roberts et al. 2016).

2.1.1 MarineBON: Downscaling AquaMaps, SDM Framework

EcoQuants has been working with MarineBON.org since 2017 and is most recently leading the working group on Biodiversity Indicators. The near-term task for EcoQuants with this community is to downscale AquaMaps.org species distributions (Kaschner et al. 2023; Ready et al. 2010) from 0.5 decimal degrees to 15 arc seconds (~55 km to ~0.5 km at the equator), the spatial resolution of the best available global bathymetric dataset GEBCO.net.

This is being accomplished by extracting the environmental preferences (Figure 2) found in the `aquamapsdata` R package and applying them to fine scale datasets using Google Earth Engine (GEE). See initial results for the blue whale in the R notebook aquamaps-downscaled and GEE script env_bluewhale. Next, we will develop this into an R function and Shiny app for being able to select any of the ~26,000 species and generate the distributional map from only the environmental preferences for 6 categories of input environmental layers (depth, temperature, salinity, primary productivity, ice concentration, oxygen) and one layer of FAO mask areas.

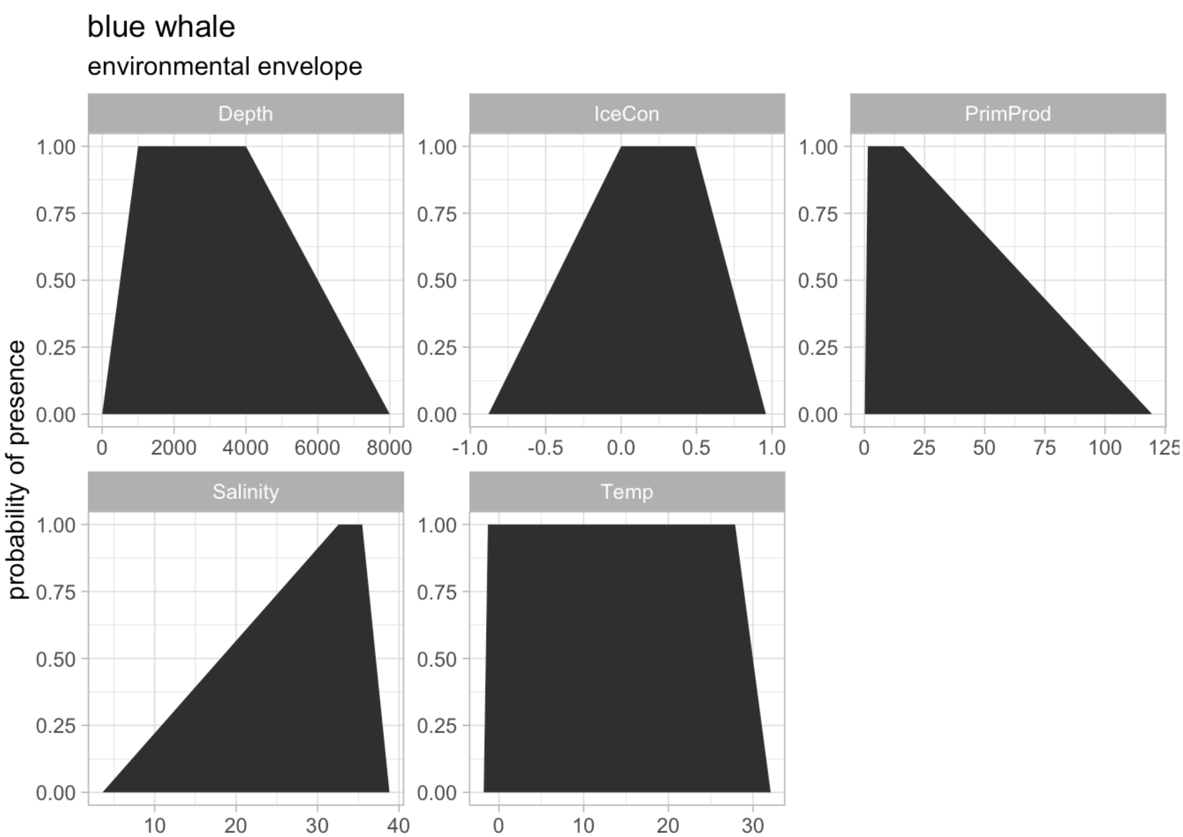


Figure 2: Plots of environmental suitability parameters from `aquamapsdata` for an example species of blue whale (*Balaenoptera musculus*).

The downscaled AquaMaps app will only generate map layers on the fly using Google Earth Engine (GEE). The download task for each individual species distribution takes 20 to 30 minutes, so we will work on optimizing this task for generating outputs using either: GEE with parallel requests; Pangeo (using cloud-enabled parallelized multi-dimensional arrays); or `gdalcubes`, which is based on GDAL and R. Once these SDMs are output as individual or multi-band cloud-optimized GeoTIFFs (COGs) online, we will reference them publicly as a spatio-temporal asset catalog (STAC). Then we will demonstrate alternate COGs and STACs that mosaic improved SDMs in space and time.

These improved SDMs will come in the form of existing SDMs by external partners with taxonomic and regional expertise as well as new SDMs we create from OBIS observational data and common modeling techniques such as Maxent. These SDMs will then be associated with marine traits, such as extinction risk, endemism, phylogenetic uniqueness, ecosystem function and similar to produce valuable indicators for further scientific exploration and management decision-making, including this proposal.

