Tools for marine conservation and spatial planning

Ben Best
November 13, 2013
Spatial Tech Lunch

Credit: Sarah Fretwell
Outline

• Discover

• Analyze

• Inform
Outline

- Discover
- Analyze
- Inform
Metadata Clearinghouses

- DIF: gcmd.nasa.gov
- FGDC to ISO 19115: data.gov, arcgis.com
- FGDC Biological Profile to EML: knb, dataone.org
Census of Marine Life Context

**Ocean Biogeographic Information System**

**Spatial Ecological Analysis of Megavertebrate Populations**
- marine mammals, seabirds, sea turtles

Field Projects

- OBIS
- Historical-MAP
- Future-MAP

Taxonomic
- CepBase
- FishBase
- Biogeoinformatics
- OBIS•SEAMAP
- ZooGene
- Seamounts

Regional / Physiographic
OBIS-SEAMAP Data Holdings

> 3,5 M records
568 datasets
(1935 – 2013)
OBIS-SEAMAP data types

- Ship & aerial surveys
- Telemetry tracking
- Acoustic
- Colonies & sites
- Genetics
- Models
- PhotoID
### Flexible: Capture Whole Dataset

<table>
<thead>
<tr>
<th>_dataset</th>
<th>_id</th>
<th>_lat</th>
<th>_lon</th>
<th>_geom</th>
<th>_sp_obs</th>
<th>_sp_tsn</th>
<th>_obs_count</th>
<th>_obs_datetimez</th>
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<tr>
<td>Track</td>
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<tr>
<td>Wind</td>
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<tr>
<td>SeaState</td>
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<tr>
<td>Swell</td>
<td></td>
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</tr>
</tbody>
</table>

- Flag required fields
- SQL Union on fields
- Query on union table
- Relate Effort / Track Tables
Spatial: Beyond Point Data

**Lines for Effort**
- Ship or aircraft observation effort
- Inferred tracks of tagged animals
- Speed / duration attributes

**Polygons for Distributions**
- Communicate area distributions
- Expected ranges / densities
- Management boundary overlays
Taxonomic

- Taxonomic Serial Number (TSN)
- XML Service for common/scientific (PHP)
- Populate Metadata with Biological Profile
- Query Up/Down Taxonomic Hierarchy
Tools for Providers

Data Factory

- web interface
- Access Control
- Upload
- Map
- Edit Metadata
- Manage Datasets
- files
  - *.csv
  - *.shp
  - *.xml

Database

- ARGOS email
- Perl parser

Upload
1. Upload your data table

In order to add a dataset you must define the type of data and browse to the data file, which should be in comma-separated value text format. For more information, see Help with getting started.
2. Match **taxonomic names**

### List of Unique Species Observed

<table>
<thead>
<tr>
<th>Species Observed</th>
<th>ITIS Name</th>
<th>ITIS #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic spotted dolphin</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Balaenoptera</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clymene dolphin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common dolphin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dwarf/pygmy sperm whale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dwarf sperm whale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fin whale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fraser’s dolphin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gray seal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minke whale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pantropical spotted dolphin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pygmy sperm whale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rough-toothed dolphin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short/Long-finned pilot whale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sperm whale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spinner dolphin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Bottlenose dolphin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Striped dolphin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unidentified dolphin</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Searching ITIS is case-sensitive. Scientific names are capitalized, except species (Genus species, i.e. "Orcinus orca"). Common names are lower-case (i.e. "humpback whale"), except where name includes a proper word (i.e. "Risso's dolphins").

**Common names containing 'Balaenoptera':**

- **Balaenoptera (Genus)**
- **Balaenoptera acutorostrata (Species)**
- **Balaenoptera acutorostrata acutorostrata (Subspecies)**
- **Balaenoptera acutorostrata scammoni (Subspecies)**
- **Balaenoptera banaorornis (Species)**
- **Balaenoptera borealis (Species)**
- **Balaenoptera borealis borealis (Subspecies)**
- **Balaenoptera borealis schlegelli (Subspecies)**
- **Balaenoptera brydei (Species)**
- **Balaenoptera edeni (Species)**
3. Enter metadata

<table>
<thead>
<tr>
<th>Identity</th>
<th>obis-seamap_19</th>
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<tbody>
<tr>
<td>Title, Full</td>
<td>Cetacean Survey in NW Atlantic</td>
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<tr>
<td>Title, Short</td>
<td>Cetaceans(NEFSC '97)</td>
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<td>Edition</td>
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**Citation information**

