Toolbox for Cumulative Impacts Analysis and the Ocean Health Index

Ben Best (bbest@nceas.ucsb.edu), Shaun Walbridge, Matt Perry, John Potapenko, Darren Hardy, Ben Halpern

ESRI UC in San Diego on July 16, 2014

Toolboxes Motivated by Papers

1. Halpern et al 2008 *Science*: **Cumulative Impacts**

A Global Map of Human Impact on Marine Ecosystems

Benjamin S. Halpern,[1]‡ Shaun Walbridge,[1]* Kimberly A. Selkoe,[1,2]*‡ Carrie V. Kappel,[1] Fiorenza Micheli,[3] Caterina D'Agrosa,[4]† John F. Bruno,[5] Kenneth S. Casey,[6] Colin Ebert,[1] Helen E. Fox,[7] Rod Fujita,[8] Dennis Heinemann,[9] Hunter S. Lenihan,[10] Elizabeth M. P. Madin,[11] Matthew T. Perry,[1] Elizabeth R. Selig,[6,12] Mark Spalding,[13] Robert Steneck,[14] Reg Watson[15]

2. Halpern et al 2012 *Nature*: **Ocean Health Index**

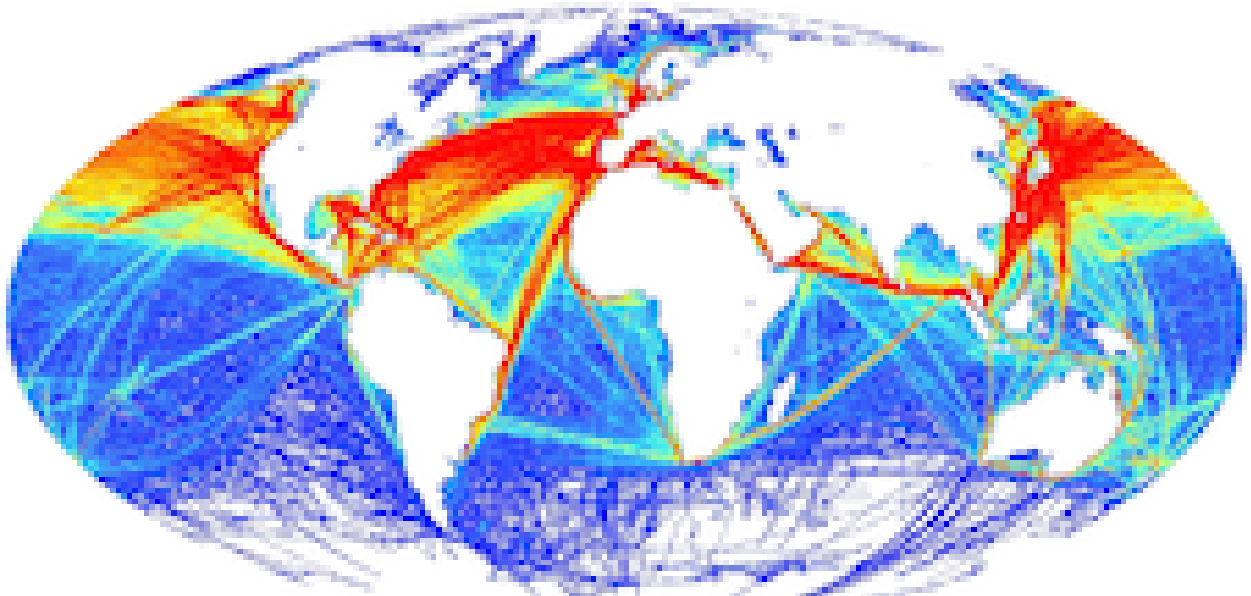
An index to assess the health and benefits of the global ocean

Benjamin S. Halpern[1,2], Catherine Longo[1], Darren Hardy[1], Karen L. McLeod[3], Jameal F. Samhouri[4], Steven K. Katona[5], Kristin Kleisner[6], Sarah E. Lester[7,8], Jennifer O'Leary[1], Marla Ranelletti[1], Andrew A. Rosenberg[5], Courtney Scarborough[1], Elizabeth R. Selig[5], Benjamin D. Best[9], Daniel R. Brumbaugh[10], F. Stuart Chapin[11], Larry B. Crowder[12], Kendra L. Daly[13], Scott C. Doney[14], Cristiane Elfes[15,16], Michael J. Fogarty[17], Steven D. Gaines[8], Kelsey I. Jacobsen[8], Leah Bunce Karrer[5], Heather M. Leslie[18], Elizabeth Neeley[19], Daniel Pauly[6], Stephen Polasky[20], Bud Ris[21], Kevin St Martin[22], Gregory S. Stone[5], U. Rashid Sumaila[6] & Dirk Zeller[6]

Cumulative Impacts

Pressures (n=17)

- **Pollution**: fertilizer, pesticides, impervious surfaces, population density, ship traffic and ports
- **Fishing Pressure**: pelagic low-bycatch, pelagic high-bycatch, demersal destructive, demersal non-destructive low-bycatch, demersal non-destructive high-bycatch, artisanal
- **Climate Change**: sea temperature anomoly, ultraviolet radiation, ocean acidification, sea level rise (***new***)
- **Other**: invasive species, oil rigs, shipping
- 1 km2 pixels in Mollweide projection. Download at nceas.ucsb.edu/globalmarine



Ecosystems (n=20)

- **Special**: coral, seagrass, mangrove, rocky reef, seamounts
- **Bottom Type and Depth**: soft or hard by shallow (0-60 m), shelf (60-200 m), slope (200 – 2000 m), deep (>2000 m)
- **Offshore Water Column**: pelagic (0 to 60 m in depths $>$ 60 m), deep (60 m to bottom)

Matrix of Weights: Ecosystem x Pressure

Driver	Mangrove	Coral Reef	Seagrass	Rocky Reef	Sub-tidal Soft Bottom	Soft Shelf (30-200m)	Hard Shelf (30-200m)	Soft Slope (200-2000m)	Hard Slope (200-2000m)	Deep Soft Benthic	Deep Hard Bottom	Deep Seamount	Surface Water	Deep Water	Rocky Intertidal	Intertidal Mud	Beach	Salt Marsh	Kelp Forest	Susp.-Feeder Reef
Nutrient Input	1.8	1.8	2.1	1.6	2.0	1.4	1.7	2.0	0.6	1.3	0.0	0.0	1.2	0.0	1.5	1.6	0.4	1.8	0.4	1.4
Nonpoint, organic pollution	1.4	1.2	1.0	2.2	1.2	1.4	0.0	2.0	0.2	1.7	0.0	0.0	1.9	1.6	2.1	2.8	0.1	1.7	1.0	2.8
Nonpoint, non-organic pollution	0.5	0.7	0.8	2.2	1.5	2.1	0.2	2.1	0.2	1.8	0.0	0.0	2.3	1.6	2.1	1.6	0.6	2.0	0.0	2.7
Direct Human	3.3	2.3	2.5	2.5	2.0	1.1	2.9	0.0	0.0	1.6	0.0	0.0	0.9	0.0	2.8	2.2	2.7	1.6	1.6	3.0
Demersal, destructive fishing	0.0	1.2	0.2	2.7	2.1	3.0	3.1	3.2	2.8	2.3	3.0	3.5	2.1	0.8	1.2	1.4	0.2	1.0	1.5	3.1
Demersal, non-destructive, high bycatch fishing	0.9	1.6	1.1	2.9	2.1	2.0	3.2	2.3	2.4	2.0	0.0	0.0	1.6	0.0	0.8	1.9	0.9	1.0	2.1	0.7
Demersal, non-destructive, low bycatch fishing	0.8	1.3	0.6	2.7	1.7	1.6	2.6	0.0	2.2	0.0	0.0	0.0	0.0	0.0	1.5	1.5	0.2	0.5	2.1	1.4
Pelagic, high by-catch fishing	0.0	0.5	0.0	2.6	0.0	1.1	2.8	0.2	0.0	1.6	0.0	0.0	3.0	2.2	0.9	0.0	0.1	0.5	0.0	0.0
Pelagic, low by-catch fishing	0.0	0.7	0.0	2.6	0.6	0.8	2.8	0.2	0.0	0.5	0.0	0.0	2.2	0.6	0.0	0.0	0.0	0.4	0.0	0.0
Artisanal fishing	1.7	2.3	0.3	2.2	0.0	0.9	1.9	0.0	0.4	0.3	0.0	0.9	1.0	0.0	1.3	0.4	0.7	0.6	0.8	1.0
Sea temperature	2.4	2.8	2.1	1.9	0.5	2.5	2.9	2.3	0.9	2.5	1.5	1.8	3.3	2.3	2.8	1.4	0.6	1.4	2.0	0.8
UV	0.2	0.8	0.5	0.7	0.3	1.9	1.8	0.0	0.0	1.3	0.0	0.0	1.5	0.0	0.9	1.3	0.0	1.1	0.1	0.0
Ocean acidification	1.2	1.1	1.4	1.1	0.1	1.7	2.5	2.1	1.6	2.2	2.7	2.7	1.8	0.0	0.9	1.0	0.0	1.3	0.0	0.7
Species Invasion	1.0	1.5	1.2	2.5	2.7	1.6	1.5	0.2	0.5	1.5	0.0	0.0	2.3	0.0	2.8	2.9	0.9	2.8	1.3	2.6
Ocean-based pollution	1.2	1.2	0.5	1.7	1.1	1.2	0.3	1.4	1.7	2.3	1.2	1.2	1.7	0.4	1.3	0.8	0.5	1.2	0.1	0.0
Commercial Activity	2.0	1.5	1.9	1.4	0.3	1.7	0.9	0.1	1.0	0.9	0.0	0.0	1.9	0.0	0.3	1.9	1.9	1.4	0.0	0.0
Benthic Structures	1.3	0.5	1.6	1.7	0.1	0.5	2.1	1.6	2.2	1.9	1.6	1.4	1.5	0.0	1.0	0.9	0.8	0.9	0.0	0.4

