Valuing Ecosystem Services of Coastal Wetlands: Protections from Surge

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Overview

Outline of talk:

- Ecosystem functions, services, values
- Overall Framework
- Chesapeake Bay Region
- Methodology
  - Scenarios: w/o wetlands, sea level rise and marsh migration
  - Econometric regression
- Results
- Conclusions and Future Research
Ecosystem Functions & Services

- Natural lands in coastal areas perform a variety of ecosystem functions:
  - e.g., carbon sequestration, habitat provision, fish nurseries, water purification, floodwater storage, storm surge attenuation

- These functions provide a set of services that has value to humans.

- A service that is getting increasing attention is protection from flooding. Especially the flooding associated with hurricane storm surge.
Hurricane Isabel flooding, Hampton Road and Virginia Beach, 2003

- Storm surge is the abnormal rise in water level due to a presence of storm/hurricane
- Hurricane Isabel (2003): Total Property damage $5.3 billion ~ 80% in VA & MD
- Insurance Information Institute ranked Virginia 9th and Maryland 18th state vulnerable to hurricane
- Recurrent flood risks on coastal areas are increasing with warmer climate, frequent storms, and increasing coastal population
Wetlands: Nature Based Flood Defense

- Wetlands attenuate surge by slowing its advance across the landscape and delaying arrival of water on the landward side.

- USACE (1963) seminal study in Louisiana:
  - Simple rule of thumb: surge heights reduced by, on average, 1m for every 14.5km of wetlands.

- Wamsley et al. (2010):
  - 5-60 km of wetland reduces 1m of surges based on storm intensity.
Overall Framework

1. Field Measurement:
   - Measurement of water level, wave and current to improve defining geospatial parameters in local and regional models

2. Modeling Approach:
   - Simulating surge and wave for local and regional scale

3. Economic Analysis:
   - Incorporate simulated hydrodynamic parameters to calculate the avoided damage
Storm Selection

A set of five storms with low to high intensity that hit or passed near the Chesapeake Bay regions in past 20 years.
Hydrodynamic Model
ADCIRC (Luetich & Westerink 1994)

Water Levels, Currents, Wind field, Bottom Friction, Roughness Length

Wave Radiation Stress

Wave model SWAN (Booij 1999)

Meteorological Forcing
- LeProvost Tidal Database
- National Hurricane Center (NHC) Best Track:
  - Hurricane Track
  - Central Pressure (Cp)
  - Radius of storm (Rp)
  - Forward Speed (Vf)
  - Approach Angle (θ)

Model Validation
- Observed maximum water surface elevations (MWSE) at Chesapeake Bay NOAA stations for each storm compared with model MWSE
- 14 NOAA stations (data used as available)
- Root Mean Square Error (RMSE) computed for each storm:

Arc StormSurge: input GIS data; output flood rasters (Ferreira et al. 2014)
RFF project focuses on environmental risks from shale gas development

Study Area: Chesapeake Bay Region
RFF project focuses on environmental risks from shale gas development

Study Area: Chesapeake Bay Region (cont.)
Methodology

- With and without wetland:
  1. A baseline scenario
  2. A counterfactual ‘without wetland’

- Sea Level Rise (SLR) and Marsh Migration (MM):
  1. A baseline scenario
  2. Highest SLR rise scenario (+7.6ft) and MM (+6ft)
  3. Lowest SRL rise scenario (+1.6ft) and MM (+2ft)

- Econometric analysis of modeling results – surge heights at parcel level as function of the extent of wetlands in surrounding land area
RFF project focuses on environmental risks from shale gas development.

Results: Storm Surge Heights

(A) Anne Arundel County, Floyd

(C) Anne Arundel County, Isabel

(B) Somerset County, Floyd

(D) Somerset County, Isabel
Scenario: With and without wetland

![Bar chart showing average flood depth (m) for different scenarios with and without wetland.]
Scenario: With and without wetland (cont.)