<table>
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<tr>
<td>Publication place:</td>
<td></td>
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<tr>
<td>Publisher:</td>
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</table>
Attracting Data Providers

1. Value-Added Services
2. Proposal Subcontracts
3. Parachute Interns
4. Data provider Workshops
5. Conference Presentations
Data Exchange Protocols

**Data Pipelines**

- OBIS-SEAMAP
- Flat Files
- Database

**Data Type:**
- point data
- raster data
- metadata
- geographic

**Tools/Protocols:**
- DIGIR
- XML
- OPeNDAP
- Z39.50
- FGDC
- WMS / WFS

**Ex. Partners:**
- OBIS
- NOAA
- NSDI
- UNEP
- WCMC
Consuming Web Map Services (WMS)

Select Environment

- Sea Surface Temperature
- Sea Surface Height
- Wind Speed and Direction

A histogram of observations over time allows you to step through the environmental background data, retrieved on-the-fly from JPL PO-DAAC WMS.
IMS: ArcIMS vs. MapServer

Web Template
- HTML
- Chameleon

Connector Script
- JavaScript/Java/ASP
- Java/PHP/Python/Perl/...

Web Server
- Tomcat
- Apache/IIS

Map Engine
- ArcIMS (*.axl)
- MapServer (*.map)

Spatial DB Adapter
- ArcSDE
- PostGIS

Database
- Oracle / SQL Server...
- PostgreSQL...

seamap.env.duke.edu/maprpt
# Serving OGC Web Services

<table>
<thead>
<tr>
<th>Geospatial Standard</th>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web Feature Service (WFS)</td>
<td>vector (points, lines, polygons)</td>
<td>XML data (GML)</td>
</tr>
<tr>
<td>Web Coverage Service (WCS)</td>
<td>raster (pixel-based imagery)</td>
<td>Scientific data (HDF, GeoTIFF…)</td>
</tr>
<tr>
<td>Web Map Service (WMS)</td>
<td>map (stack of raster/vector layers)</td>
<td>Image (GIF, JPEG…)</td>
</tr>
</tbody>
</table>

http://seamap.env.duke.edu/prod/mapservice/ogc?

WMS

REQUEST=GetMap&SERVICE=wms&VERSION=1.1.1
&HEIGHT=200&WIDTH=300
&LAYERS=bath,spdistr,land,tsn180537

Right whales across datasets

WFS

REQUEST=GetFeature&SERVICE=wfs&VERSION=1.0.0
&TYPENAME=eff2

Effort lines for dataset #2
**OBIS Portal Architecture – Current**

**Database**
- Rutgers Univ.

**Amazon Cloud**
- A replicated set for development
- (R&D environment supported via Amazon grant to Duke)

**Search Interface**
- Duke Univ.

**DiGIR or File transfer**
- Team members also data providers:
  - OBIS-SEAMAP, Duke University
  - Caribbean NRIC, Simón Bolívar

**Data providers**

**Internet**

**Web site**
- Simón Bolívar
Portal Infrastructure

**Front Page**
- Drupal 6

**Search Interface**
- OpenLayers 2.9
- EXTJS 3.1
- Javascript
- PHP 5.3

**Mapping Engine**
- GeoServer 2.1 (custom?)

**Database**
- PostGIS 1.4
- PostgreSQL 8.4

**Apache 2**

**Tomcat 6**

**Ubuntu**

**VLIZ & INCOIS machines**
Data Access

- **Search Interface**
  - OpenLayers
  - EXTJS stores Javascript

- **WMS requests**
  - WMS images

- **Mapping Engine**
  - GeoServer

- **OBIS Store**

- **PHP**
  - AJAX calls
  - JSON

- **Database**
  - ADODB
  - PostGIS
  - PostgreSQL

- **Data Access**

This diagram illustrates the flow of data access through various technologies and tools, including OpenLayers, EXTJS stores, GeoServer, OBIS Store, PHP, AJAX calls, JSON, ADODB, PostGIS, and PostgreSQL, in the context of a search interface and mapping engine.
Outline

• Discover
• Analyze
  – Ingest
  – Model
• Inform
Multidimensional Data

- depth: 3
- temp: $3 \times 3 \times 3$
- latitude: 3
- longitude: 3
- + time: 10 $\rightarrow$ temp: $3 \times 3 \times 3 \times 10$

Metadata
- Transformations
  $SST = \text{integer} \times 0.075 - 3$
- Missing Values
- Source
- Projections
  - ...
Scientific Data Formats