Result

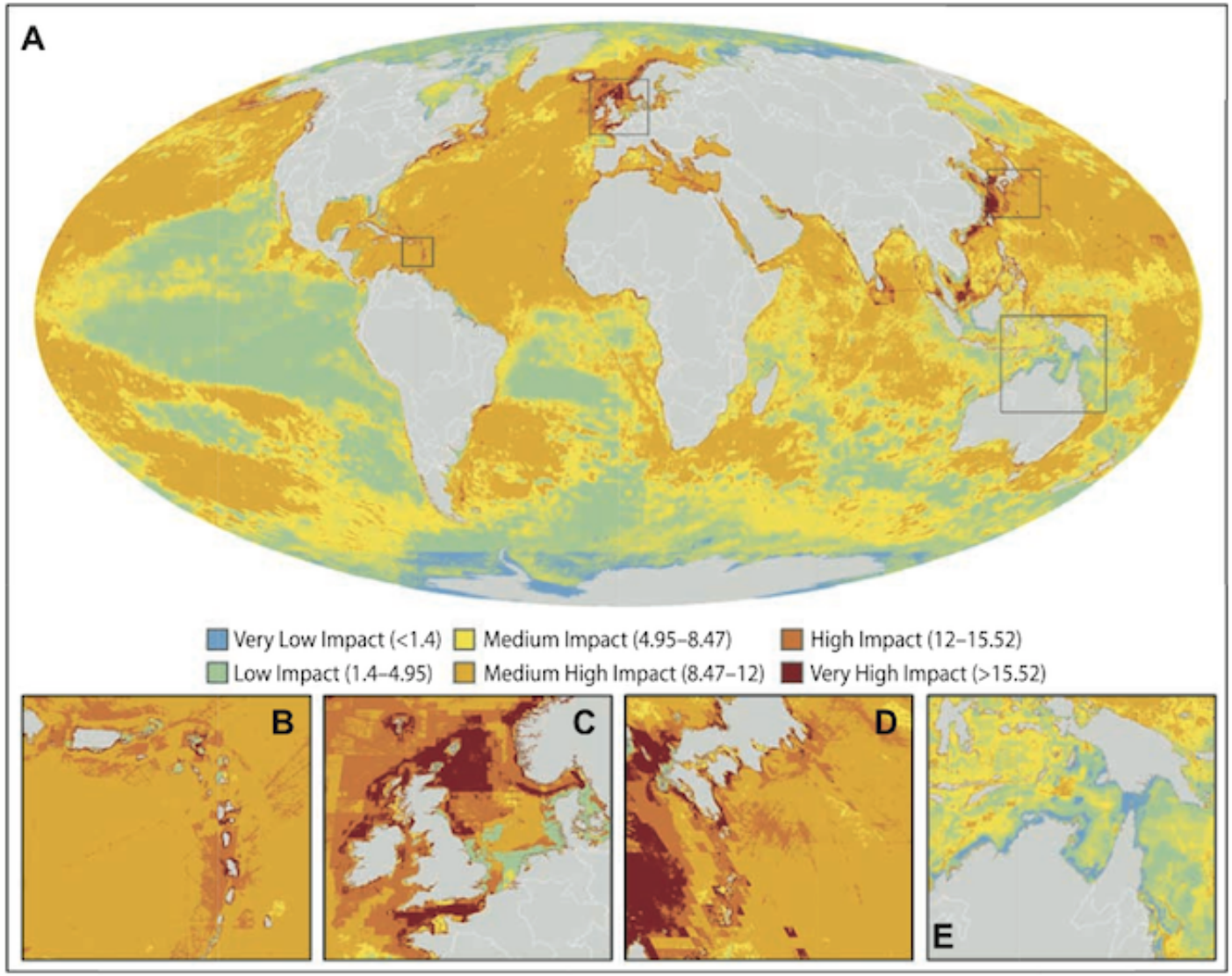


Fig. 1. Global map (**A**) of cumulative human impact across 20 ocean ecosystem types. (Insets) Highly impacted regions in the Eastern Caribbean (**B**), the North Sea (**C**), and the Japanese waters (**D**) and one of the least impacted regions, in northern Australia and the Torres Strait (**E**).

Equation

$$I_C = \sum_{i=1}^{n} \sum_{j=1}^{m} P_i * E_j * w_{i,j}$$

- I_C cumulative impact score, per 1km pixel

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- P_i log-transformed and normalized human pressure [0-1]

Equation

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- I_C cumulative impact score, per 1km pixel
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- E_j presence or absence of ecosystem j [0,1]

Equation

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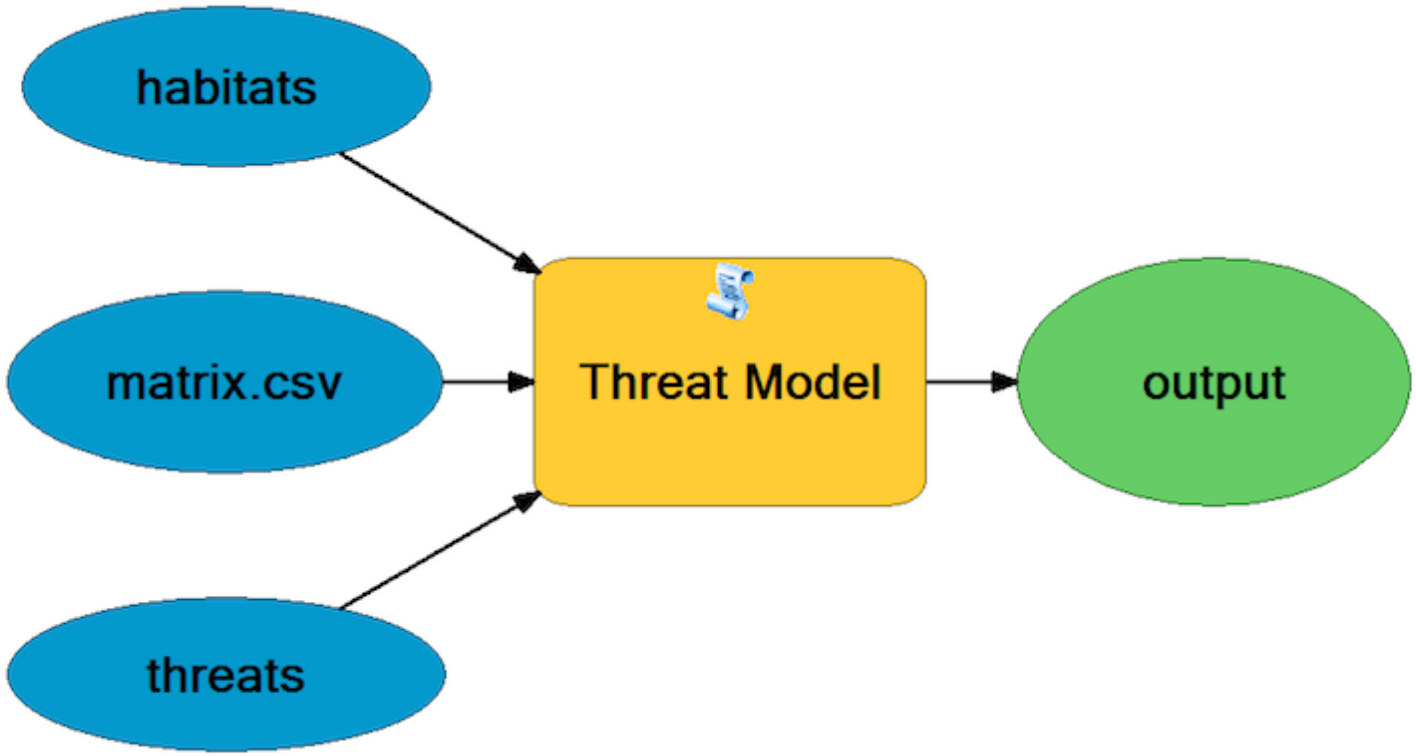
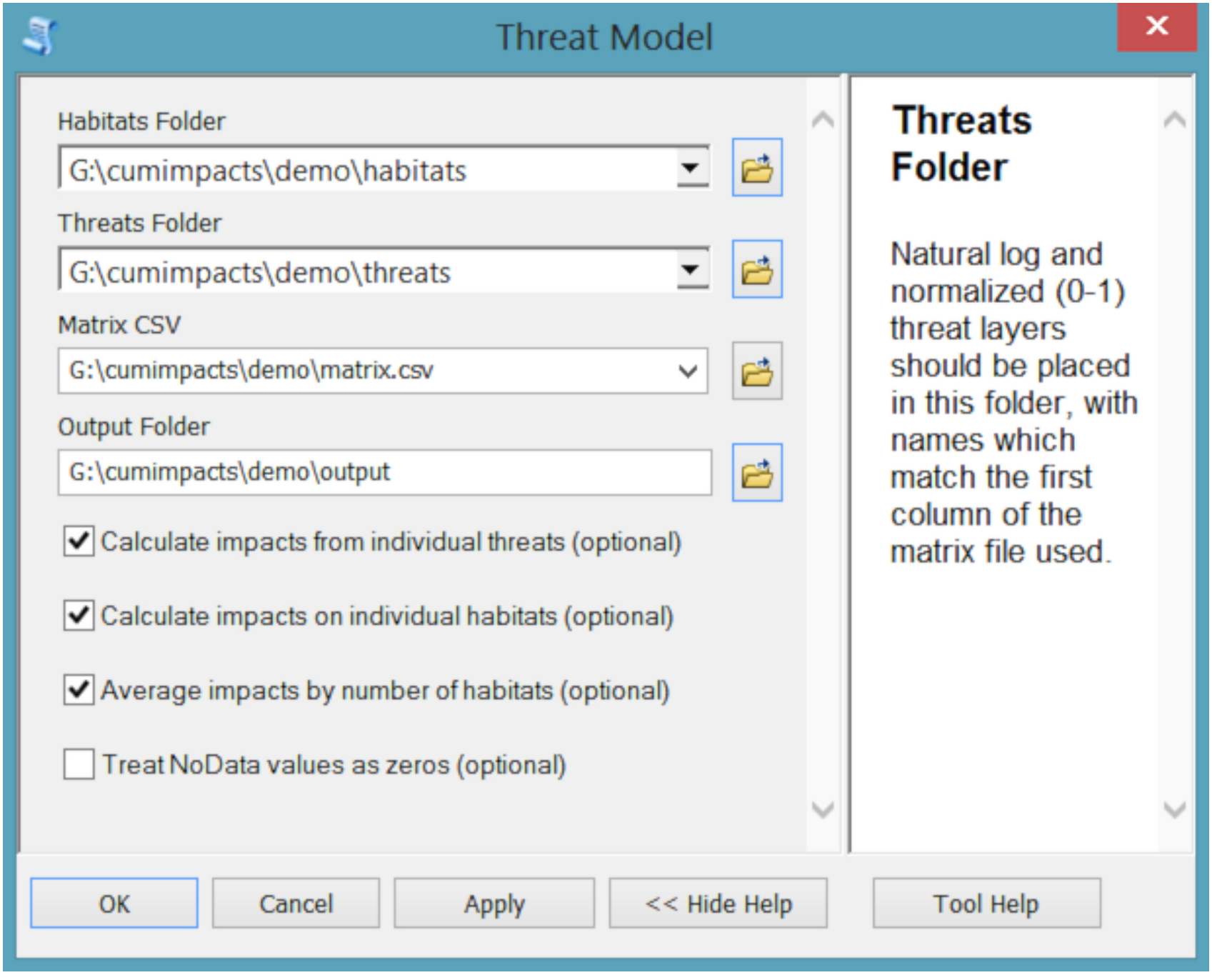
- I_C cumulative impact score, per 1km pixel
- P_i log-transformed and normalized human pressure [0-1]
- E_j presence or absence of ecosystem j [0,1]
- $w_{i,j}$ weight for pressure i and ecosystem j [0-3.3]