2.2 Applying Weights

In order to match species distributions with species traits assignment of common taxonomic identifiers, such as the `aphia_id` from MarineSpecies.org, is critical. Several APIs exist for accessing species traits, including MarineSpecies.org/traits, FishBase.org. For example, summing extinction risk was performed by matching with the IUCN RedList API (Figure 3).

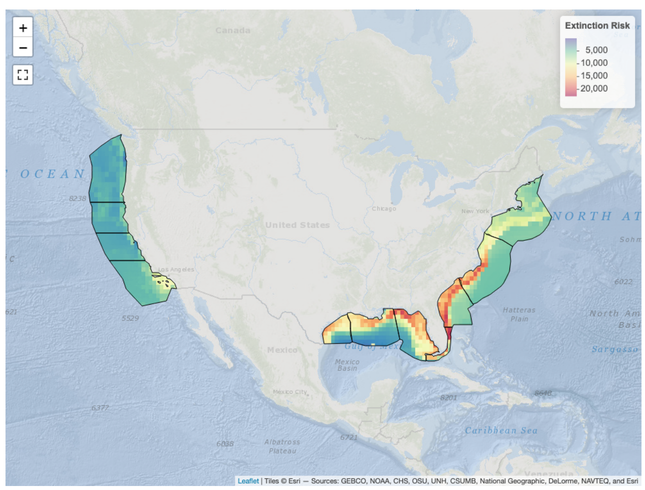


Figure 3: Screenshot of interactive map of extinction risk across federal waters for the contiguous United States (Best in review).

Species sensitivities to offshore wind have been applied to the Mid-Atlantic by Ecoquants (Best and Halpin 2019) to minimize impact on birds in space and cetaceans in time (Figure 4).

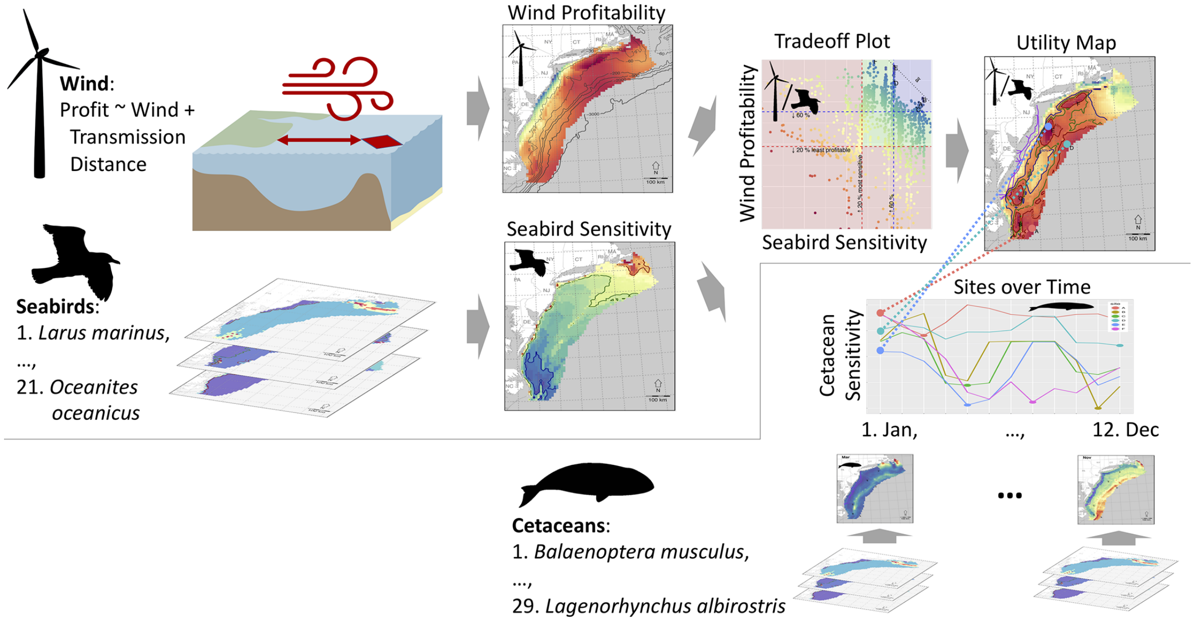


Figure 4: Overview of methods for bringing together wind profitability, seabird sensitivity over space, and cetacean sensitivity in time (Best and Halpin 2019).

Similar species-specific weights are available elsewhere in the US, e.g. for offshore wind on birds (Adams et al. 2016a, 2016b; Kelsey et al. 2018). Sensitivity to oil & gas offshore industry has also been heavily explored and reviewed for similar species weights (Murawski et al. 2021, 2023; Michael et al. 2022). EcoQuants has recent experience proposing an update to a NOAA Biological Opinion related mitigating oil & gas ship traffic on the critically endangered Rice's whale (*Balaenoptera ricei*) in the Gulf of Mexico [ecoquants.com/ricei; Best (2023)].

Beyond weights applied to individual species, taxonomic groupings, various habitats or intensity of stressors all can have different weights. EcoQuants has experience applying and visualizing the weighted goals for the Ocean Health Index (Figure 5).

Identifying conflict with human use has been advanced by applying weights to atlases (D'lorio et al. 2015). These can be paired with mitigation strategies (Industrial Economics, Inc. 2012) in output reports.

2.3 Summarize and Compare by Area of Interest

When scoring comparison is key, especially if the value is unitless. When summarizing the previous species richness (Figure 1) by zone (Figure 6), we can readily see the differences between zones.

