The economic impact of freshwater inputs to an estuarine fishery

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Background and purpose

Freshwater inputs affect coastal ecology and productivity

- Salinity, nutrients, temperature

Increasing demand for freshwater, climate change ➔ reduced inputs, increased variability

Little information available on economic impacts

- Temperate estuaries among the most productive ecosystems in the world
- Coastal resources rarely prioritized
Background and purpose

This research: investigate the relationship between freshwater inputs and fishery performance in the Georgia blue crab fishery

Blue crab (*Callinectes sapidus*)
- Second to shrimp in value to GA
- Coastal estuaries, small vessels, effectively open-access
- Depend on moderate salinity in numerous ways (spawning, recruitment, juvenile/adult mortality)
- Significant fishery declines over past 20 years, linked to drought/elevated salinity
Background and purpose

Despite significant declines since mid-1990s, increasing demand has kept participation relatively high.
Background and purpose

Lowest point for fishery (early-2000s) coincided with historic drought conditions; reversal of a marginal recovery in 2010 similarly coincided with another severe drought.
Background and purpose

Drought has played a major factor, but water withdrawals have increased dramatically since 1950.
Empirical Approach

Focus on six sounds
• Three riverine, three tidal
• Represents ~55% of harvests from 2001 to 2012
• Treat sounds as independent fisheries
Empirical Approach

Structural, bioeconomic model of the fishery; multiple life stages; quarterly transitions

• Do reductions in freshwater inputs negatively impact the fishery?
• If so, identify specific biophysical mechanisms

Focus on salinity

• Able to account for unmonitored freshwater sources
• Good proxy for flow in river-dominated sounds (estuaries)
• Increase statistical power
Empirical Approach

* = salinity impacts

- Salinity
  - Adult Stock*
    - Trips
    - Harvest
      - Revenues
    - Escapement
  - Juvenile Stock*

Time $t-4$

Time $t$

Time $t+1$
Empirical approach

Four-equation system

- Evolution of adult stock; recruitment
- Effort transition; harvest production function

\[ X_{q+1,s} = \theta_0 + \theta_1 sal_{q+1,s} + \theta_2 temp_{q+1,s} + \theta_3 \left( X_{q,s} - h_{q,s} \right) + \theta_4 R_{q,s} + \varepsilon \]

\[ \ln\left( \frac{R_{q,s}}{X_{q+1,s}} \right) = \eta_0 + \eta_1 sal_{q,s} + \eta_2 sal_{q-4,s} + \eta_3 temp_{q,s} + \eta_4 temp_{q-4,s} + \eta_5 X_{q-4,s} + \varepsilon \]

\[ \ln\left( h_{q,s} \right) = \alpha_0 + \alpha_1 \ln\left( tr_{q,s} \right) + \alpha_2 \ln\left( X_{q,s} \right) + \varepsilon \]

\[ tr_{q,s} - tr_{q-4,s} = \beta_0 + \beta_1 \left( p_{q-1,s} \cdot h_{q-1,s} - p_{q-5,s} \cdot h_{q-5,s} \right) + \varepsilon \]

Quarter and sound fixed effects; year trend variable

System estimated via Zellner’s SUR

- Allows for correlation in error structure between equations
Data and Estimation

Harvest and stock abundance data from GDNR
- Commercial harvest: 1989-2012, > 200K trip obs
- Stock survey trawls (w/ salinity, temp): 1976-2012, >90K obs

Estimate system from 2001-2012 (data quality issues)
- Adults: escapement, juveniles (q-1) (1%); salinity (q) negative (10%)
- 1 ppt increase in salinity -> 4% lower abundance
- Recruitment: spawning stock (q-4) (1%); salinity (q) negative (1%); salinity (q-4) negative (5%)
- 1 ppt increase in salinity (q), 13% fewer juvs; 1 ppt increase in salinity (q-4), 7% fewer juvs
- Harvest and effort adjustment equations as expected

Robustness checks: Alternative salinity specifications, recruitment structure; full time series – results are robust
Economic Impact

Develop counterfactual salinity profiles from a simulated minimum flow standard (MFS)

- As if, in three riverine sounds, flow were maintained @ >25% of seasonal historical (>1960) averages