Tool in Model

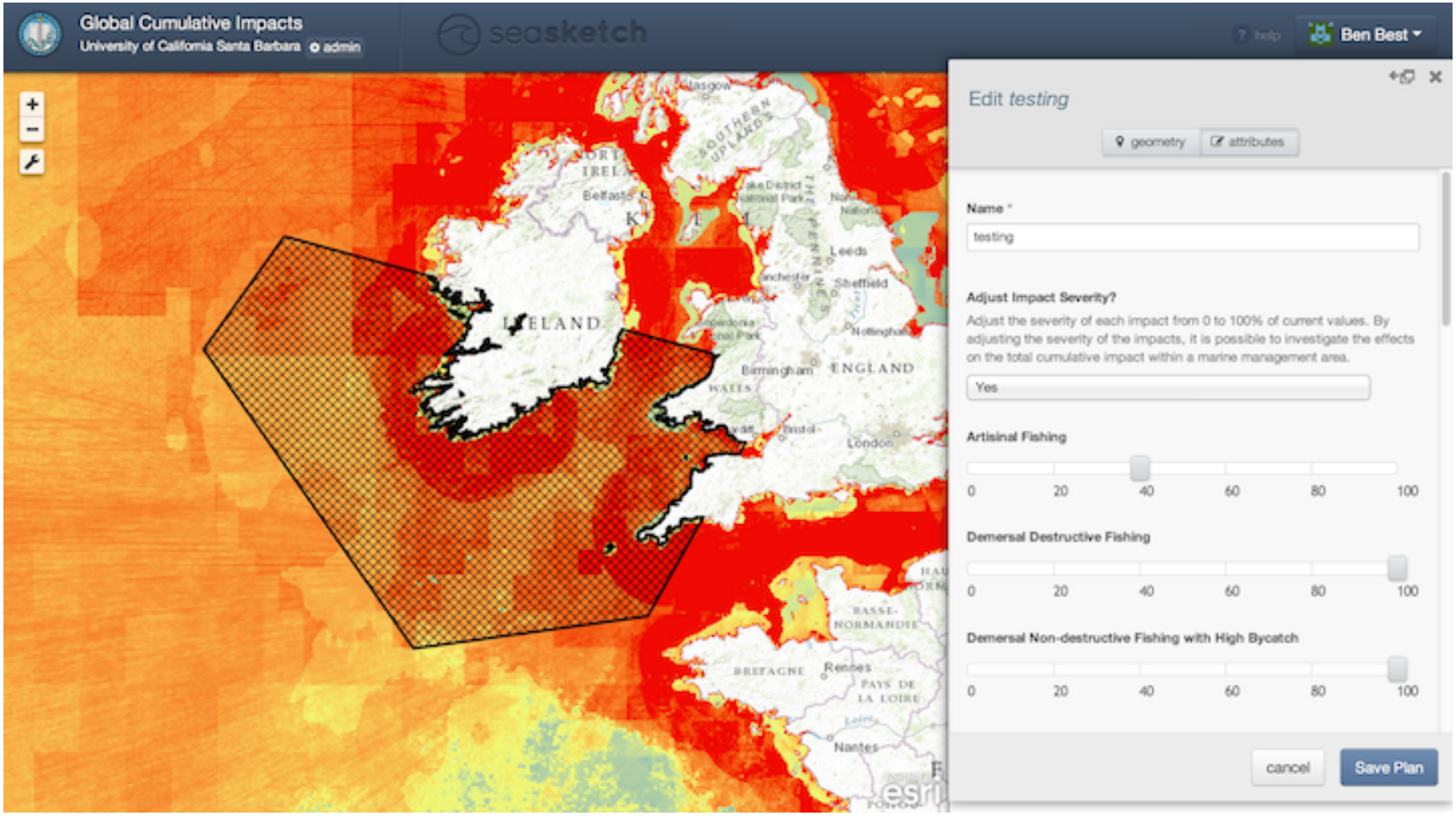


Tool Form


Threat Model
Habitats Folder
G:\cumimpacts\demo\habitats
Threats Folder
G:\cumimpacts\demo\threats
Matrix CSV
G:\cumimpacts\demo\matrix.csv
Output Folder
G:\cumimpacts\demo\output
Calculate impacts from individual threats (optional)
Calculate impacts on individual habitats (optional)
Average impacts by number of habitats (optional)
Treat NoData values as zeros (optional)
Threats Folder
Natural log and normalized (0-1) threat layers should be placed in this folder, with names which match the first column of the matrix file used.
OK
Cancel
Apply
<< Hide Help
Tool Help

SeaSketch Integration

- impacts.seasketch.org by Dan Yocum, Will McClintock



Next

- Download Python Toolbox at github.com/ohi-science/cumimpacts
  - Linked from ohi-science.org
  - Soon linked from nceas.ucsb.edu/globalmarine
- Update with numpy matrix math for speed up: 2 hours to 20 seconds (Dan Yocum)

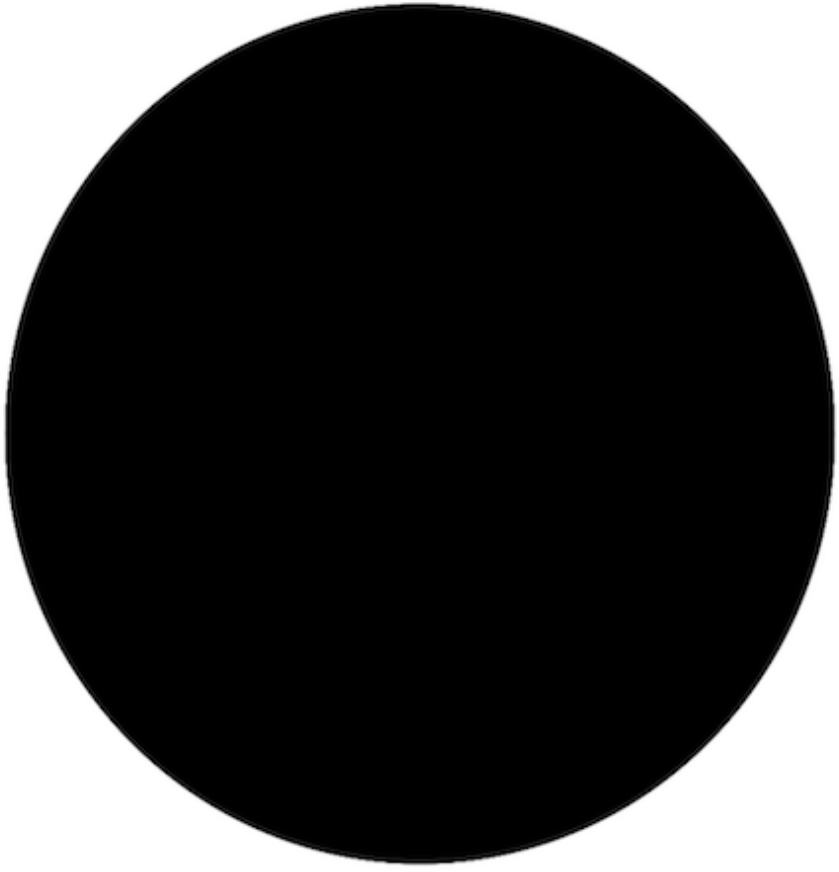
Ocean Health Index

What is a Healthy Ocean?

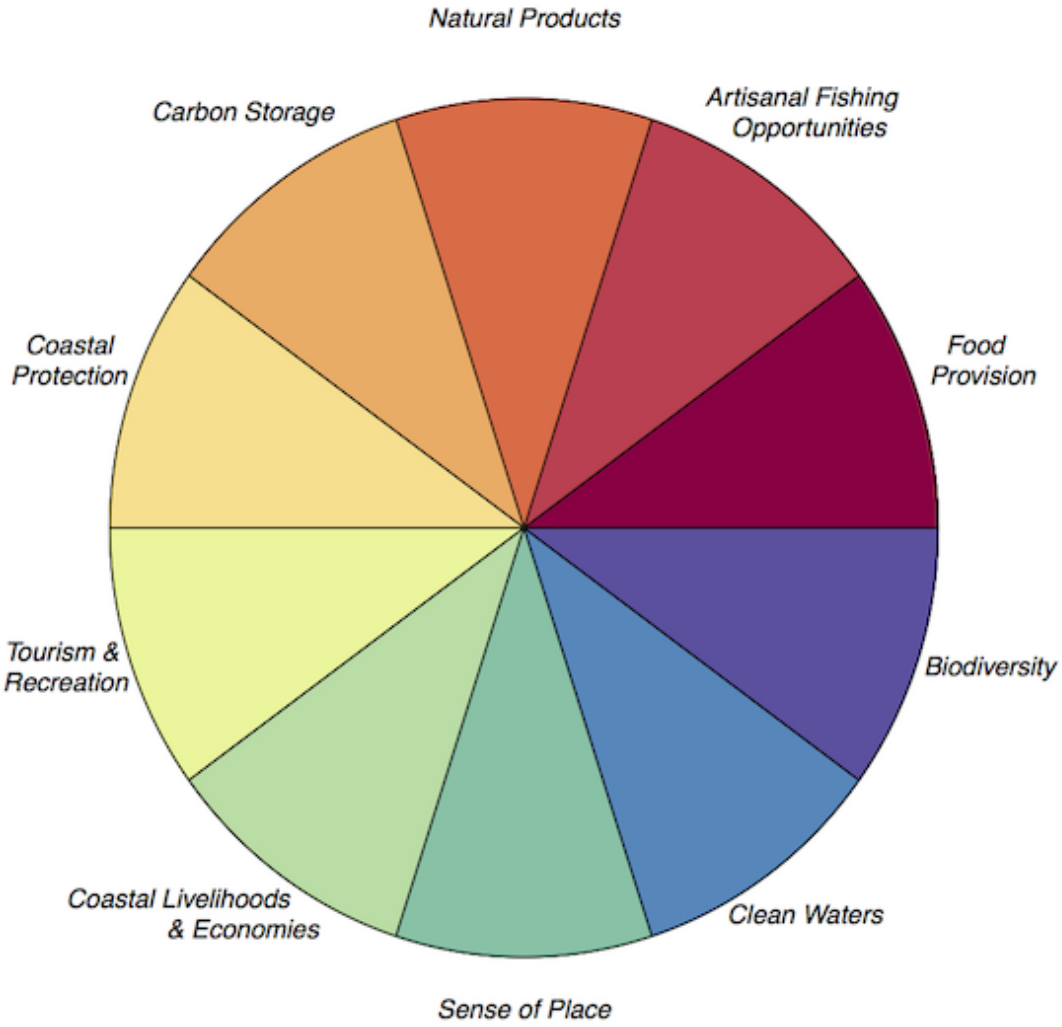
- Is it pristine?

- "A healthy ocean *sustainably* delivers a range of *benefits* to ***people*** *now* and in the *future*."