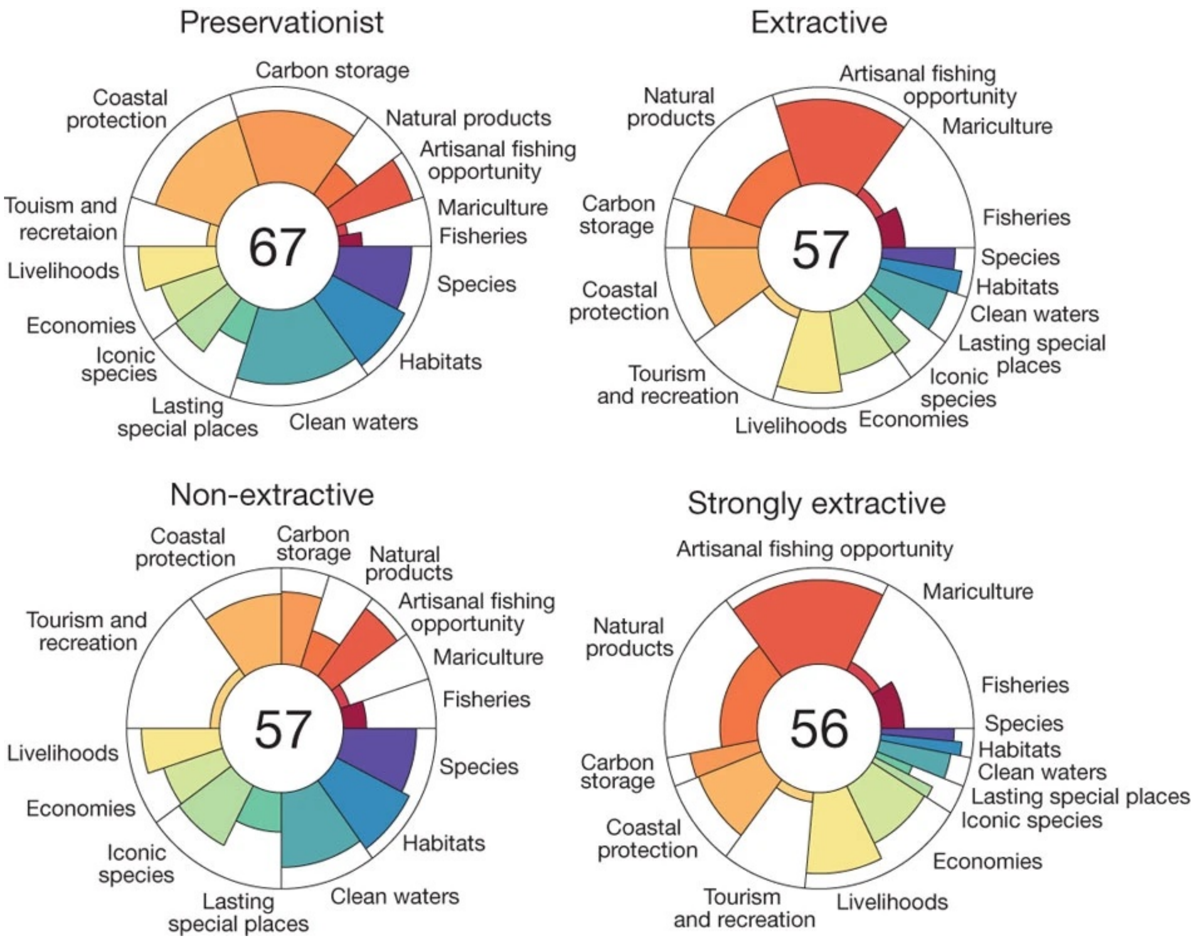


Figure 5: In this "flower" plot the weighted average in the middle can change depending on the weights, which are visualized as the width of each "petal", even though the scores for each goal, depicted as the length of each petal, are the same (Halpern et al. 2012).

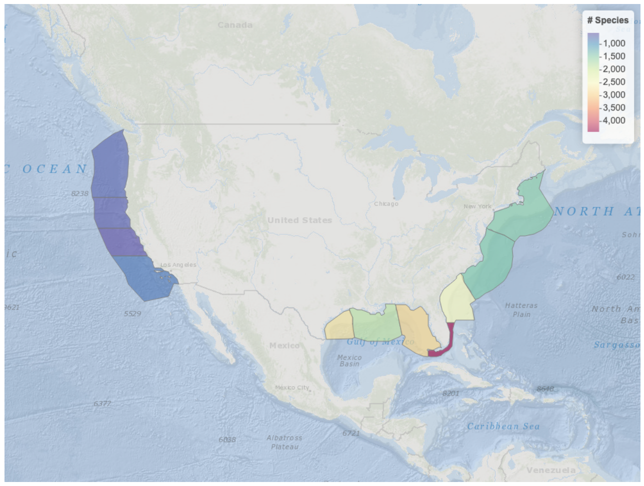


Figure 6: Screenshot of interactive map of average species richness by zone across federal waters for the contiguous United States. (Best in review)

To drill down further within a given zone, we can calculate the standard deviation from the mean in an example zone (Figure 7), hence depicting relatively high and low values intra-zone. Blocks are the smallest units that were aggregated up from the pixel (Best in review).

3 Interactive Applications

The following applications were all built with the application framework Shiny based in the R scientific programming language. They demonstrate EcoQuants' capabilities relevant to this proposal and open-source ethos – links to all source code are provided.

