The Coastal Barrier Island Network (CBIN): Management Strategies for a Global Change Future

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Coastalbarrierisland.org
Global Distribution of Barrier Islands

Pilkey 2005
Barrier Island Ecology

- Barrier islands protect coastlines from extreme episodic storm events (EESE, e.g. tsunami, hurricanes, nor’easters) on a world scale.

- Highly vulnerable to global change (land-sea ecotone).

- Dynamic substrate: vulnerability and stability linked to the presence of native vegetation.
Understanding Barrier Island Ecosystems

Little is known about the influence of Extreme Episodic Storm Events (EESE) on species fitness (survival) and distribution patterns.

GLOBAL WARMING =

Sea Level Rise +

More Frequent/Intense EESE
Extreme Episodic Storm Events (EESE)
Sustaining Barrier islands the expensive way!

Sand acquisition
Sand Retention
Geotubes – Gulf Coast, USA
Hurricane Ike– Galveston, TX, 2008

Geotube
Importance of Barrier Island Vegetation?

(1) Stabilization, Vulnerability, Recovery—protection from storm surge locally and for adjacent coastal communities—*economics* and esthetics

(2) Biodiversity and Extinction—loss of important genomes

Can *barrier island vegetation* be used to *lessen storm damage and erosion*—thus, *help reduce economic impacts due to a dynamic substrate*?
Study Site: south end, Topsail Island, NC

North Carolina

Ocean side primary dunes
Types of Barrier Islands

• There are many ways to categorize barrier islands:
  - Vegetation
  - Sediment Stability
  - Tidal Range
  - Storm Exposure

These factors generate different Ecological Stability and Vulnerability.

Barrier Island Vegetation--

**Hydrology ↔ Geology ↔ Vegetation**

South Topsail Island, NC

- inlet
- ocean
- foredunes
- embryo dunes
- maritime forest
THE LAND-SEA ECOTONE
One of the most dynamic and severe abiotic gradients among plant communities (hydrology + geology + biology).
Dune Zonation

Ocean | Wave Zone | Drift Line | Foredunes | 1° Dune | 2° Dune

C. edentula
A. pumilus
I. imbricata

H. bonariensis

Research Site
Development !!
Save the Dunes!!
Maritime Forest
Research Objectives— which species are most effective at stabilizing substrate and providing wind protection?

First consideration— future **SURVIVAL** !!

- Calculation of annual photosynthetic carbon gain (ACG)

- Seasonal photosynthesis (ACG), growth, and regeneration patterns with and w/o storm events (EESE model)

- Relate ACG to mortality/regeneration according to storm frequency and intensity predictions (GCM models)

- Adult/seedling survival before/after storms— **Ecological Vulnerability, Resistance, and Resilience**
Most Vulnerable to EESE !!

embryo dune
Colonizing Species of Embryo and Foredunes—Most Vulnerable!

*Amaranthus pumilus* (Seabeach Amaranth, federally endangered);
*Iva imbricata* (Seacoast Beach Elder);
*Caklie edentula* (Sea Rocket)
*Hydrocotyl bonariensis* (Dollar Weed);
*Uniola paniculata* (Sea Oats)
Amaranthus pumilus - annual herb

- Colonizes lowest tidal position of sanddunes (high water mark, wrack line)
- Federally endangered (USFWS 1993) and globally (G2) imperiled species (Marcone 2000)
A. pumilus
Overwash Impacts
Sand burial
Mechanical damage
PHYSIOLOGICAL IMPACTS

Which species are most resistant/resilient to EESE??
Field Measurements (Pre-storm and Post-storm)

Compare native species, e.g. dune vs maritime forest

--Annual Photosynthetic Carbon Gain
  leaf level
  whole-plant level

--Growth Response and Biomass
  above and below ground

--Reproductive Effort
  flowers, seeds, vegetative

--Reproductive success (species survival)
  viable seedlings (new germinants)
Photosynthetic Response to Light (PRL)

Open- afternoon
Closed- morning
Noon Overwash Data

Sept 1, 2004

A (CO₂ Assimilation Rate, umol m⁻² s⁻¹)

PPFD (Photosynthetic Photon Flux Density, umol m⁻² s⁻¹)
## Estimated Storm Overwash Impacts on Annual Carbon Gain (ACG) and Subsequent Reproduction

<table>
<thead>
<tr>
<th>STORM TYPE</th>
<th>% DECLINE</th>
<th># Germinants</th>
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<tbody>
<tr>
<td>Minor Tidal Surge (MTS)</td>
<td>2-5</td>
<td>0-5</td>
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<tr>
<td>Major</td>
<td>10</td>
<td>20-30</td>
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<tr>
<td>2 Majors</td>
<td>50-70</td>
<td>70-90</td>
</tr>
<tr>
<td>3 Majors</td>
<td>70-90**</td>
<td>90-100</td>
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<tr>
<td>Major + 4 MTS</td>
<td>50-70</td>
<td>40-60</td>
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</table>

** no viable seed production
IMPACTS ON GROWTH AND REPRODUCTION
Biomass Allocation

Leaves

Stems

Roots
**A. pumilus** Biomass Allocation

**Summer 2004**

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**Sampling Dates**

- 3-Jun-04
- 20-Jun-04
- 9-Jul-04
- 17-Jul-04
- 4-Sep-04

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**Percent (%) Total Biomass**

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**Hurricane Alex**

- 31 July – 6 Aug 2004

**T.S. Bonnie**

- 3 – 13 Aug 2004

**Hurricane Gaston**

- 27 Aug – 1 Sept 2004

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**DATE**

- 3-Jun-04
- 20-Jun-04
- 9-Jul-04
- 17-Jul-04
- 4-Sep-04

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**leaf**

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**stem**

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**root**

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**flower**

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Physiological Conclusions

• Annual Photosynthetic carbon gain (ACG), growth, and reproduction substantially impacted by EESE.