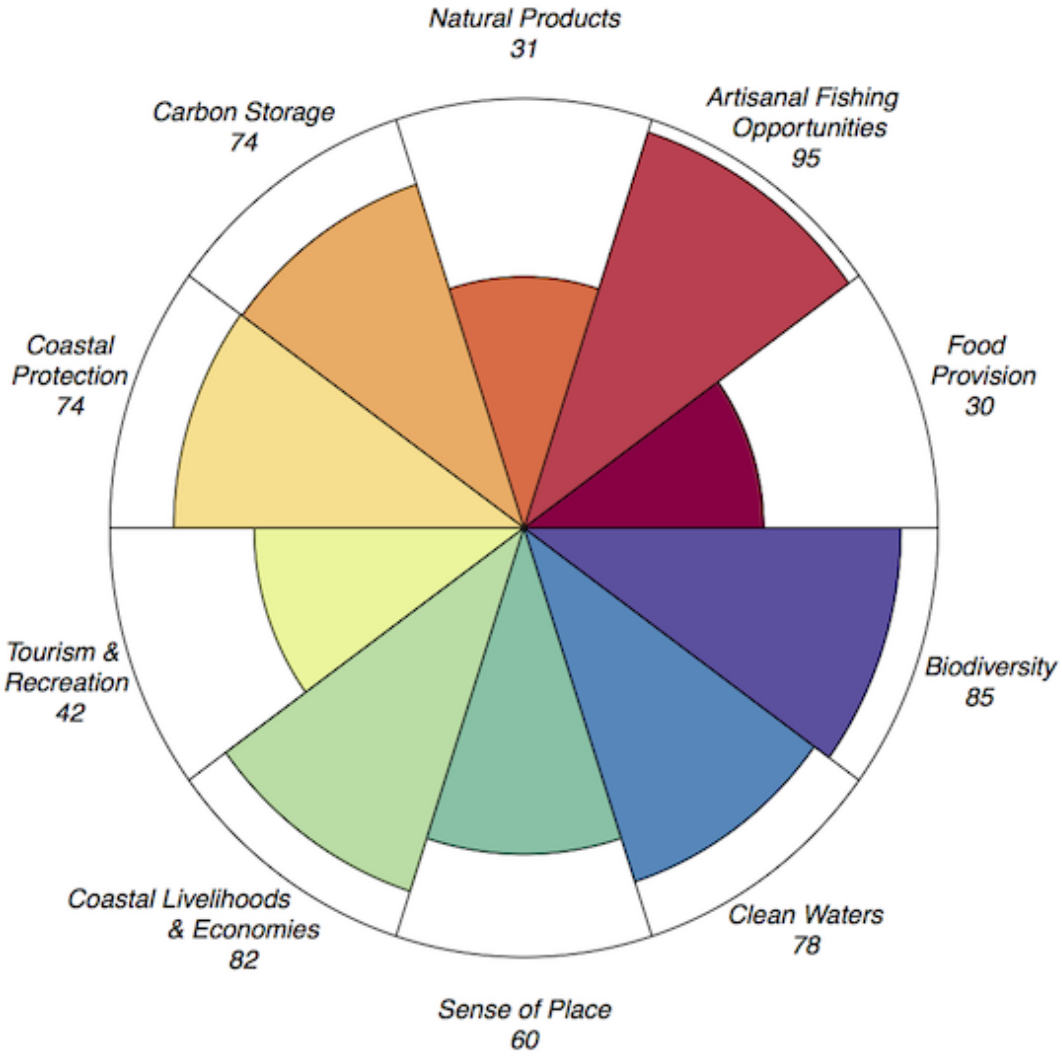
Ocean Health?