3.1 CalCOFI.io

The oceanographic app (Figure 8) interpolates values into a contour map for desired times, areas, and depths. Areas can be selected from existing areas or custom drawn on the map. Visualizations are also available as functions in the new R library `calcofi4r`.

3.2 MarineEnergy.app

Select tags (technology, stressor, and/or receptor), draw location and generate a report (Figure 9)

This novel marine energy application (Barr et al. 2022) uses a Google login (any email works) to save reports, which are rendered via an API. The Shiny app simply parameterizes the request.

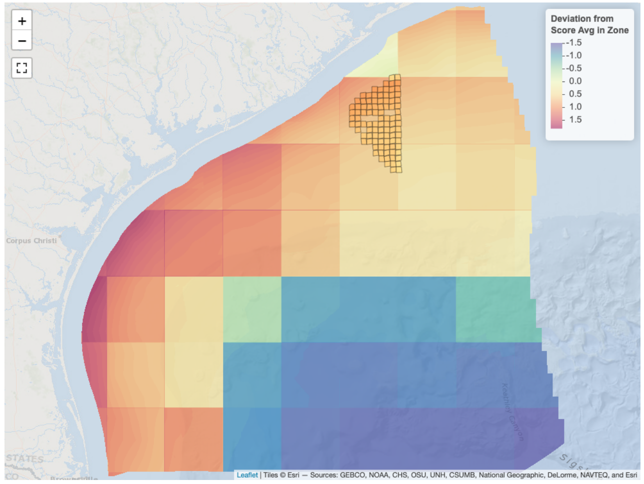


Figure 7: Screenshot of interactive map of Western Gulf of Mexico zone showing deviation from the score average within the zone. Blocks are outlined in black and scores visible on hover (Best in review).

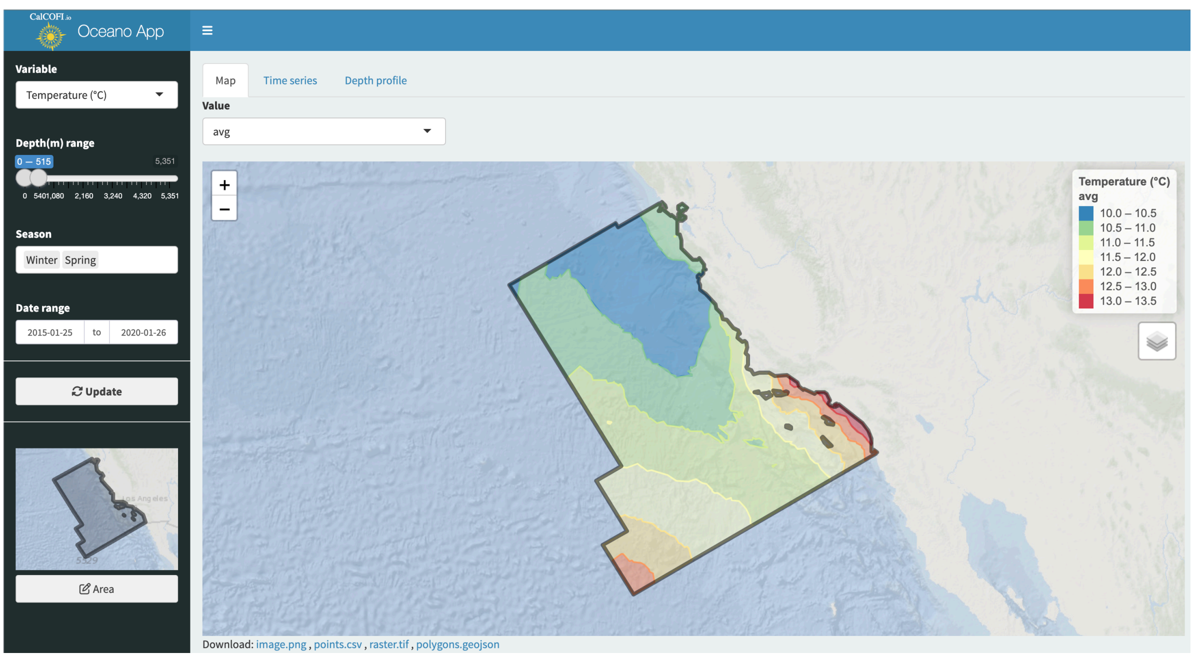


Figure 8: Screenshot of CalCOFI oceanographic application (source code) showing ability to generate contours on the fly as well as select existing or custom areas of interest over which to summarize in space, time or depth.

Spatial querying on receptor datasets originating from MarineCadastre.gov is performed when a custom Area is drawn.

