A Process-Based Model for Valuing Coastal Protection Services

Greg Guannel, K. Arkema, M. Papenfus, G. Verutes, J. Davis
J. Bernhardt, A. Guerry, C.-K. Kim, M. Ruckelshaus, and J. Toft
Coastal Protection Model in Marine InVEST
1. Coastal protection in Marine InVEST
2. Theory behind the model
3. Illustrative example
Coastal Protection Model

Two Types of Habitats
- Living
- Non-living

Two Types of Hazards
- Erosion
- Flooding
Habitats Characteristics

Living Habitats

Non-Living Habitats
Coastal Protection Model

**Inputs**

1a Coastal Exposure Index
- Know the Environment
- Generate Scenarios

1b Erosion/Inundation Model
Erosion/Inundation Model
Define Environment

Public Land

Private Land

$
Define Driving Conditions

BIG EVENT

Public Land

Private Land
Example Management Action

15 hrs Storm

Offshore

Beach
Storm Simulation

Tropical

Hurricane Georges 2230 UTC 27 September 1998
Max. 1-min sustained surface winds (kt) for marine exposure
Analysis based on 855 m AGL C-130 Recon missions adj. to sfc. from 1763 - 2100 Z;
Three GPS dropwindsondes, C-MAN, buoys, and ships from 1000 - 2100 Z;
CIMSS GOES Low-Level cloud drift winds adj. to sfc from 1100 Z;
2230 z position extrapolated from 2111 z for using 320 deg @ 7 kt

Extra-Tropical

Pacific Surface Analysis
Valid: 06h 02 Mar. to 00h 04 Mar. 1999

Fig. 1b. The wind circulation of Hurricane Georges as of 27 September 1998, based on the composite datasets of the NOAA Atlantic Oceanographic and Meteorological Laboratory, Hurricane Research Division.

Figure 6. The track of the 2–4 March 1999 La Niña storm, with the pattern of atmospheric pressures at the time of the storm’s peak.
Big Storm = Increased Water Level
(Non-)Living Habitat
Decrease Water Level
Run Storm Surge Model

Estimate surge from 2D model
Run Wave Model

15 hrs Storm

$H_{\text{max}} = 3\text{m}$

$T = 8\text{s}$

Dean & Bender, 2006
Increased Water Level = Erosion/Inundation

Area eroded
Kriebel and Dean, 1993
(Non-)Living Habitat
Provide Protection

$\Delta \text{Erosion}=2\text{m or }9\text{m}^3$
Avoided beach erosion
Avoided re-nourishment cost
Avoided property damages
Avoided number of people affected
Property value: $5,000/m²

Shoreline

Property line

Nourishment Cost: $5/m³

Property value: $5,000/m²
Valuation

- Avoided re-nourishment cost
- Avoided property damages
Conclusion

- Qualitative and quantitative tools to value services from habitats
- Wide variety of marine and coastal habitats can be incorporated
- Process-based model estimates erosion and inundation during storms
- Plenty of guidance provided to interpret inputs and outputs
Future Steps

⇒ Tier1a available February 2011
Future Steps

- Tier1a available February 2011
- Tier1b available mid-2011
Future Steps

- Tier1a available February 2011
- Tier1b available mid-2011
- Guidance and databases
Questions?

PICK ME!!!
PICK ME!
PICK ME!!
PICK ME!
PICK ME!!
PICK ME!!!
PICK ME!!
PICK ME!
Social Variables

What is the land used for?
Where do people live?
Can they evacuate easily?
Incorporation of Man-Made Structures

Stability of wall

Amount of overtopping
Bonus!

Long-Terms Impacts

Thom and Shreffler, 1994

+ Erosion of adjacent sites
Run Wave Model

15 hrs Storm
\[ H_{\text{max}} = 3 \text{m} \]
\[ T = 8 \text{s} \]

Mendez & Losada, 2004

Dean & Bender, 2006
1) Relative exposure of this area?
2) Protection value of existing habitats?
Coastal Exposure Index
A Screening and Evaluation Tool
## Coastal Exposure Index