• Properties
  – Can store scalars, vectors, arrays, vgroups...
  – “Self-describing” = metadata in header

• Most Common
  – Network Common Data Format (netCDF: .nc .cdf)
    • Created by: National Center for Supercomputing Applications (NCSA)
    • Thematic focus: atmospheric modeling
  – Hierarchical Data Format (HDF: .hdf .hdf4 .hdf5)
    • Created by: University Corporation for Atmospheric Research (UCAR)
    • Thematic focus: satellite remote sensing
OPeNDAP

Open-source Project for a Network Data Access Protocol

• OPeNDAP form (.html .dds .das):
  http://oceanwatch.pfeg.noaa.gov/thredds/dodsC/satellite/MB/chla/8day.html

• MATLAB command:
  loaddods('http://las.pfeg.noaa.gov/OceanWatch-FDS/LAS/MB/chla8day?
  MBCHLA[1033:1033] [0:0] [3218:3379] [4558:4760]')

• Python: pydap

```python
>>> from pydap.client import open_url
>>> dataset = open_url('http://test.opendap.org/dap/data/nc/coads_climatology.nc')
>>> var = dataset['SST']
>>> var.shape
(12, 90, 180)
>>> var.type
<class 'pydap.model.Float32'>
>>> print var[0,10:14,10:14]  # this will download data from the server
[[ -1.26285708e+00 -9.99999979e+33 -9.99999979e+33 -9.99999979e+33]
 [ -7.69166648e-01 -7.79999971e-01 -6.75454497e-01 -5.95714271e-01]
 [ 1.28333330e-01 -5.00000156e-02 -6.36363626e-02 -1.41666666e-01]
 [ 6.38000011e-01 8.95384610e-01 7.21666334e-01 8.10000002e-01]]
```
Oceanographic Data Online

Pointers: CoMLmaps.org > HowTo > Layers and Resources

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**Boundaries**
Data that define international borders, maritime boundaries and administrative units.

- **Maritime Boundaries Geodatabase**
  Global maritime boundaries and exclusive economic zones (EEZ)

- **Global Administrative Areas**
  Global country and administrative boundaries

- **Large Marine Ecosystems**
  Large Marine Ecosystems (LME)

---

**Human Impact**
Data about anthropogenic impacts on marine ecosystems

- **Human Impacts to Marine Ecosystems**
  Global data on human impacts to marine ecosystems

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**Physical Environment**
Base physical environment data

- **Global Self-consistent, Hierarchical, High-resolution Shoreline (GSHHS)**
  GSHHS database v1.1.0

- **Marine Ecoregions of the World (MEOW)**
  Global marine realms, provinces, and ecoregions

- **ETOP01 Global Topography**
  1 arc-minute global topography

- **SRTM 30 Plus Global Topography**
  30 arc-second global topography

---

**Oceanographic Data**
Physical and biological oceanographic data

- **AVHRR Sea Surface Temperature**
  AVHRR Oceans Pathfinder SST data

- **Ocean Primary Productivity**
  Primary productivity data

- **QuikSCAT Wind**
  QuikSCAT wind data

- **NASA OceanColor Chlorophyll**
  NASA OceanColor Chlorophyll A data

- **HYCOM model output**
  Global HYCOM + NOODA Hindoast data

- **AVISO Sea Surface Height**
  AVISO sea surface height (SSH) data

- **AVISO Geostrophic Currents**
  AVISO geostrophic current data

- **AVISO Significant Wave Height**
  AVISO Significant Wave Height

- **AVISO Surface Wind**
  AVISO Surface Winds
Marine Geospatial Ecology Tools (MGET) HDF/netCDF converters
These evolved to tools specific to popular products.
Interoperability

MGET “tools” are really just Python functions with input and output parameters:

```python
def DoSomething(input1, input2, output1)
```

Python programmers can call MGET functions directly. To facilitate interoperability, MGET exposes these functions as COM Automation objects and ArcGIS tools.