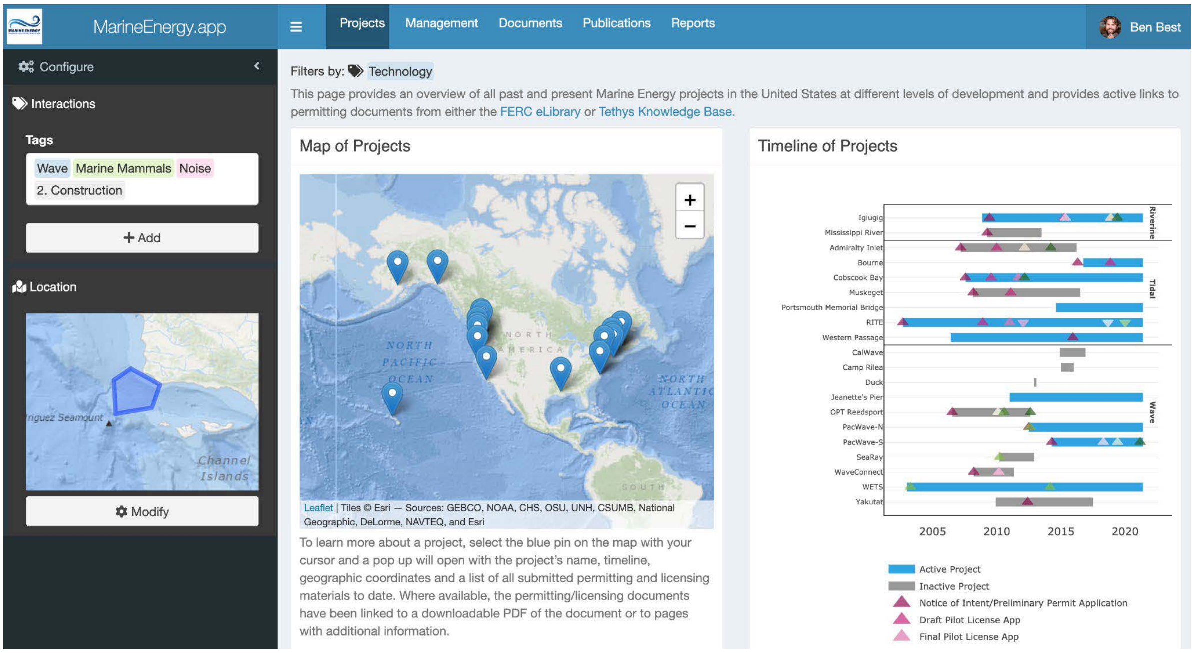


Figure 9: Screenshot of Marine Energy application (source code). The reporting application has an expandable sidebar for inputting a set of Tags as Interactions and a Location as a polygon. The top menu allows the user to navigate across content types. Here the Projects display a map and timeline of marine energy projects. Once the user submits the Add button on the Tags, the Projects map and timeline will reduce to just the Wave technology. Each of the content types filters on different tags, which are color coded. The Reports section enables users to save their reports (after logging in with a Google account) and share the online link with others (Barr et al. 2022).

3.3 NREL Uses

Assign weights to human uses, species distributions and habitats. Sum them up to determine most sensitive areas. (Figure 10)

3.4 Ocean Health Index

The Ocean Health Index uses a framework of 10 broad goals with status, pressures, trend and status. The flower plot (Figure 5) visualizes the score of each goal as its extent, and the weighted value to the overall score as the petal width. The interactive application (Figure 11) shows different values on hover.

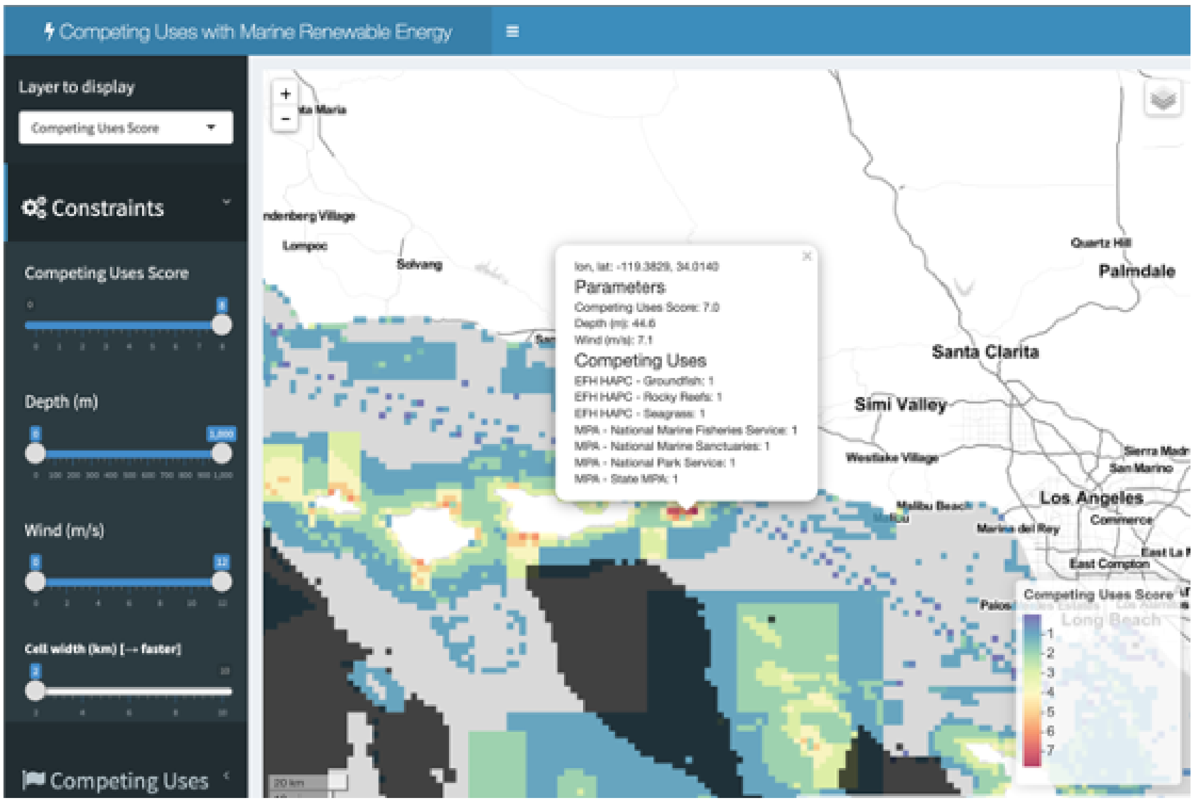


Figure 10: Screenshot of NREL Uses application (source code) showing sliders to apply constraints.