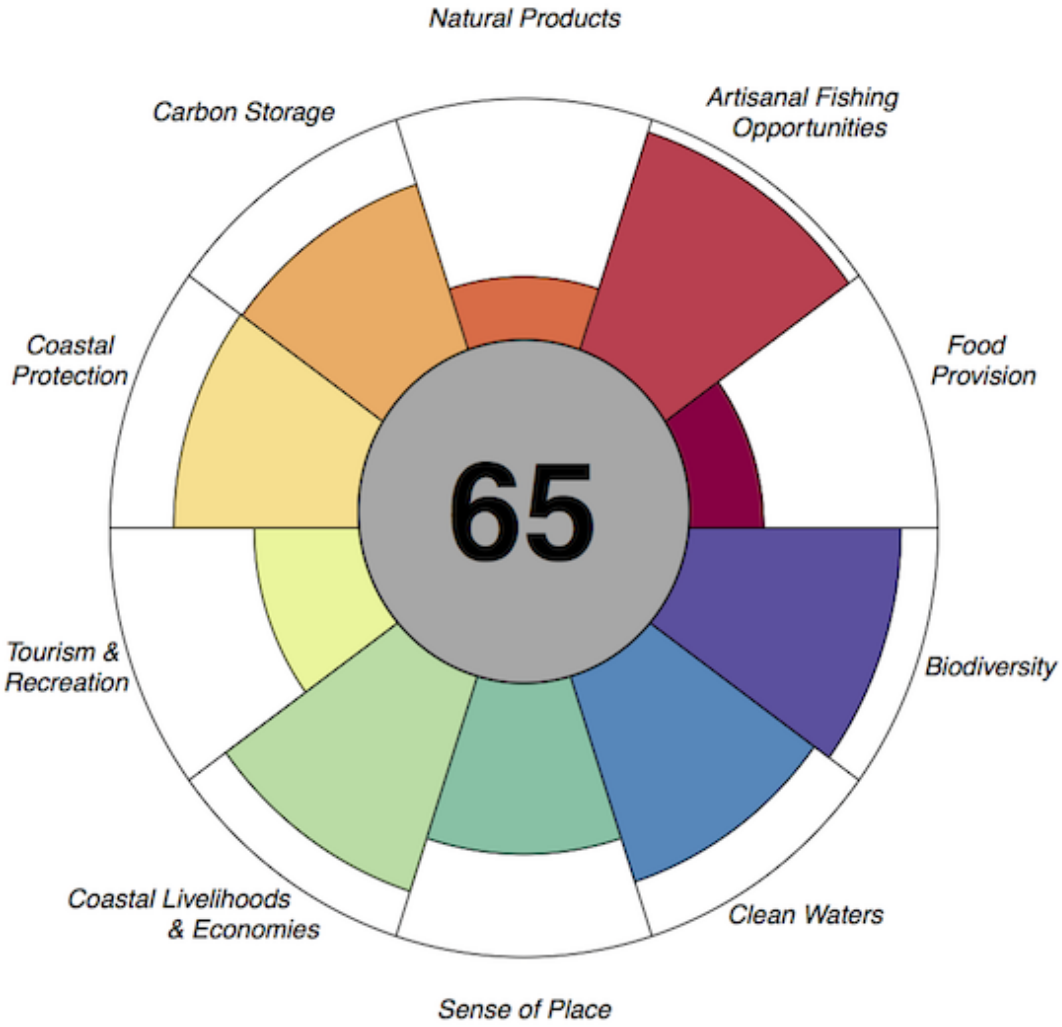
Ocean Health Goals



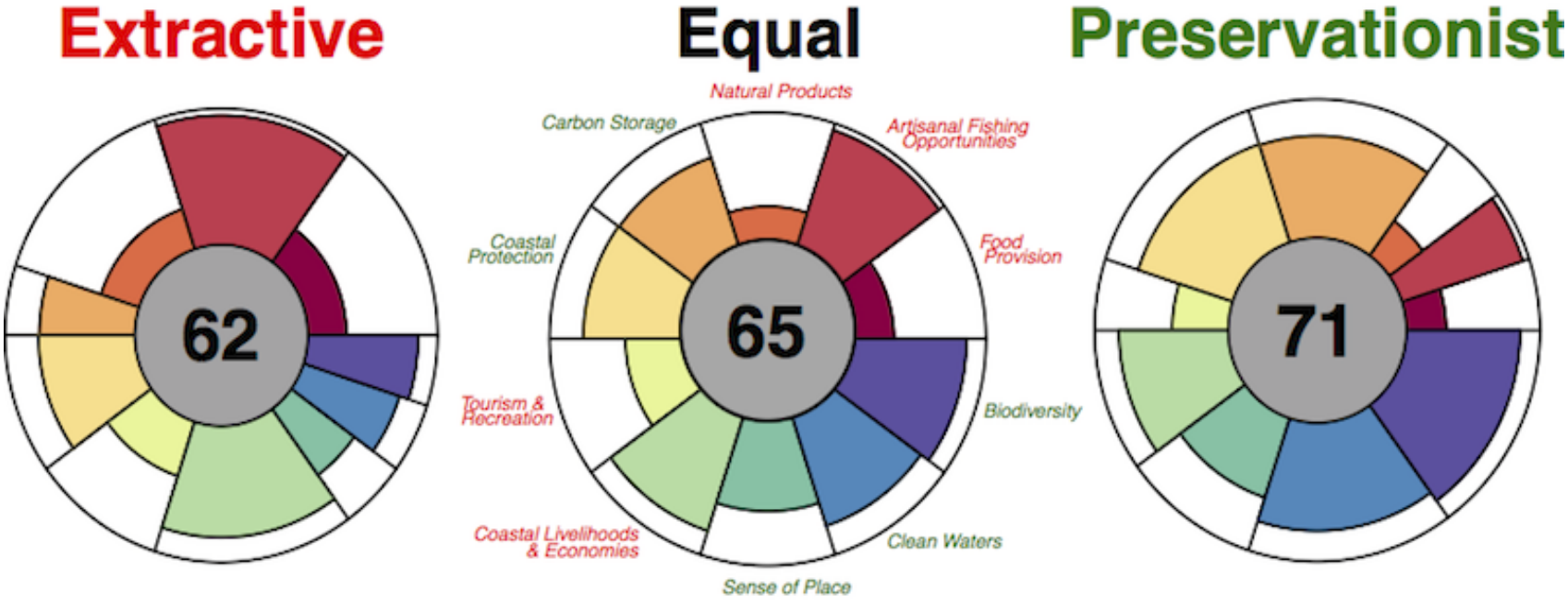
Ocean Health Scores



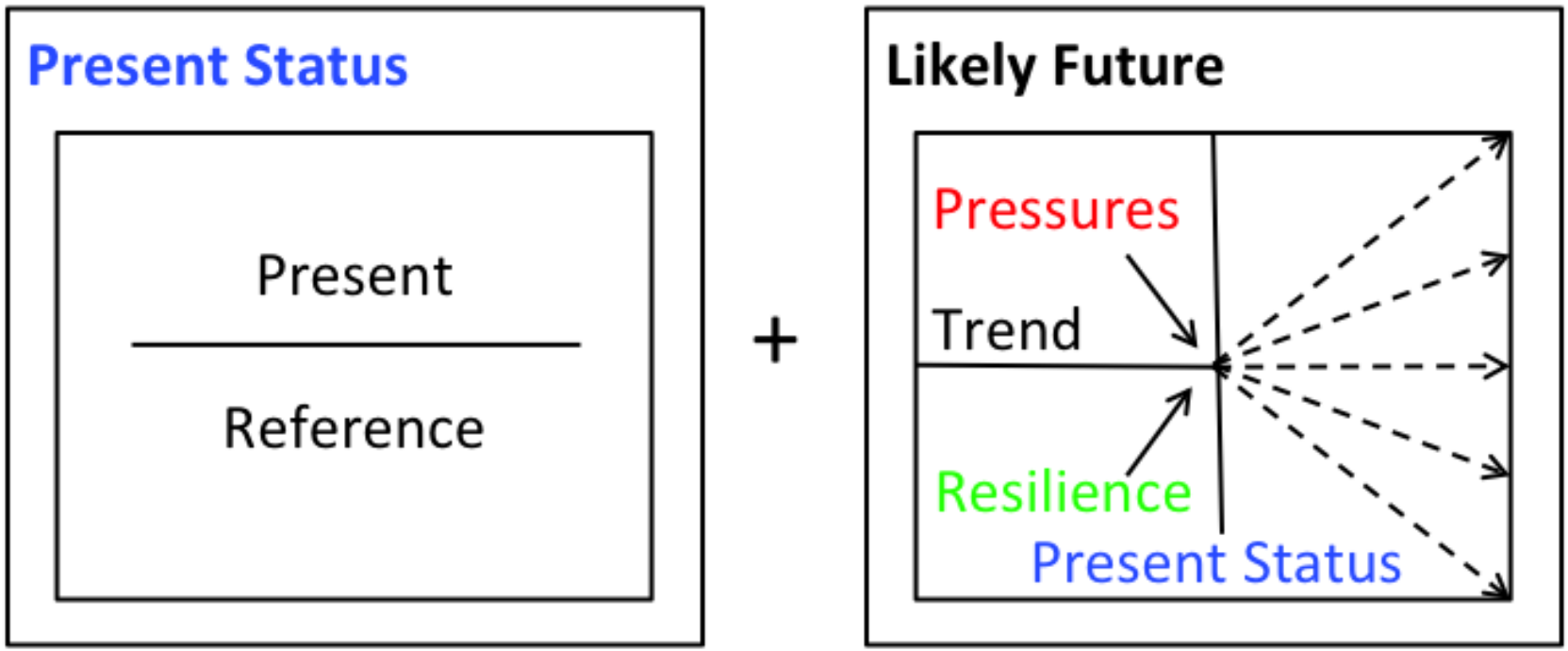
Ocean Health Index



Ocean Health Weighted



Dimensions

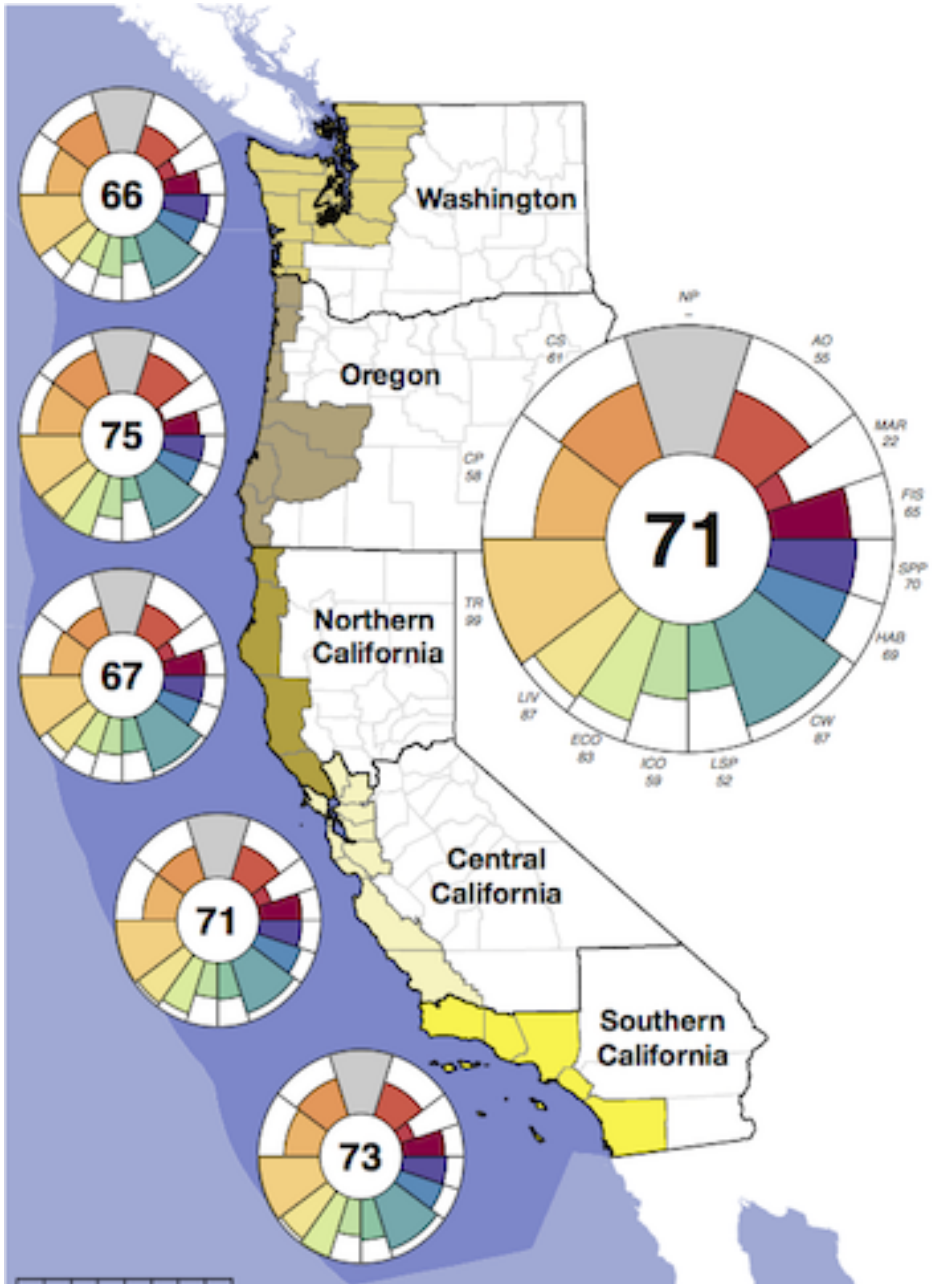

Present Status
Present
Reference
+
Likely Future
Pressures
Trend
Resilience
Present Status

Toolbox Goals

- **Recalculate** OHI globally or regionally using alternative weights, equations, layers, etc.
- **Regionalize** based on administrative boundaries finer than EEZ.
- **Visualize** results to highlight best opportunities for improving ocean health.
- **Interface** with easy-to-use forms for sliding weights and concocting scenarios.
- **Automate** with tools for manipulating input layers and calculating OHI scores for sensitivity analyses.