COM-capable program: C / C++ / C#, Visual Basic, R, MATLAB, Java, etc.
The Python functions can invoke C++, MATLAB, R, ArcGIS, and COM classes.
Outline

• Discover
• Analyze
  – Ingest
  – Model
• Inform
Detecting SST fronts

- MGET provides tools that detect oceanographic features in remote sensing images
- These are some of the most popular tools in MGET
Cayula & Cornillon algorithm

Daytime SST 03-Jan-2005

Step 1: Histogram analysis

Optimal break 27.0 °C

Bimodal

Temperature

Frequency

Step 2: Spatial cohesion test

Strong cohesion → front present

Weak cohesion → no front

~120 km

ArcGIS model

Example output

Mexico

Front

28.0 °C

25.8 °C

Marine Geospatial Ecology Tools
Connectivity
Conversion
Data Management
Data Products
Fishery Analysis
Oceanographic Analysis
Spatial and Temporal Analysis
Statistics

Mexico ArcGIS model
Application: Modeling density of critically endangered right whales

Roberts, Best, Halpin, et al. (in prep)
Mesoscale eddies

- This tool detects eddies in SSH images collected by NASA/CNES radar altimeters.
Gulf stream eddies

Image from http://www.oc.nps.edu/
Okubo-Weiss eddy detection

\[ u = -\frac{g}{f} \frac{\partial h}{\partial y}, \quad v = \frac{g}{f} \frac{\partial h}{\partial x}. \]

\[ \omega = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}, \quad s_n = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}, \quad s_s = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}. \]

\[ W = s_n^2 + s_s^2 - \omega^2, \]

Example output

Aviso DT-MSLA 27-Jan-1993
Red: Anticyclonic  Blue: Cyclonic

SSH anomaly

Negative \( W \) at eddy core
Application: fisheries ecology

• Are tuna and swordfish catches in the northwest Atlantic correlated with eddies?

Chelton’s eddy database

- MGET also includes tools that provide easy access to data products published by other NASA grantees.
- By improving access to these products from GIS, we hope to increase use by ecologists.

Habitat patches

Ocean currents data

Larval density rasters

Tool downloads data for the region and dates you specify

Edge list feature class representing dispersal network

Treml et al animation
Model species habitat

- Point observations of species
- Gridded environmental data
- Bathymetry
- SST
- Chlorophyll

Probability of occurrence predicted from environmental covariates

Predictive model

\[ g(\mu) = \beta_0 + \beta_1 x_1 + \cdots + \beta_m x_m \]
Invoke R from ArcGIS
MGET statistics tools

- Lots of tools, many more planned
- Built from Ben Best’s ArcRStats / HabMod projects
- Tools require the R statistics program to be installed on your computer
Exploratory analysis

Density Histogram tool

Scatterplot Matrix tool

Distance to nesting beach (m)
Fitting statistical models

Term plots

ROC plots

Fit GAM

model.rdata

Plot ROC of Binary Classification Model

Points

Output cutoff

Summary bd

roc.png
Predicting habitat maps from the model

Input #1: The fitted model

Input #2: Cutoff value

Input #3: Rasters for predictor variables

Predicted species presence

Binary habitat (cutoff = 0.025)

Bayesian probability that predicted presence ≥ 0.025
Calculate species diversity
Outline

• Discover

• Analyze

• Inform
Project Synergies: Archive to Modeling

Data Providers → Datasets → Geo-Archive → Website → Geospatial Web Services → Scientific Workflows

- Archive Users
- Model Users

Datasets

OBIS•SEAMAP

Website

Geospatial Web Services

Scientific Workflows

SDSS

Data Providers

Model Users
SDSS: Summarize by Region

Select Region by

1. Drop-down list (OPAREAs, MPAs, EEZ)
2. Enter polygon coordinates
3. Draw on map

Return:
- Effort, Obs
- Min, Max, Mean
- Histogram
- Coordinates
ROC Curve to Binary Habitat in SDSS

Example:
baleen guild (fin, blue, sei, Bryde's) in summer
Application: Offshore Energy Compliance

MarineCadastre.gov

- **Purpose**: spatial information for determining environmental compliance for siting offshore wind farms and oil exploration.
- **Transferred**: predictive density models of cetaceans and turtles by season for US Atlantic and Pacific waters.
Application: Cetacean Mapping & Sound

CetSound.noaa.gov

- Purpose: organize best available information on the distribution of cetaceans and noise that may disturb them within all US waters.