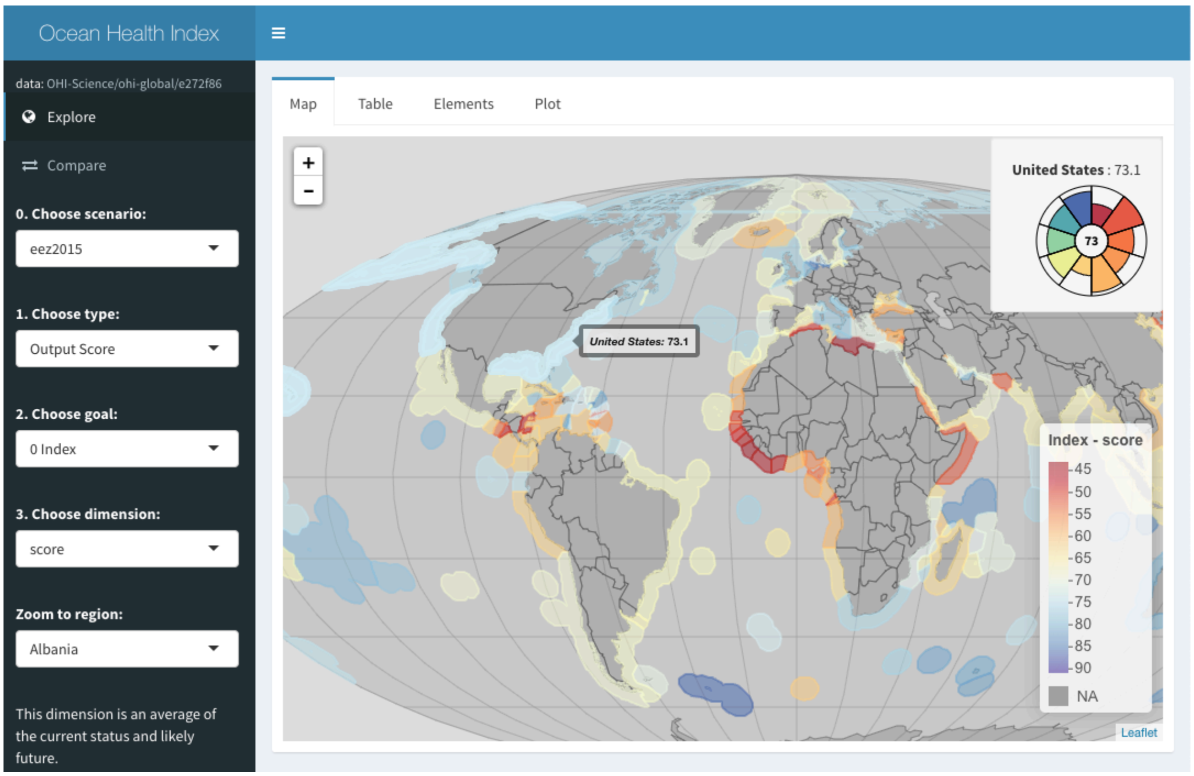
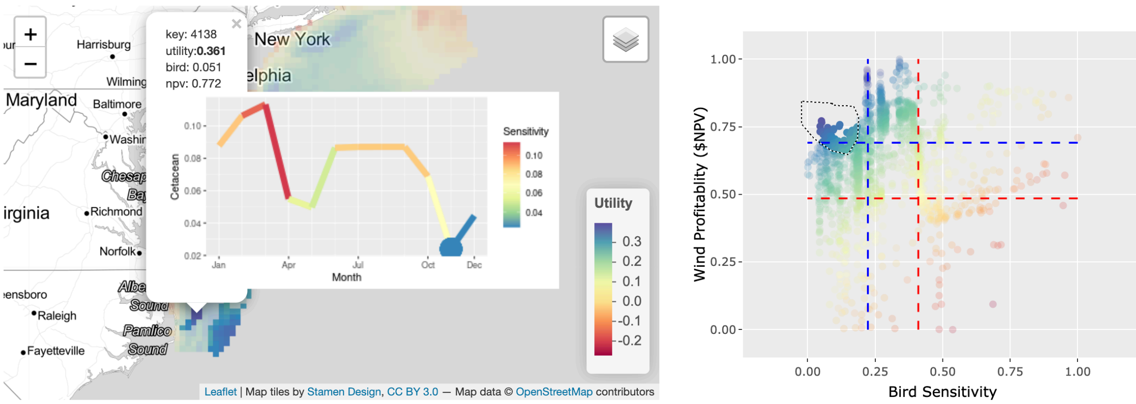


Figure 11: Screenshot of Ocean Health Index application (source code) showing scores on hover with flower plot from equally weighted goals (See Figure 5).

3.5 Tradeoffs

A tradeoff plot can visualizes two objectives at once. Selecting win-win areas in the plot, such as high wind and low seabird sensitivity, highlights those places on the map. (Figure 12)



rank	utility	bird	npv	key
4	0.361	0.051	0.772	4138
7	0.357	0.052	0.766	4079
14	0.353	0.046	0.752	4020
19	0.343	0.046	0.732	3961

Figure 12: Screenshot of Tradeoffs application (source code) showing the ability to lasso pixels in tradeoff space to show up on the map and clicking on a given pixel to identify month of year to minimally impact marine mammals.