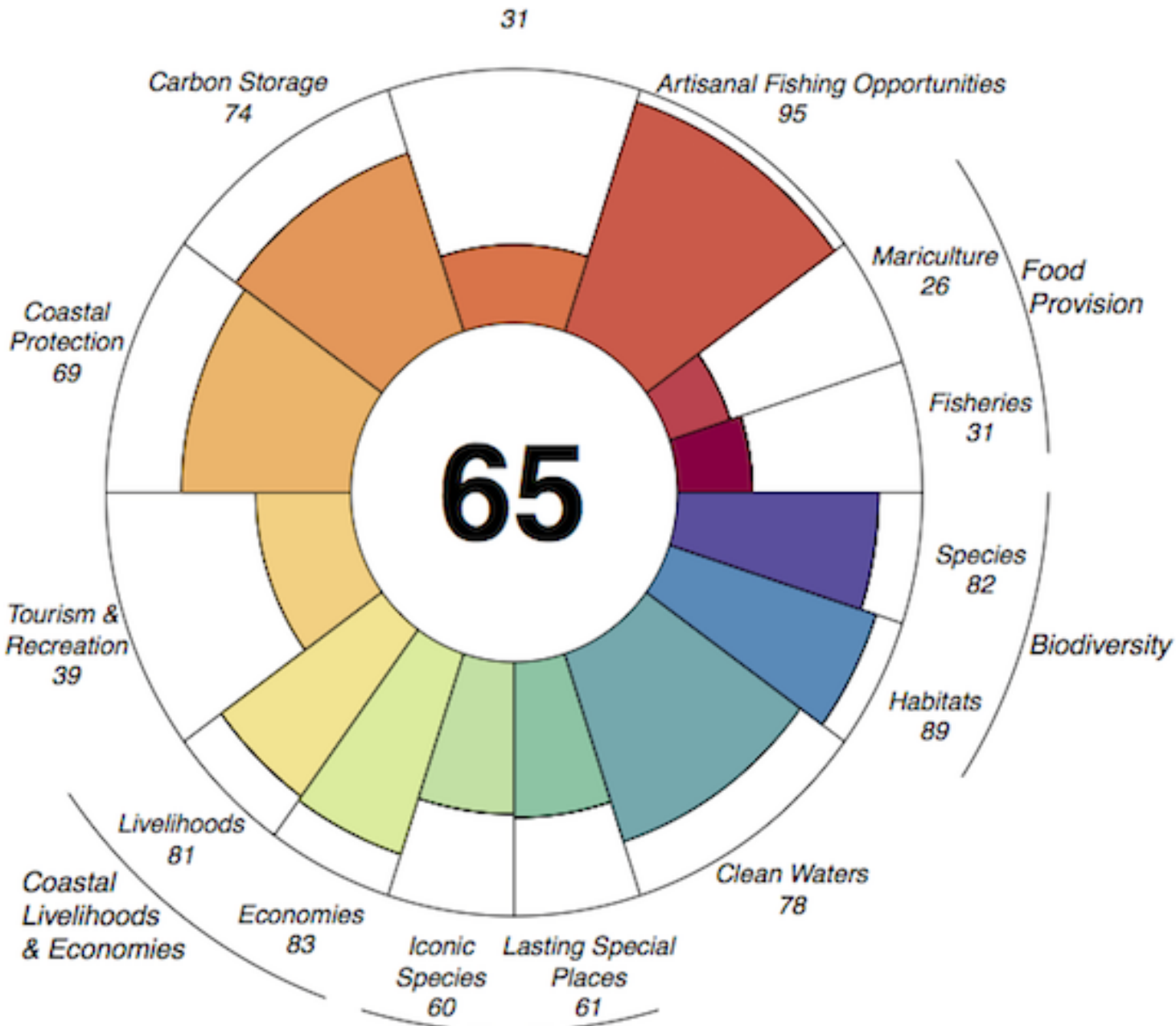
Regionalize

US West Coast Halpern et al (2014) *PLoS ONE*



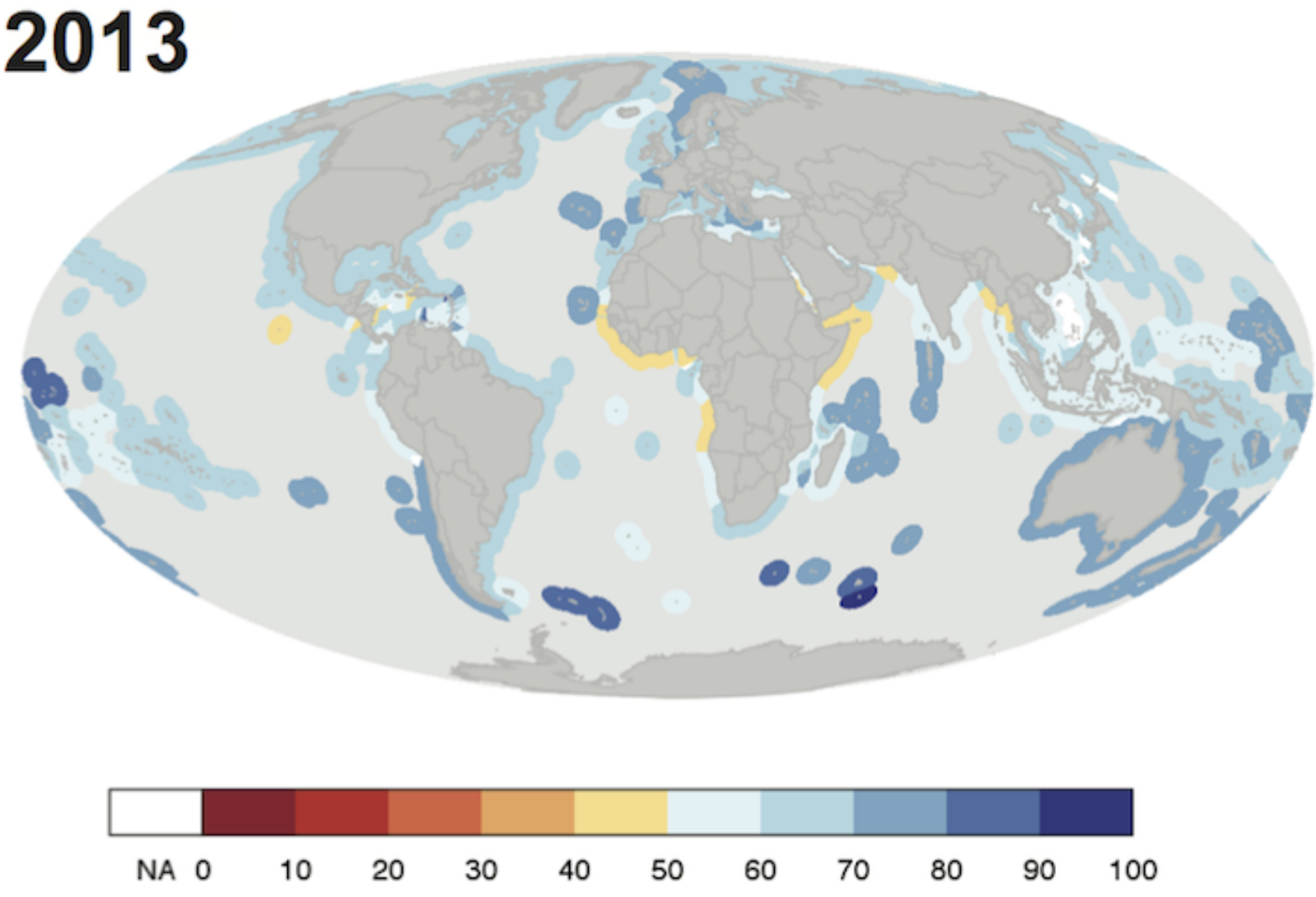
Visualize

Flower

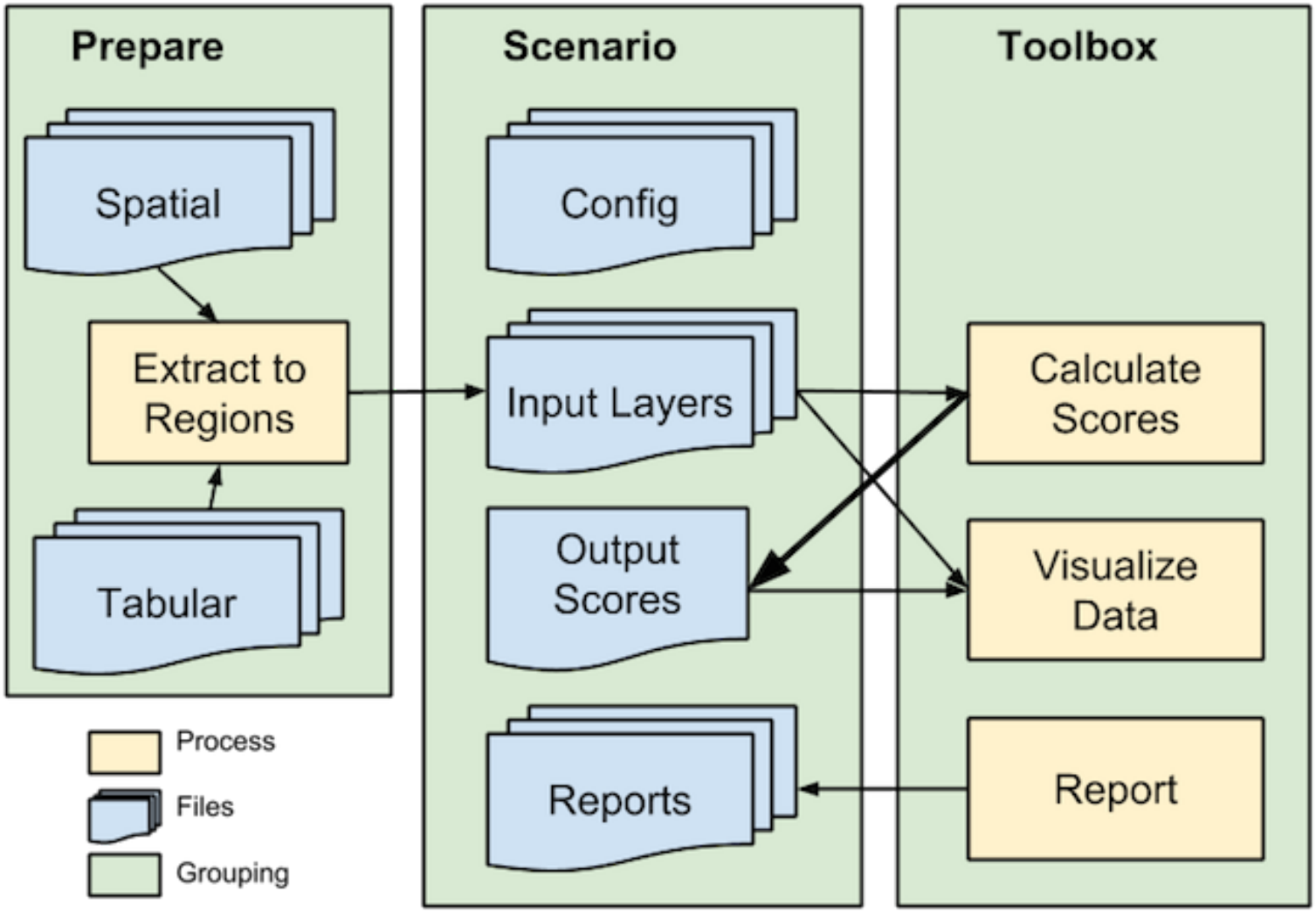


Visualize

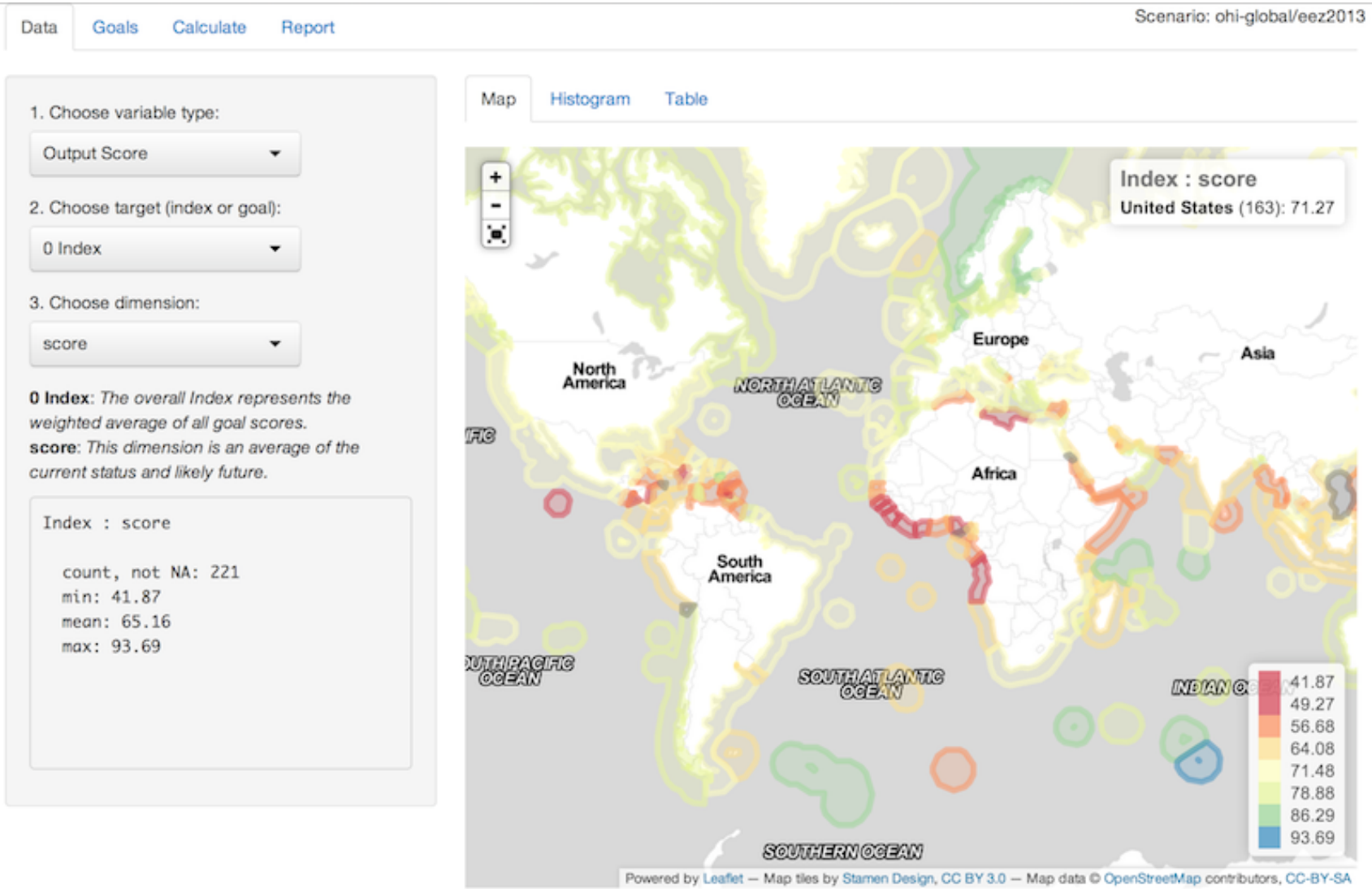