<table>
<thead>
<tr>
<th>Variable</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geomorphology</strong></td>
<td>Rocky, cliffed coast, fiord, fiord</td>
<td>Medium cliff, indented coast</td>
<td>Low cliff, glacial drift, alluvial plain</td>
<td>Cobble beach, estuary, lagoon, bluff</td>
<td>Barrier beach, sand beach, mud flat, delta</td>
</tr>
<tr>
<td><strong>Natural Habitats</strong></td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
<tr>
<td><strong>Sea Level Change</strong></td>
<td>Net decrease</td>
<td></td>
<td>±1</td>
<td>Net rise</td>
<td></td>
</tr>
<tr>
<td><strong>Wave Exposure</strong></td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td>Higher value</td>
<td></td>
</tr>
<tr>
<td><strong>Wind Exposure</strong></td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td>Higher value</td>
<td></td>
</tr>
<tr>
<td><strong>Shelf Length</strong></td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td>Higher value</td>
<td></td>
</tr>
<tr>
<td><strong>Tidal Range</strong></td>
<td>No Ranking of Tidal Range – Just Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Coastal Exposure Index

<table>
<thead>
<tr>
<th>Rank</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geomorphology</td>
<td>Rocky, cliffed</td>
<td>Medium cliff,</td>
<td>Low cliff,</td>
<td>Cobble beach,</td>
<td>Barrier beach,</td>
</tr>
<tr>
<td></td>
<td>coast, fiord, fiard</td>
<td>indented coast</td>
<td>glacial drift, alluvial plain</td>
<td>estuary, lagoon, bluff</td>
<td>sand beach, mud flat, delta</td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
<tr>
<td>Sea Level Change</td>
<td>Net decrease</td>
<td></td>
<td>±1</td>
<td>Net rise</td>
<td></td>
</tr>
<tr>
<td>Wave Exposure</td>
<td>Lower value</td>
<td></td>
<td>Average value</td>
<td></td>
<td>Higher value</td>
</tr>
<tr>
<td>Wind Exposure</td>
<td>Lower value</td>
<td></td>
<td>Average value</td>
<td></td>
<td>Higher value</td>
</tr>
<tr>
<td>Shelf Length</td>
<td>Lower value</td>
<td></td>
<td>Average value</td>
<td></td>
<td>Higher value</td>
</tr>
<tr>
<td>Tidal Range</td>
<td></td>
<td></td>
<td>No Ranking of Tidal Range – Just Value</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Coastal Exposure Index

<table>
<thead>
<tr>
<th>Variable</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geomorphology</strong></td>
<td>Rocky, cliffed coast, fiord, fiord</td>
<td>Medium cliff, indented coast</td>
<td>Low cliff, glacial drift, alluvial plain</td>
<td>Cobble beach, estuary, lagoon, bluff</td>
<td>Barrier beach, sand beach, mud flat, delta</td>
</tr>
<tr>
<td><strong>Natural Habitats</strong></td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
<tr>
<td>Sea Level Change</td>
<td>Net decrease</td>
<td>±1</td>
<td>Net rise</td>
<td>Higher value</td>
<td>Higher value</td>
</tr>
<tr>
<td>Wave Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td>Higher value</td>
<td>Higher value</td>
</tr>
<tr>
<td>Wind Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td>Higher value</td>
<td>Higher value</td>
</tr>
<tr>
<td>Shelf Length</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td>Higher value</td>
<td>Higher value</td>
</tr>
<tr>
<td>Tidal Range</td>
<td>No Ranking of Tidal Range – Just Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Coastal Exposure Index

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rank</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology</td>
<td>1</td>
<td>Rocky, cliffed coast, fiord, fiard</td>
<td>Medium cliff, indented coast</td>
<td>Low cliff, glacial drift, alluvial plain</td>
<td>Cobble beach, estuary, lagoon, bluff</td>
<td>Barrier beach, sand beach, mud flat, delta</td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>2</td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>3</td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>4</td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>5</td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
</tbody>
</table>