• More than 2 major storm events per summer can reduce annual reproductive success to zero, indicating potential extinction.

• Consecutive years of lower ACG and the timing of EESE will lead to accelerated extinction??

• Maritime species much less impacted compared to dune species
FIRST, we must stop biasing decisions towards the use of engineered structures on coasts, at the expense of utilizing native vegetation to achieve the same purposes.

SECOND, we should begin to investigate more deeply the hypothesis that vegetated barrier island ecosystems can modify and control the sedimentary dynamics in response to gradual phenomena like sea level rise (as long as the rate is not too fast), but cannot completely resist discrete disturbances such as EESE.

THIRD, from an economic perspective, vegetation management should not focus on stabilization during EESE. We know that coastal ecosystems contribute 77% of global ecosystem services, a value of ~33 trillion $USD per year (Martínez et al., 2007), and barrier islands are an integral part of approximately 12% of these coastal ecosystems (Pilkey and Fraser, 2003). Moreover, beaches and dunes support a USA tourism industry valued at $USD 322 billion per year, more than 25 times the contribution of the National Park Service system to the USA economy (Houston, 2008).

FOURTH, we need to develop laws analogous to Section 404 of the Clean Water Act (which protects wetlands from being developed or backfilled) to protect undeveloped beaches, sand dunes, maritime forests, and other critical barrier island habitats.
FIFTH, we need to bring about a change in legal mindset about how to manage developed barrier islands. For example, the State of Texas in the USA, defines the public-private property line as the ecological reality of the native vegetation line (Open Beaches Act, Texas Natural Resources Code 61.011, see FEAGIN, 2005), enhancing the ecological resistance and resilience (recovery rate) of a developed shoreline to EESE.

SIXTH, federal governments could purchase as many undeveloped islands and contiguous marginal properties as necessary to enable ecosystem sustainability. In the USA, beyond the original Coastal Barrier Resources Act of 1982 that prevented federal assistance for activities supporting commercial development of barrier islands and which designated certain parklands and national seashores to be preserved, no federal framework exists today for sustaining these ecosystems. In the USA, there are still many barrier island ecosystems that are undeveloped.

SEVENTH, we need to begin thinking about our cultural view of these ecosystems. The challenge may require re-envisioning our thinking about these landscapes, rather than re-envisioning the landscapes. Why did we start calling these features ‘barrier islands’? Should we not call them ‘migrating islands’?
Barrier islands are naturally unstable and will, potentially, become more so, in response to factors such as sea level rise and extreme episodic storm events (EESE). We should aim for a strategy of stabilizing the natural sedimentary processes with plant species that occur naturally across barrier island landscapes, rather than trying to only use expensive artificial structures and accretion methods.

Overall, we must adapt more effectively with BI dynamism so that ecosystem sustainability might also be possible.
Urbanized Ecosystems

Defn: *maintaining commercial/private development while sustaining ecosystem properties and critical services.*

Possible solutions to sea level rise and Increased storm impact:

--Increased structural resistance and resilience
--Mobile structures that can move *with* the substrate (decadal cycles)
--Use of native vegetation for enhancing structural R and R and reducing erosion (e.g. maritime forest closer to beach, setback requirements).
--Conservation of enough undeveloped BI landscapes to insure ecosystem sustainability.
The Future of Coastal Barrier Islands, and the Coastline as we know it ??
THANK YOU
**Sample Light Response Curve**

- **Rate of Maximum Photosynthesis ($A_{max}$)**
- **Quantum Efficiency of CO$_2$ Assimilation**
- **Light Compensation Point; Where Photosynthesis and Respiration are Equal**
- **Rate of Dark Respiration**
- **Photosynthetic Photon Flux Density (PPFD); $\mu$mol m$^{-2}$ s$^{-1}$**

- **Photo-inhibition;** when a plant ceases to photosynthesize for a variety of factors including extremely high light levels, drought, and other stressors.

The diagram illustrates the relationship between the rate of photosynthesis and the photosynthetic photon flux density (PPFD). The rate of photosynthesis varies with the PPFD, reaching a peak at $A_{max}$, after which it decreases due to photo-inhibition.
Maximum Photosynthesis, $A_{\text{max}}$

- Collection Dates: Jun, Jul, Aug, Sep, Oct

- $A_{\text{max}}$ (umol m$^{-2}$ s$^{-1}$)
  - AM $A_{\text{max}}$
  - Noon $A_{\text{max}}$

- EESE's

Graph shows the variation of $A_{\text{max}}$ over time with data points for AM and Noon times, indicating the peak in August and a decrease thereafter.
A. pumilus Biomass Allocation
2004 Growing Season

Sampling Dates
3-Jun-04 20-Jun-04 9-Jul-04 17-Jul-04 4-Sep-04

% of Total Biomass Allocation
0.0 0.2 0.4 0.6 0.8 1.0

DATE
3-Jun-04 20-Jun-04 9-Jul-04 17-Jul-04 4-Sep-04

flower
root
stem
leaf

% of Total Biomass Allocation
Ecophysiology of Organism Survival Under EESE

Annual Photosynthetic Carbon Gain

Growth

Reproduction

Ultimate Mortality

Instantaneous Mortality

Species Survival

Ecological Facilitation

Ecological Facilitation
<table>
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<th>Variable</th>
<th>AM</th>
<th>PM</th>
<th>Seasonal</th>
<th>Pre/Post EESE</th>
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<td>No</td>
<td>Yes (Sept)</td>
<td>Yes (+)</td>
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