Map



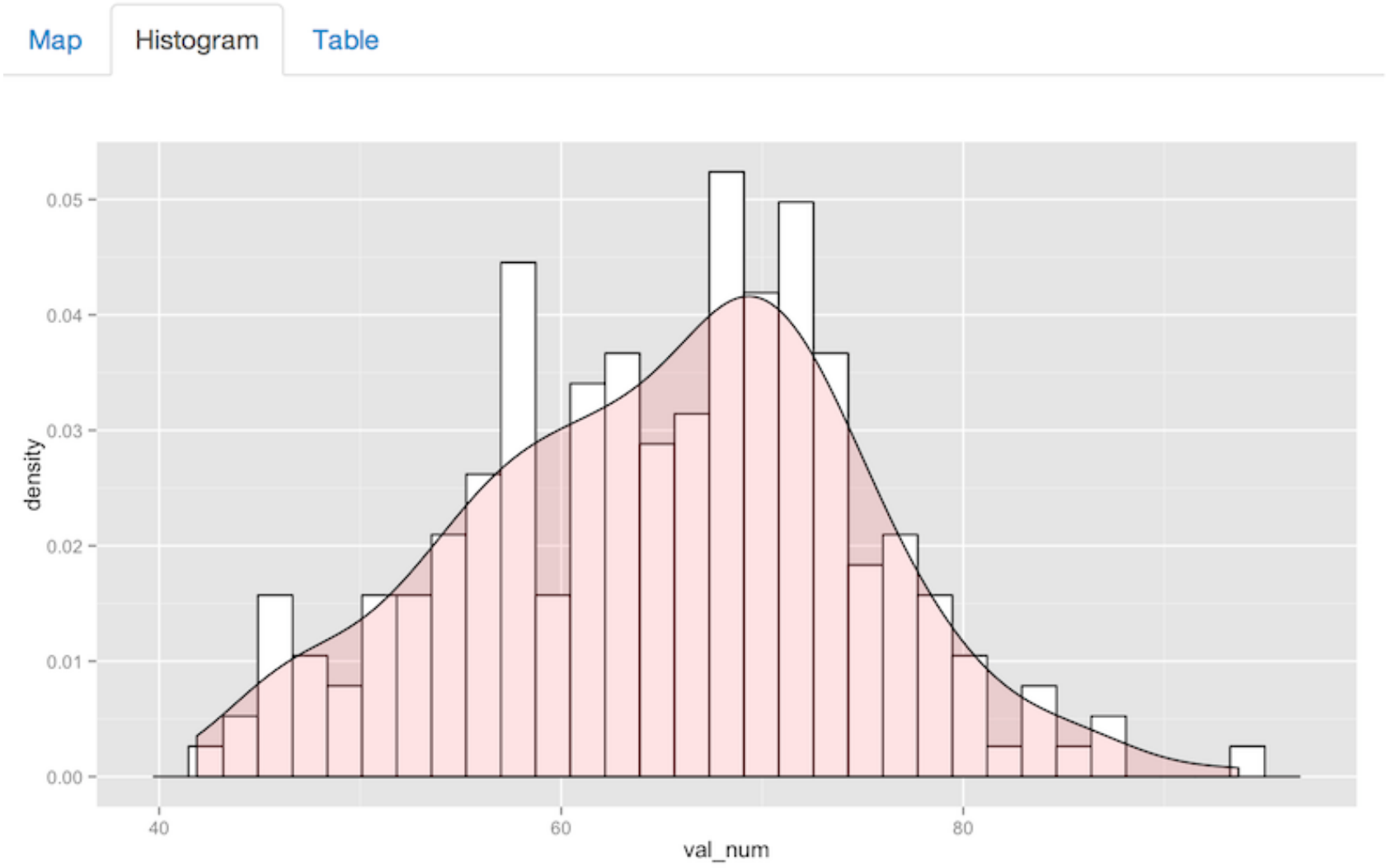
Process


Prepare
Scenario
Toolbox
Spatial
Extract to Regions
Tabular
Config
Input Layers
Output Scores
Reports
Calculate Scores
Visualize Data
Report
Process
Files
Grouping