### Sea Level Change
- Net decrease
- ±1
- Net rise

### Wave Exposure
- Lower value
- Average value
- Higher value

### Wind Exposure
- Lower value
- Average value
- Higher value

### Shelf Length
- Lower value
- Average value
- Higher value

### Tidal Range
- No Ranking of Tidal Range – Just Value
# Coastal Exposure Index

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rank</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology</td>
<td>1</td>
<td>Rocky, cliffed</td>
<td>Medium cliff,</td>
<td>Low cliff,</td>
<td>Cobble beach, estuary,</td>
<td>Barrier beach, sand beach,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>coast, fiord, fiord</td>
<td>indented</td>
<td>glacial drift,</td>
<td>lagoon, bluff</td>
<td>mud flat, delta</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Medium cliff,</td>
<td></td>
<td>Low cliff,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>indented coast</td>
<td></td>
<td>glacial drift,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Low cliff, glacial drift,</td>
<td>alluvial plain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>4</td>
<td>Cobble beach,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>estuary, lagoon, bluff</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Barrier beach, sand beach,</td>
<td>mud flat, delta</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Habitats</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coral reef,</td>
<td>High dune,</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mangrove,</td>
<td>marsh</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>coastal forest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea Level Change</td>
<td></td>
<td></td>
<td></td>
<td>±1</td>
<td></td>
<td>Net rise</td>
</tr>
<tr>
<td>Wave Exposure</td>
<td></td>
<td>Net decrease</td>
<td>Average value</td>
<td></td>
<td></td>
<td>Higher value</td>
</tr>
<tr>
<td>Wind Exposure</td>
<td></td>
<td>Lower value</td>
<td>Average value</td>
<td></td>
<td></td>
<td>Higher value</td>
</tr>
<tr>
<td>Shelf Length</td>
<td></td>
<td>Lower value</td>
<td>Average value</td>
<td></td>
<td></td>
<td>Higher value</td>
</tr>
<tr>
<td>Tidal Range</td>
<td></td>
<td></td>
<td></td>
<td>No Ranking of Tidal Range – Just Value</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Coastal Exposure Index

<table>
<thead>
<tr>
<th>Rank</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Geomorphology</td>
<td>Rocky, cliffed coast, fiord, fiord</td>
<td>Medium cliff, indented coast</td>
<td>Low cliff, glacial drift, alluvial plain</td>
<td>Cobble beach, estuary, lagoon, bluff</td>
<td>Barrier beach, sand beach, mud flat, delta</td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
<tr>
<td>Sea Level Change</td>
<td>Net decrease</td>
<td>±1</td>
<td>Net rise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shelf Length</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tidal Range</td>
<td>No Ranking of Tidal Range – Just Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Area eroded in absence of vegetation: 4 m²/m
Area eroded in presence of vegetation: 2 m²/m
Estimate Avoided Erosion

Area eroded
Kriebel and Dean, 1993
Increased Water Level = Erosion/Inundation

- Amount beach lost
- Re-nourishment cost
- Property damages
- Number of people affected
(Non-)Living Habitat
Provide Protection

- Avoided beach erosion
- Avoided re-nourishment cost
- Avoided property damages
- Avoided number of people affected
Inputs

Physical Characteristics

Habitat

Social Data

Storm Characteristics

Management Action
Outputs

Relative Exposure

Avoided Eroded and Inundated Area

Number of People Affected

Amount of Property Damage

Short & Long Term Effects of Seawalls
Data, Data, Data
Data, Data, Data

Global Bathymetry
Data, Data, Data

Global Bathymetry

Habitats drag and friction coefficients
Data, Data, Data

- Global Bathymetry
- Habitats drag and friction coefficients
- Default beach profiles parameters
### Index Variables

<table>
<thead>
<tr>
<th>Rank</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geomorphology</td>
<td>Rocky, cliffed</td>
<td>Medium cliff,</td>
<td>Low cliff,</td>
<td>Cobble beach,</td>
<td>Barrier beach,</td>
</tr>
<tr>
<td></td>
<td>coast, fiord, fiard</td>
<td>indented coast</td>
<td>glacial drift,</td>
<td>estuary,</td>
<td>sand beach,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>alluvial plain</td>
<td>lagoon, bluff</td>
<td>mud flat, delta</td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>Coral reef, mangrove,</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
<tr>
<td></td>
<td>coastal forest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea Level Change</td>
<td>Net decrease</td>
<td>±1</td>
<td></td>
<td></td>
<td>Net rise</td>
</tr>
<tr>
<td>Wind Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td></td>
<td></td>
<td>Higher value</td>
</tr>
<tr>
<td>Wave Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td></td>
<td></td>
<td>Higher value</td>
</tr>
<tr>
<td>Shelf Length</td>
<td>Lower value</td>
<td>Average value</td>
<td></td>
<td></td>
<td>Higher value</td>
</tr>
<tr>
<td>Tidal Range</td>
<td></td>
<td>No Ranking of Tidal Range – Just Value</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