4 Infographics

Visualize the ecosystem with icons clickable to popup windows with data and details. Infographics (Spector et al. 2021) (Figure 13) have been used on SanctuaryWatch and the NOAA Integrated Ecosystem Assesment (e.g., for the California Ecosystem Status Report).

5 Project Management

5.1 Key Personnel & Project Manager

Benjamin D. Best, PhD, is for EcoQuants LLC, the current project manager, environmental data scientist, CEO and the only full-time employee. All of the products mentioned in association with EcoQuants in this Technical Quotation are his work. His CV is attached and online.

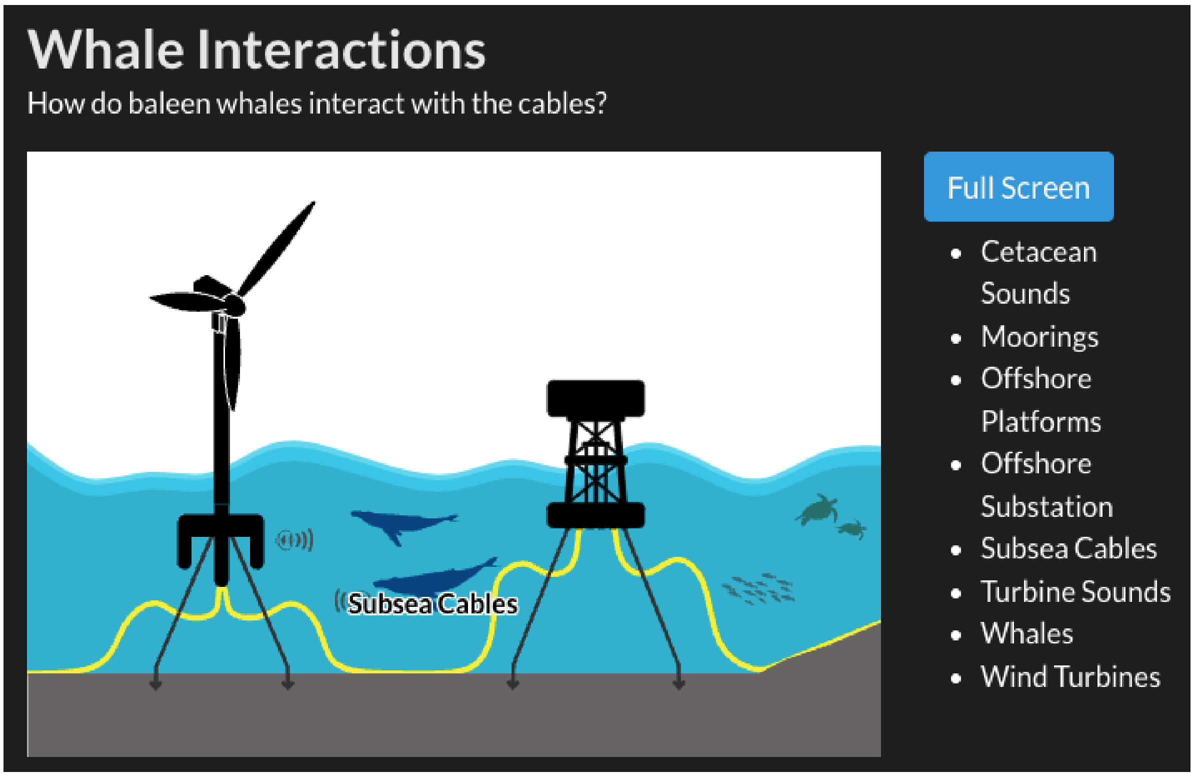


Figure 13: Screenshot of interactive infographic (source code) informing on whale interactions with offshore wind energy, built using the infographiq JavaScript library. Clicking on elements in the scene or contents on the right opens a window with multimedia content describing in detail.

In the past EcoQuants has hired subcontractors to handle extra workload. Now that EcoQuants is an LLC and an S-Corporation, bringing on another full-time hire is much easier bureaucratically. Given graduate university connections teaching at Duke (Nicholas School of the Environment) and UC Santa Barbara (Bren School of Env. Sci. & Mgmt.; Masters in Environmental Data Science), a steady crop of capable graduates could be available for a position opening.

5.2 Github Approach

EcoQuants has long taken advantage of project management tools in Github, and even taught a graduate class on it: EDS 211: Team Science, Collaborative Analysis and Project Management. This equates to extensive use of issues, task lists, mentions, projects and the new Project Roadmap.

6 Reproducible Results

This Technical Quotation was produced using the principles of reproducible research (Lowndes et al. 2017) with the R programming language (R Core Team 2023). All source code for this proposal can be found at github.com/ecoquants/boem-esi.

References

Adams, Josh, Emily C. Kelsey, Jonathan J. Felis, and David M. Pereksta. 2016a. "Collision and Displacement Vulnerability Among Marine Birds of the California Current System Associated with Offshore Wind Energy Infrastructure." US Geological Survey.

———. 2016b. "Data for Calculating Population, Collision and Displacement Vulnerability Among Marine Birds of the California Current System Associated with Offshore Wind Energy Infrastructure (Ver. 2.0, June 2017)." U.S. Geological Survey. https://doi.org/10.5066/F79C6VJ0.