Area Flooded in Baseline and Counterfactual (No Wetlands) Scenarios, by Hurricane (in sq. km)

<table>
<thead>
<tr>
<th>Storm</th>
<th>Baseline</th>
<th>Counterfactual, Without Wetlands</th>
<th>Difference (% difference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dennis</td>
<td>656</td>
<td>1,145</td>
<td>489 (74.5%)</td>
</tr>
<tr>
<td>Floyd</td>
<td>855</td>
<td>1,321</td>
<td>466 (54.5%)</td>
</tr>
<tr>
<td>Isabel</td>
<td>1,586</td>
<td>2,167</td>
<td>581 (36.6%)</td>
</tr>
<tr>
<td>Ernesto</td>
<td>980</td>
<td>1,415</td>
<td>436 (44.4%)</td>
</tr>
<tr>
<td>Irene</td>
<td>1,221</td>
<td>1,788</td>
<td>567 (46.5%)</td>
</tr>
</tbody>
</table>
Calculate damages at individual property level using depth-damage functions

- Residential parcels only
- Account of no. of stories & basement

RFF project focuses on environmental risks from shale gas development

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Floyd</th>
<th>Isabel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dennis</td>
<td>$55.3</td>
<td>$454.0</td>
</tr>
<tr>
<td>Floyd</td>
<td>$67.7</td>
<td></td>
</tr>
<tr>
<td>Isabel</td>
<td>$454.0</td>
<td></td>
</tr>
<tr>
<td>Ernesto</td>
<td>$60.8</td>
<td></td>
</tr>
<tr>
<td>Irene</td>
<td>$248.3</td>
<td></td>
</tr>
</tbody>
</table>

(a) Floyd

(b) Isabel

Difference in damage ($):
- $<0
- $0
- $0.01 - $100,000
- $100,000 - $200,000
- $200,000 - $400,000
- $400,000 - $600,000
- $600,000 - $800,000
- $800,000 - $1,000,000
- $1,000,000 - $1,500,000
- $1,500,000 - $2,000,000
- $2,000,000 - $4,000,000
- $4,000,000 - $7,500,000
- $7,500,000 - $14,000,000
- $14,000,000 - $20,000,000
- $>20,000,000
Methodology

- Sea Level Rise (SLR) and Marsh Migration (MM):
  (i) A baseline scenario
  (ii) Highest SLR rise scenario (+7.6ft) and MM (+6ft)
  (iii) Lowest SRL rise scenario (+1.6ft) and MM (+2ft)
Scenario: SLR and MM

Total Flooded Area (Km²)

- Maximum SLR
- Minimum SLR
- Current

Orange: Strong Cyclones (Isabel)
Blue: Weak Cyclone (Dennis)
### Scenario: SLR and MM (cont.)

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Household Property Damage (Million USD) (Increase from Baseline)</th>
<th>Total No. of Flooded Household (% Increase from Baseline)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Storms/Scenarios</strong></td>
<td>Dennis</td>
<td>Isabel</td>
</tr>
<tr>
<td><strong>Baseline/Current</strong></td>
<td>$7.7</td>
<td>$264</td>
</tr>
<tr>
<td><strong>Minimum SLR</strong></td>
<td>$69.9 ($62.2)</td>
<td>$488 ($224)</td>
</tr>
<tr>
<td><strong>Maximum SLR</strong></td>
<td>$1,580 ($1572.3)</td>
<td>$2,310 ($2046)</td>
</tr>
</tbody>
</table>
Methodology

- Econometric analysis of modeling results – surge heights at parcel level as function of the extent of wetlands in surrounding land area
Regression analysis

- MDProperty View data on all parcels in Maryland
- Construct 500-m buffer around each flooded parcel
- Calculate % of flooded area of buffer that is wetlands
- Econometric model:
  - Use data for 8 tropical cyclones, 1996-2011
  - Estimate surge heights as a function of %wetlands, and several control variables
  - Allow effects to vary by hurricane
## Regression results