High and consolidated >low and unconsolidated
# Index Variables

<table>
<thead>
<tr>
<th>Rank</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>Rocky, cliffed coast, fiord, fiard</td>
<td>Medium cliff, indented coast</td>
<td>Low cliff, glacial drift, alluvial plain</td>
<td>Cobble beach, estuary, lagoon, bluff</td>
<td>Barrier beach, sand beach, mud flat, delta</td>
</tr>
<tr>
<td>Geomorphology</td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>Sea Level Change</td>
<td>Net decrease</td>
<td>±1</td>
<td>Net rise</td>
<td>Wind Exposure</td>
</tr>
<tr>
<td>Wave Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shelf Length</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tidal Range</td>
<td>No Ranking of Tidal Range – Just Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Index Variables

<table>
<thead>
<tr>
<th>Rank</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geomorphology</td>
<td>Rocky, cliffed coast, fiord, fiord</td>
<td>Medium cliff, indented coast</td>
<td>Low cliff, glacial drift, alluvial plain</td>
<td>Cobble beach, estuary, lagoon, bluff</td>
<td>Barrier beach, sand beach, mud flat, delta</td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
</tbody>
</table>

### Sea Level Change
- Net decrease
- ±1
- Net rise

### Wind Exposure
- Lower value
- Average value
- Higher value

### Wave Exposure
- Lower value
- Average value
- Higher value

### Shelf Length
- Lower value
- Average value
- Higher value

### Tidal Range
- No Ranking of Tidal Range – Just Value

---

**Water goes up: land disappears**
## Index Variables

<table>
<thead>
<tr>
<th>Rank</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Geomorphology</td>
<td>Rocky, cliffed coast, fiord, fiard</td>
<td>Medium cliff, indented coast</td>
<td>Low cliff, glacial drift, alluvial plain</td>
<td>Cobble beach, estuary, lagoon, bluff</td>
<td>Barrier beach, sand beach, mud flat, delta</td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
<tr>
<td>Sea Level Change</td>
<td>Net decrease</td>
<td>±1</td>
<td></td>
<td>Net rise</td>
<td></td>
</tr>
<tr>
<td>Wind Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shelf Length</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tidal Range</td>
<td>No Ranking of Tidal Range – Just Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Strong winds = higher storm surge & waves, and flying debris**
# Index Variables

<table>
<thead>
<tr>
<th>Rank</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geomorphology</td>
<td>Rocky, cliffed coast, fiord, fiard</td>
<td>Medium cliff, indented coast</td>
<td>Low cliff, glacial drift, alluvial plain</td>
<td>Cobble beach, estuary, lagoon, bluff</td>
<td>Barrier beach, sand beach, mud flat, delta</td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
<tr>
<td>Sea Level Change</td>
<td>Net decrease</td>
<td>±1</td>
<td>Net rise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shelf Length</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tidal Range</td>
<td>No Ranking of Tidal Range – Just Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Larger waves cause more erosion
### Index Variables

<table>
<thead>
<tr>
<th>Rank</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>Rocky, cliffed coast, fiord, fiard</td>
<td>Medium cliff, indented coast</td>
<td>Low cliff, glacial drift, alluvial plain</td>
<td>Cobble beach, estuary, lagoon, bluff</td>
<td>Barrier beach, sand beach, mud flat, delta</td>
</tr>
<tr>
<td>Geomorphology</td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble...</td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>Sea Level Change</td>
<td>Net decrease</td>
<td>±1</td>
<td>Net rise</td>
<td></td>
</tr>
<tr>
<td>Wind Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shelf Length</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tidal Range</td>
<td>No Ranking of Tidal Range – Just Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rank</td>
<td>Very Low</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td>------</td>
<td>----------</td>
<td>-----</td>
<td>----------</td>
<td>------</td>
<td>-----------</td>
</tr>
<tr>
<td>Variable</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Geomorphology</td>
<td>Rocky, cliffed coast, fiord, fiard</td>
<td>Medium cliff, indented coast</td>
<td>Low cliff, glacial drift, alluvial plain</td>
<td>Cobble beach, estuary, lagoon, bluff</td>
<td>Barrier beach, sand beach, mud flat, delta</td>
</tr>
<tr>
<td>Natural Habitats</td>
<td>Coral reef, mangrove, coastal forest</td>
<td>High dune, marsh</td>
<td>Low dune</td>
<td>Seagrass, kelp</td>
<td>Bare sand, gravel, cobble..</td>
</tr>
<tr>
<td>Sea Level Change</td>
<td>Net decrease</td>
<td>±1</td>
<td>Net rise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave Exposure</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shelf Length</td>
<td>Lower value</td>
<td>Average value</td>
<td>Higher value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tidal Range</td>
<td>No Ranking of Tidal Range – Just Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Data, Data, Data
Data, Data, Data