- Built: gap analysis and data discovery framework based on region, species and month for the following tiers:

  1. Habitat-based Density Models
  2. Stratified Density Models
  3. Probability of Occurrence
  4. Observations
  5. Records Exist
  7. Important Areas
Outline

- Discover
- Analyze
- Inform
Ocean Health Index - Global

- Natural Products: 40
- Carbon Storage: 75
- Artisanal Fishing Opportunities: 87
- Coastal Protection: 73
- Mariculture: 10
- Fisheries: 25
- Food Provision: 25
- Biodiversity: 79
- Species: 79
- Habitats: 88
- Clean Waters: 78
- Livelihoods: 84
- Economies: 67
- Iconic Species: 70
- Lasting Special Places: 41
- Tourism & Recreation: 10
- Coastal Livelihoods & Economies: 67
- Sense of Place: 60

Halpern et al. (2012) *Nature*
Global Index Scores
Regionalized OHI

Halpern et al (~submitted) Cons Letters

Elfes et al (in review) Cons Letters
Goals of OHI Toolbox

• **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.
Toolbox

Local Desktop Interfaces
- Application
- Workflow Tools
- Programming Interfaces

Engines
- R
- ArcGIS
- OpenGIS

Data
- Text Files
- Database

Remote Web Services (optional)
- Maps
- Charts
Workflow
Cumulative Impacts
ArcGIS Python Toolbox

Threat Model

Runs a weighted threat model based on habitats and threats, and calculates a number of summary statistics and footprint analyses.
App: Data
App: Goals
App: Goals
App: Calculate

Select scenario (from /Users/bbest/ohi_tbx/scenarios):
- global_2012_nature

Scenario: global_2012_nature
- goals.csv: PASS
- layers_navigation.csv: PASS
- pressures_matrix.csv: PASS
- resilience_matrix.csv: PASS
- resilience_weights.csv: PASS
App: Report

Compare with scenario:

[None]

Include:
- Equations
- Flowers
- Histograms
- Maps
- Paths
- Tables

Generate Report
Viz: Histograms

Count

Coastal Livelihoods & Economies

Index Score

0 20 40 60 80 100

0 15 10

0 5 10

0 20 40 60 80 100

0 10 0 10

0 5 10

0 20 40 60 80 100

0 10 0 10

0 5 10

Viz: Histograms

Count

Coastal Protection

0 20 40 60 80 100

0 10 0 10

0 5 10

Food Provision

0 12 0 6

0 10 0 10

0 5 10

Artisanal Fishing Opportunities

0 10 0 10

0 5 10

Coastal Protection

0 10 0 10

0 5 10

Tourism & Recreation

0 10 0 10

0 5 10

Biodiversity

0 10 0 10

0 5 10

Clean Waters

0 10 0 10

0 5 10

Sense of Place

0 12 0 6

0 10 0 10

0 5 10

Natural Products

0 8 0 4

0 4 0 2

0 10 0 10

0 5 10

Carbon Storage

0 4 0 2

0 10 0 10

0 5 10

Indiv Ex Score

0 10 0 10

0 5 10

Clean Waters

0 10 0 10

0 5 10

Biodiversity

0 10 0 10

0 5 10

Viz: Histograms

Count

Coastal Livelihoods & Economies

Index Score

0 20 40 60 80 100

0 15 10

0 5 10

0 20 40 60 80 100

0 10 0 10

0 5 10

0 20 40 60 80 100

0 10 0 10

0 5 10

0 20 40 60 80 100

0 10 0 10

0 5 10

0 20 40 60 80 100

0 10 0 10

0 5 10

Viz: Histograms

Count

Coastal Protection

0 10 0 10

0 5 10

Tourism & Recreation

0 10 0 10

0 5 10

Biodiversity

0 10 0 10

0 5 10
Viz: Box Plots
Software Specs

• Javascript libraries
  – d3: path diagram
  – leaflet: chloropleth maps

• R packages
  – shiny: R server to Bootstrap JS/CSS
  – rgdal,raster,sp: raster/vector read/write
  – rgeos: spatial operations
  – ggplot2: pretty plots
  – sqldf: sqlite querying on data.frames
  – knitr: reporting
  – ohi: Ocean Health Index custom functions

• Workflow
  – ArcGIS Python toolbox & script tools
  – Kepler Jython actors
# R “Spatial” Libraries

<table>
<thead>
<tr>
<th>R package</th>
<th>Functions</th>
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<td>Rgdal</td>
<td><code>rw</code> raster and vector (OGR)</td>
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<td>maptools</td>
<td><code>rw</code> shapefiles</td>
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<td>RODBC</td>
<td><code>rw</code> Access (geo)databases</td>
</tr>
<tr>
<td>spatstat</td>
<td>point pattern analysis</td>
</tr>
<tr>
<td>sp</td>
<td>common R spatial classes with projection</td>
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See: [nceas.ucsb.edu/~frazier/RSpatialGuides](nceas.ucsb.edu/~frazier/RSpatialGuides)
Acknowledgements + bbest@nceas.ucsb.edu

- **SEAMAP**: E Fujioka, J Cleary, B Donnelly, P Halpin. seamap.env.duke.edu


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