Toolbox: Data | Map



Toolbox: Data | Histogram



Toolbox: Goals

Data | Goals | Calculate | Report

Scenario: ohi-global/eez2013

Food Provision:
Mariculture:
0 0.5 1

Fisheries:
0 0.5 1

Artisanal Opportunity:
0 1

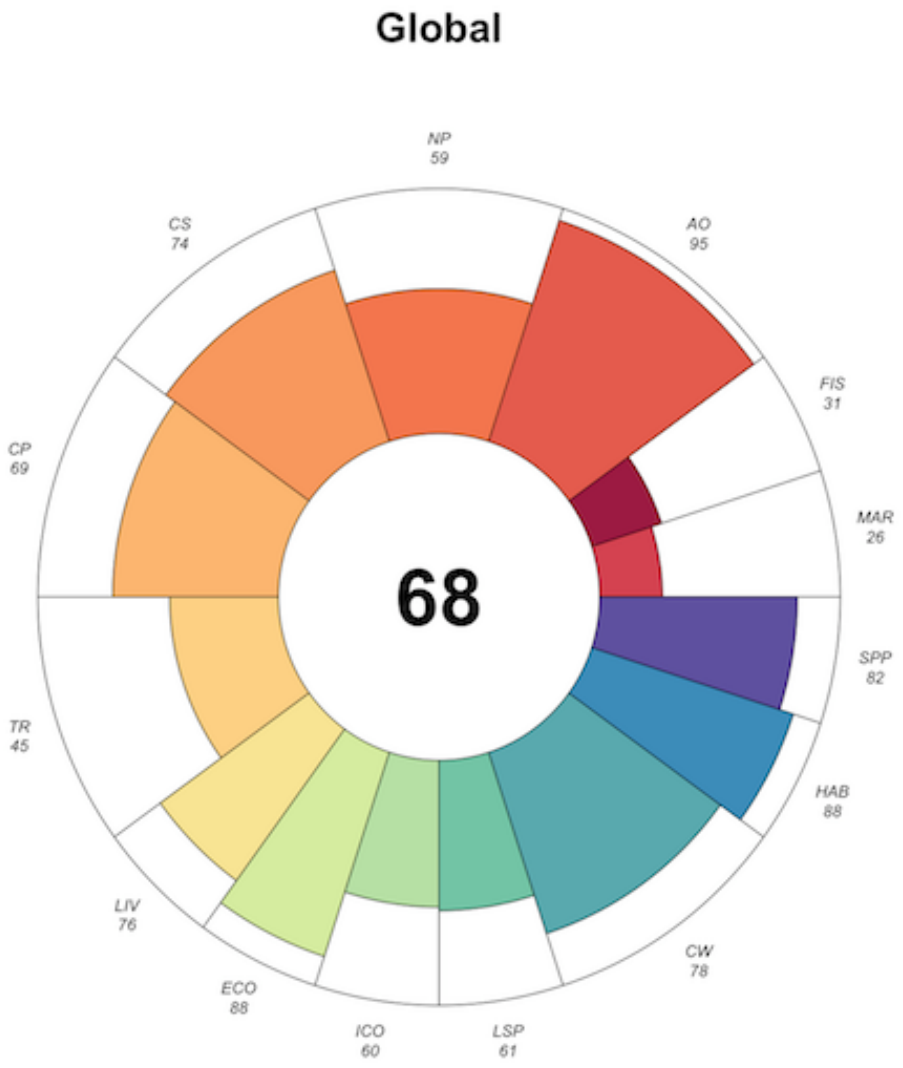
Natural Products:
0 1

Carbon storage:
0 1

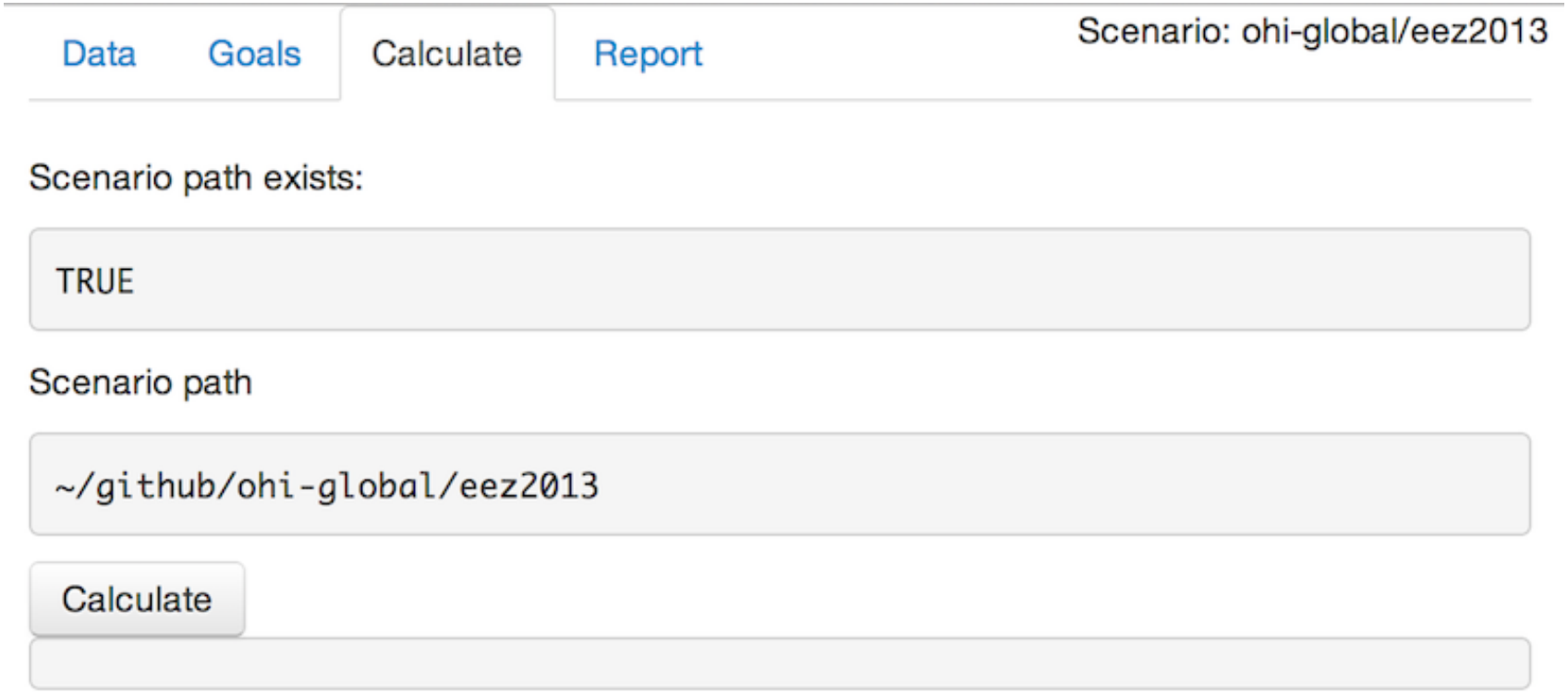
Coastal protection:
0 1

Tourism & Recreation:
0 1

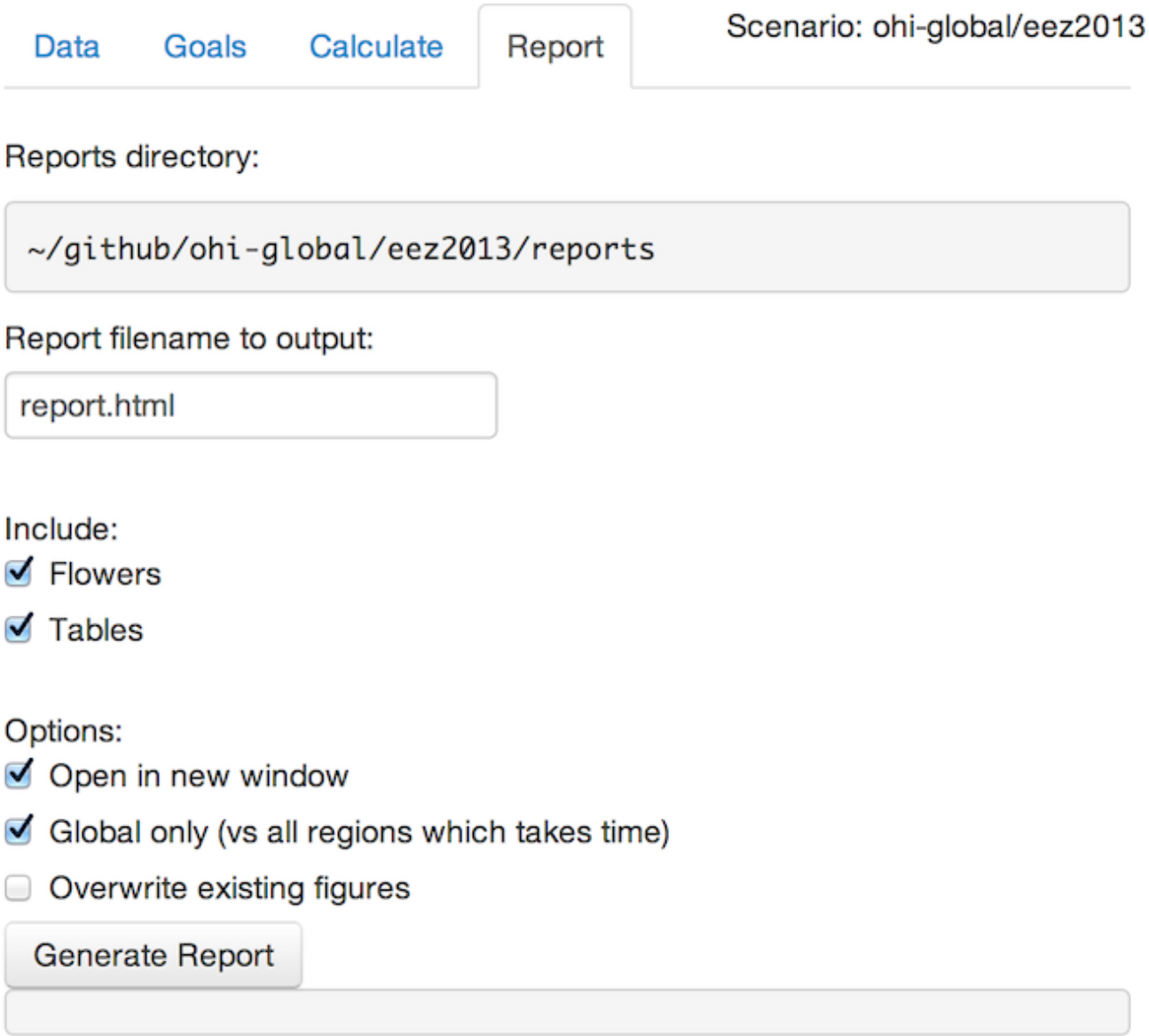
Coastal Livelihoods & Economies:
Livelihoods:



Toolbox: Calculate



Toolbox: Report



Toolbox: Report -> Result

- Western Sahara (63)
  - Flower
  - Scores
- Yemen (47)
  - Flower
  - Scores

Ocean Health Index Report

GLOBAL (0)

Flower

Scores

	score	status	future
Index	68.18	NA	68.64
Food Provision	32.52	30.30	34.74

Regionalization Strategy

- examples
  - Baltic
  - Israel biogeographic and political
- globally
  - political: Global Administrative Areas (GADM)
  - biogeographic: Marine Ecoregions of the World (MEOW)
  - data:
    - pressures: extract from 1km Cumulative Impact rasters (Halpern et al 2008, Halpern et al *in draft*)
    - other: weight country values from ohi-global by area / coastal population / ... of region
  - populate ohi-[country] scenario repository
  - deploy to ShinyApps.io for interactive website

Scenario files

- layers.csv, layers/

Scenario files

- layers.csv, layers/
  - *.csv

Scenario files

- layers.csv, layers/
  - *.csv
- scenario.R, conf/

Scenario files

- layers.csv, layers/
  - *.csv
- scenario.R, conf/
  - config.R

Scenario files

- layers.csv, layers/
  - *.csv
- scenario.R, conf/
  - config.R
  - pressures_matrix.csv, resilience_matrix.csv, resilience_weights.csv

Scenario files

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  - *.csv
- scenario.R, conf/
  - config.R
  - pressures_matrix.csv, resilience_matrix.csv, resilience_weights.csv
  - goals.csv

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  - *.csv
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  - pressures_matrix.csv, resilience_matrix.csv, resilience_weights.csv
  - goals.csv
  - functions.R

Scenario files

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  - pressures_matrix.csv, resilience_matrix.csv, resilience_weights.csv
  - goals.csv
  - functions.R
- spatial/regions_gcs.js

Scenario files

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  - goals.csv
  - functions.R
- spatial/regions_gcs.js
- launchApp_code.R, launchApp.bat (Win), launchApp.command (Mac)

Scenario files

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  - *.csv
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- scores.csv

Scenario files

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  - pressures_matrix.csv, resilience_matrix.csv, resilience_weights.csv
  - goals.csv
  - functions.R
- spatial/regions_gcs.js
- launchApp_code.R, launchApp.bat (Win), launchApp.command (Mac)
- scores.csv
- results/report.html, /figures

Simulation

For example, calculate Baltic Health Index every year using scenarios `bhi1980,..., bhi2014` as folders.

```
library(ohicore)

for (dir_scenario in sprintf('~/ohibaltic/bhi%d', 1980:2014
  setwd(dir_scenario)

  conf    = Conf('conf')
  layers = Layers('layers.csv', 'layers')
  scores = CalculateAll(conf, layers)

  write.csv(scores, 'scores.csv')
}
```

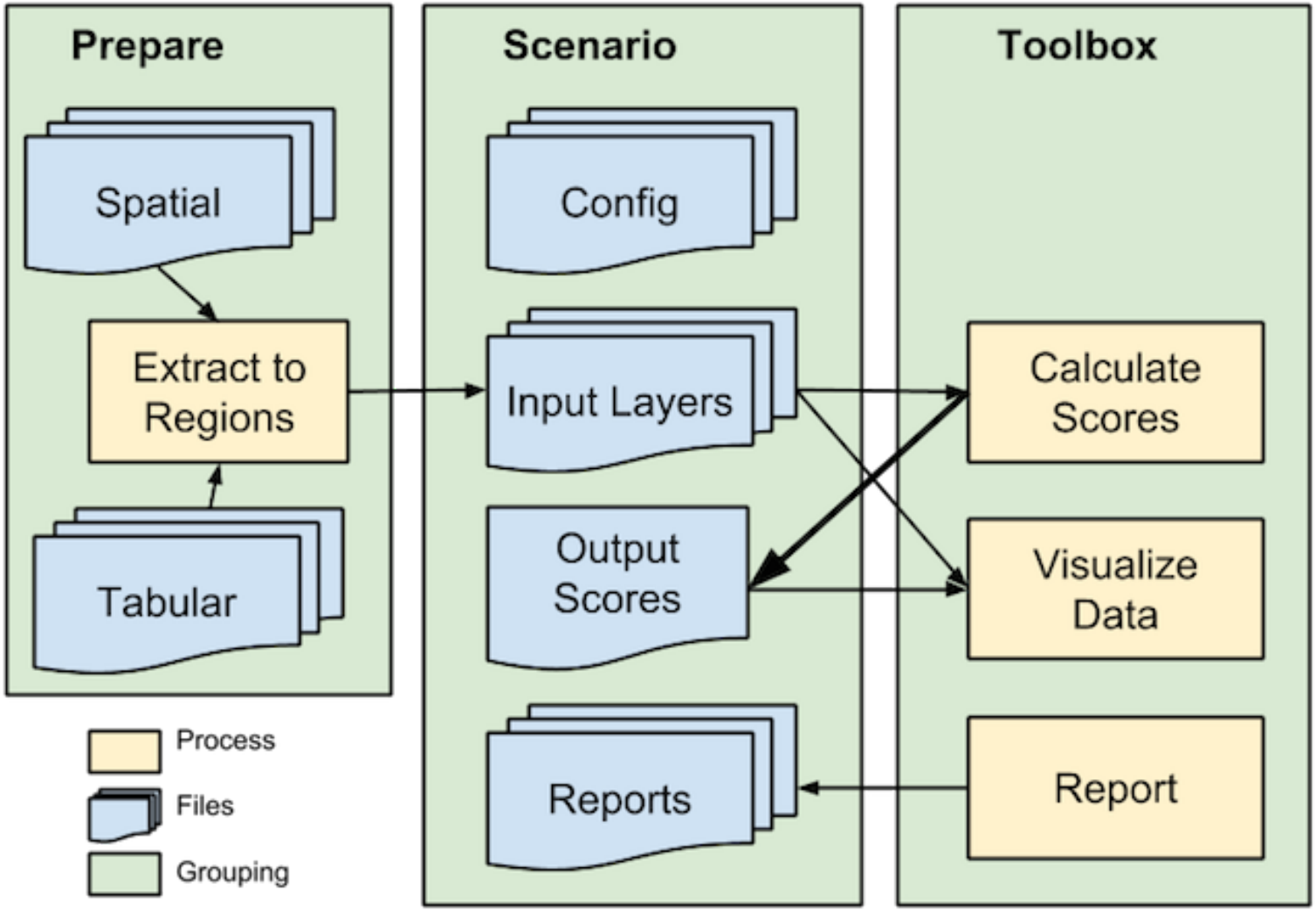
Software choices for reproducible science

free, cross-platform, open source, web based:

- **csv** (comma-seperated value) data files. ancillary: md, json, shp, geotiff
  - Excel poor with Unicode, file locking. Try OpenOffice instead.
- **R** having libraries `shiny` web application, `ggplot2` figures, `dplyr` data manipulation
  - RStudio excellent front end
- **Github** repositories:
  - **backup** to offsite archive, and **rewind** changes
  - **document** changes of code and files with issues and messages
  - **collaborate** with others and **publish** to web site

Github Repositories

`ohiprep` | `ohi-[scenario]` | `ohicore`



OHI for Github

1. Install R library: `ohicore`

```
library(devtools)
install_github('ohi-science/ohicore')
```

1. Collaborate on a scenario: eg `ohi-global`

- `https://github.com/OHI-Science/ohi-global`
- **Download** ZIP, **Clone**, **Fork**
- install script

For More. . .

- ohi-science.org

For More. . .

- ohi-science.org
- bbest@nceas.ucsb.edu

For More...

- ohi-science.org
- bbest@nceas.ucsb.edu
- bbest.github.io/talks/2014-07_ohi-cumimpacts_esri-uc