Global:
- Population
Data, Data, Data

Global:
- Population
- Shoreline
Data, Data, Data

Global:
- Population
- Shoreline
- Shelf position
Data, Data, Data

Global:
- Population
- Shoreline
- Shelf position
- Wind statistics
Data, Data, Data

Global:
- Population
- Shoreline
- Shelf position
- Wind statistics
- Wave statistics
Detecting the Presence of Habitats
Detecting the Presence of Habitats
Dissipation of Wave Energy via Drag Force

\[
\frac{1}{8} \rho g \frac{\partial E C_g}{\partial x} = -D_{Brk} - D_{Bot} - D_{Veg}
\]

\[
F = \frac{1}{2} \rho C_D b_v N u |u|
\]

Kobayashi et al., 1993

Bradley & Houser, 2009
• 47 studies with 167 data points
  marsh (21), seagrass (17), kelp (5), and mangrove (4)
  46 studies report wave attenuation

• 25 studies with 138 data points to fit $C_d$
  marsh (9), seagrass (12), kelp (2), and mangrove (2)
**Living Habitats**

- **Type**
- **Height**
- **Depth**
- **Density**
- **Extent**
- **Diameter**
Non-Living Habitats

Type

Length

Height

Type of Vegetation
Winds

ΔInundation

Management Action

ΔErosion

Δ=Service

Waves

FEMA

USGS

PD Photos
Wind Exposure

Top 5% wind speeds
Wind Exposure

Top 5% wind speeds
Wind Exposure

Top 5% wind speeds

\[ WiEx_{Site} = \sum_{n=1}^{16} U_n F_n P_n \]
Wind Exposure

Top 5% wind speeds

\[ WiEx_{\text{Site}} = \sum_{n=1}^{16} U_n F_n P_n \]

\[ REI_{\text{Site}} = \frac{WiEx_{\text{Site}}}{WiEx_{\text{AllSites}}} \]
Wave Exposure

Top 5% deep-water wave heights
Wave Exposure

$\mathcal{P}_{\text{Site}} = \sum_{\text{Top 5\%}} 0.5H^2T$

$WaveExp_{\text{Site}} = \frac{\mathcal{P}_{\text{Site}}}{\sum_{\text{AllSites}} \mathcal{P}}$

Top 5% deep-water wave heights
Additional Outputs
Living Habitats

Type

Extent

Height:

Depth

Density

Diameter

Flexibility
US scientist calls for action to save Bimini's coral reefs

Dr James M Cervino speaks out over island's environment

I am speaking out of concern and as a scientist with years of experience in coral reef health and the development of sustainable development that has occurred over the past five years. Dr Cervino says:

 Developers should not be allowed to develop or regenerate the area. This will help preserve and protect the coral reefs.

A long term plan to preserve the area will be carried out by the government to stop the destruction of the coral reefs.

Local and international environmental groups and academics are urging the government to stop the destruction of the coral reefs.

The destruction of the island has caused a serious threat to coral and marine life. The destruction of the island will also cause a direct threat to local life as well as resulting in the destruction of the island. The damage and destruction to marine life could cause problems with the environment, marine life, energy and food. It will increase in global temperature and increase the level of erosion as well as combined with the destruction of mangroves - an essential food and water source and even change in local snow.
Conclusion

- Value services of habitats that protect against erosion and inundation
- Tier 1a: Qualitative and quick evaluation tool
- Tier 1b: Quantitative process-based model