<table>
<thead>
<tr>
<th>Dep. Variable: flood height on parcel (in meters)</th>
<th>Basic model</th>
<th>Hurricane-specific wetlands effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parcel elevation</strong></td>
<td>0.0102</td>
<td>0.0102</td>
</tr>
<tr>
<td></td>
<td>(0.00859)</td>
<td>(0.00862)</td>
</tr>
<tr>
<td><strong>A zone</strong></td>
<td>0.0855***</td>
<td>0.0858***</td>
</tr>
<tr>
<td></td>
<td>(0.0232)</td>
<td>(0.0232)</td>
</tr>
<tr>
<td><strong>V zone</strong></td>
<td>0.0929***</td>
<td>0.0935***</td>
</tr>
<tr>
<td></td>
<td>(0.0255)</td>
<td>(0.0256)</td>
</tr>
<tr>
<td><strong>Buffer area flooded (as fraction of total buffer area)</strong></td>
<td>1.008***</td>
<td>1.005***</td>
</tr>
<tr>
<td></td>
<td>(0.172)</td>
<td>(0.174)</td>
</tr>
<tr>
<td><strong>Open water in flooded area of buffer (as fraction of flooded area)</strong></td>
<td>-0.255</td>
<td>-0.256</td>
</tr>
<tr>
<td></td>
<td>(0.143)</td>
<td>(0.144)</td>
</tr>
<tr>
<td><strong>Wetlands in flooded area of buffer (as fraction of flooded area)</strong></td>
<td>-0.189</td>
<td>-0.368**</td>
</tr>
<tr>
<td></td>
<td>(0.123)</td>
<td>(0.153)</td>
</tr>
<tr>
<td><strong>Wetlands in flooded area of buffer*Fran</strong></td>
<td>0.250***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0531)</td>
<td></td>
</tr>
<tr>
<td><strong>Wetlands in flooded area of buffer*Dennis</strong></td>
<td>0.119</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0777)</td>
<td></td>
</tr>
<tr>
<td><strong>Wetlands in flooded area of buffer*Floyd</strong></td>
<td>0.104</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0788)</td>
<td></td>
</tr>
<tr>
<td><strong>Wetlands in flooded area of buffer*Isabel</strong></td>
<td>0.289***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0535)</td>
<td></td>
</tr>
<tr>
<td><strong>Wetlands in flooded area of buffer*Ernesto</strong></td>
<td>0.0341</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0191)</td>
<td></td>
</tr>
<tr>
<td><strong>Wetlands in flooded area of buffer*Hanna</strong></td>
<td>0.233***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0368)</td>
<td></td>
</tr>
<tr>
<td>*<em>Wetlands in flooded area of buffer <em>irene</em></em></td>
<td>0.209***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0524)</td>
<td></td>
</tr>
<tr>
<td><strong>Constant</strong></td>
<td>-0.204*</td>
<td>-0.201**</td>
</tr>
<tr>
<td></td>
<td>(0.0863)</td>
<td>(0.0830)</td>
</tr>
<tr>
<td><strong>Hurricane FEs</strong></td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>292,622</td>
<td>292,622</td>
</tr>
<tr>
<td><strong>R-squared</strong></td>
<td>0.220</td>
<td>0.221</td>
</tr>
</tbody>
</table>

Robust SEs in parentheses.

***p<0.01, **p<0.05, *p<0.10
## Value of Protective Service, by storms

<table>
<thead>
<tr>
<th>Hurricane</th>
<th>Marginal Value of Wetlands, per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bertha</td>
<td>$48</td>
</tr>
<tr>
<td>Fran</td>
<td>$105</td>
</tr>
<tr>
<td>Dennis</td>
<td>$106</td>
</tr>
<tr>
<td>Floyd</td>
<td>$138</td>
</tr>
<tr>
<td>Isabel</td>
<td>$90</td>
</tr>
<tr>
<td>Ernesto</td>
<td>$118</td>
</tr>
<tr>
<td>Hanna</td>
<td>$35</td>
</tr>
<tr>
<td>Irene</td>
<td>$204</td>
</tr>
</tbody>
</table>

Differences across hurricanes due to:

- Hurricane intensity & track
- Estimated relationship between wetland area and surge heights, by parcel
- Property values
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Value of Protective Services, by County

Avg for Maryland (Hurricane Irene) = $204/acre
Conclusions

(1) Wetlands in the Chesapeake Bay region provided protective services ranging in value from $55 to $454 million;

(2) The value is highest in the worst hurricanes; this means that wetlands may become increasingly valuable with climate change;

(3) The value also varies significantly across the landscape; zero to values as high as $14 million per census tract in Hurricane Isabel.

(4) Higher rate of SLR and marsh migration will cause a rapid increase in flood damage.

(5) Value of lost wetlands = $132/acre
Future steps...

- **Short Run:**
  - Economic regressions: Alternative buffer sizes (1000-m)
  - Sensitivity of results to depth-damage functions
  - Valuation of protective services for future scenarios

- **Longer Run:**
  - Incorporation of erosion based damage due to hurricane
  - Targeting new wetlands conservation areas: i.e. Virginia
Thank you!

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