Barr, Zach W., Ben Best, William J. Peplinski, Craig Jones, Grace Chang, Jesse D. Roberts, and Sharon Kramer. 2022. "Novel Marine Energy Environmental Compliance Reporting Application Summarizes Disparate Content by Tags and Location." In *Offshore Technology Conference*. OnePetro. https://doi.org/10.4043/31946-MS.

Best, Benjamin D. in review. "Offshore Habitat Assessment for US Wind Energy." Resources Legacy Fund.

———. 2023. "Spatial Analysis of Ship Strike Risk for Rice's Whale in the Gulf of Mexico." Earthjustice.

Best, Benjamin D., and Patrick N. Halpin. 2019. "Minimizing Wildlife Impacts for Offshore Wind Energy Development: Winning Tradeoffs for Seabirds in Space and Cetaceans in Time." *PLOS ONE* 14 (5): e0215722. https://doi.org/10.1371/journal.pone.0215722.

D'lorio, M., H. Selbie, J. Gass, and C. Wahle. 2015. "The Pacific Regional Ocean Uses Atlas: Data and Tools for Understanding Ocean Space Use in Washington, Oregon, and Hawaii." *US Department of the Interior, Bureau of Ocean Energy Management, Pacific OCS Region, Camarillo, CA. OCS Study BOEM* 14: 2015.

Davies, Ian M., Robert Watret, and Matt Gubbins. 2014. "Spatial Planning for Sustainable Marine Renewable Energy Developments in Scotland." *Ocean & Coastal Management*, Science in support of governance of wave and tidal energy developments, 99 (October): 72–81. https://doi.org/10.1016/j.ocecoaman.2014.05.013.

Elith, J., and J. Leathwick. 2009. "Conservation Prioritisation Using Species Distribution Modelling." *Spatial Conservation Prioritization: Quantitative Methods and Computational Tools*, 70–93.

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.

Industrial Economics, Inc. 2012. "Identification of Outer Continental Shelf Renewable Energy Space-Use Conflicts and Analysis of Potential Mitigation Measures." OCS Study BOEM 2012-083. Herndon, VA: U.S. Department of the Interior, Bureau of Ocean Energy Management.

Kaschner, K., K. Kesner-Reyes, C. Garilao, J. Segschneider, J. Rius-Barile, T. Rees, and R. Froese. 2023. "AquaMaps: Predicted Range Maps for Aquatic Species. Retrieved from https://www.aquamaps.org."

Kelsey, Emma C., Jonathan J. Felis, Max Czapanskiy, David M. Pereksta, and Josh Adams. 2018. "Collision and Displacement Vulnerability to Offshore Wind Energy Infrastructure Among Marine Birds of the Pacific Outer Continental Shelf." *Journal of Environmental Management* 227 (December): 229–47. https://doi.org/10.1016/j.jenvman.2018.08.051.

Lowndes, Julia S. Stewart, Benjamin D. Best, Courtney Scarborough, Jamie C. Afflerbach, Melanie R. Frazier, Casey C. O'Hara, Ning Jiang, and Benjamin S. Halpern. 2017. "Our Path to Better Science in Less Time Using Open Data Science Tools." *Nature Ecology & Evolution* 1 (6): 1–7. https://doi.org/10.1038/s41559-017-0160.

Michael, Pamela E., Kathy M. Hixson, J. Christopher Haney, Yvan G. Satgé, Jeffrey S. Gleason, and Patrick G. R. Jodice. 2022. "Seabird Vulnerability to Oil: Exposure Potential, Sensitivity, and Uncertainty in the Northern Gulf of Mexico." *Frontiers in Marine Science* 9.

Murawski, Steven A., Martin Grosell, Cynthia Smith, Tracey Sutton, Kenneth M. Halanych, Richard F. Shaw, and Charles A. Wilson. 2021. "Impacts of Petroleum, Petroleum Components, and Dispersants on Organisms and Populations." *Oceanography* 34 (1): 136–51. https://www.jstor.org/stable/27020066.

Murawski, Steven A., Patrick T. Schwing, William F. Patterson, Tracey T. Sutton, Paul A. Montagna, Rosanna J. Milligan, Samantha B. Joye, et al. 2023. "Vulnerability and Resilience of Living Marine Resources to the Deepwater Horizon Oil Spill: An Overview." *Frontiers in Marine Science* 10.

Niedoroda, A, S Davis, M Bowen, E Nestler, J Rowe, R Balouskus, M Schroeder, B Gallaway, and R Fechhelm. 2014. "A Method for the Evaluation of the Relative Environmental

Sensitivity and Marine Productivity of the Outer Continental Shelf."

R Core Team, R. 2023. "R: A Language and Environment for Statistical Computing." Vienna, Austria.

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.

Roberts, Jason J., Benjamin D. Best, Laura Mannocci, Ei Fujioka, Patrick N. Halpin, Debra L. Palka, Lance P. Garrison, et al. 2016. "Habitat-Based Cetacean Density Models for the U.S. Atlantic and Gulf of Mexico." *Scientific Reports* 6 (March): 22615. https://doi.org/10.1038/srep22615.

Spector, Pike, Benjamin D. Best, Jai Ranganathan, Tylar Murray, Jennifer A. Brown, Chris Caldow, Gabrielle Canonico, and Andrew DeVogelaere. 2021. "Webenizing Condition Reports: Communicating Data-Driven Ecosystem Indicators in a Visually Engaging and Interactive Online Platform," National Marine Sanctuaries Conservation Series, no. ONMS-21-11.

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.