<table>
<thead>
<tr>
<th>Sound (river)</th>
<th>Flow (ft³/s) (2001-2012)</th>
<th>Flow (ft³/s) (1960-2012)</th>
<th>25% min flow (ft³/s)</th>
<th># binding quarters</th>
<th>Salinity (PSU)</th>
<th>25% min salinity (PSU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ossabaw (Ogeechee)</td>
<td>Mean 1,496</td>
<td>2,242</td>
<td>1,514</td>
<td>12 of 44</td>
<td>24.30</td>
<td>23.14</td>
</tr>
<tr>
<td></td>
<td>SD 1,566</td>
<td>2,048</td>
<td>1,531</td>
<td>4.77</td>
<td>4.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min 72</td>
<td>72</td>
<td>277</td>
<td>13.78</td>
<td>13.78</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max 6,611</td>
<td>13,003</td>
<td>6,611</td>
<td>32.94</td>
<td>29.16</td>
<td></td>
</tr>
<tr>
<td>St. Andrews (Satilla)</td>
<td>Mean 1,641</td>
<td>2,280</td>
<td>1,748</td>
<td>18 of 44</td>
<td>26.25</td>
<td>24.92</td>
</tr>
<tr>
<td></td>
<td>SD 2,035</td>
<td>2,456</td>
<td>1,938</td>
<td>3.94</td>
<td>2.94</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min 43</td>
<td>43</td>
<td>301</td>
<td>17.13</td>
<td>17.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max 9,213</td>
<td>12,513</td>
<td>9,213</td>
<td>35.17</td>
<td>29.45</td>
<td></td>
</tr>
<tr>
<td>St. Marys</td>
<td>Mean 538</td>
<td>622</td>
<td>560</td>
<td>16 of 44</td>
<td>29.53</td>
<td>27.74</td>
</tr>
<tr>
<td></td>
<td>SD 664</td>
<td>613</td>
<td>638</td>
<td>3.30</td>
<td>2.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min 24</td>
<td>24</td>
<td>97</td>
<td>23.38</td>
<td>23.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max 2,693</td>
<td>3,507</td>
<td>2,693</td>
<td>37.55</td>
<td>30.98</td>
<td></td>
</tr>
</tbody>
</table>
Economic Impact

Perform counterfactual, recursive simulation of fishery outcomes in three riverine sounds, assuming MFS (Ossabaw shown)
## Economic Impact

Improvements in fishery revenue ranging from 13-18%

<table>
<thead>
<tr>
<th>Sound</th>
<th>Pounds</th>
<th>Revenue</th>
<th>Trips</th>
<th>Adults</th>
<th>Juveniles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>5,859,303</td>
<td>$5,443,606</td>
<td>13791</td>
<td>18.6</td>
<td>10.0</td>
</tr>
<tr>
<td>Ossabaw 25% Min</td>
<td>6,751,835</td>
<td>$6,413,160</td>
<td>14339</td>
<td>19.4</td>
<td>19.3</td>
</tr>
<tr>
<td>% Dif</td>
<td>15.2%</td>
<td>17.8%</td>
<td>4.0%</td>
<td>4.3%</td>
<td>92.8%</td>
</tr>
<tr>
<td>Actual</td>
<td>5,147,541</td>
<td>$4,681,558</td>
<td>20385</td>
<td>13.3</td>
<td>7.1</td>
</tr>
<tr>
<td>St. Andrews 25% Min</td>
<td>5,699,699</td>
<td>$5,293,000</td>
<td>20727</td>
<td>14.8</td>
<td>17.3</td>
</tr>
<tr>
<td>% Dif</td>
<td>10.7%</td>
<td>13.1%</td>
<td>1.7%</td>
<td>11.4%</td>
<td>144.3%</td>
</tr>
<tr>
<td>Actual</td>
<td>2,464,449</td>
<td>$2,056,656</td>
<td>10254</td>
<td>11.5</td>
<td>7.0</td>
</tr>
<tr>
<td>St. Marys 25% Min</td>
<td>2,837,854</td>
<td>$2,398,257</td>
<td>10452</td>
<td>12.4</td>
<td>17.8</td>
</tr>
<tr>
<td>% Dif</td>
<td>15.2%</td>
<td>16.6%</td>
<td>1.9%</td>
<td>8.1%</td>
<td>153.4%</td>
</tr>
</tbody>
</table>

Sounds represent 35% of historical harvest volume, two largest rivers in GA not included (Savannah, Altamaha) due to lack of data (represent additional ~30%)
Discussion

Implied “value” of water

• ~ $1-7 / acre-ft

Comparable to some agricultural valuations

• Estimated annuity value of water rights in Georgia (hedonic model of land prices, Petrie and Taylor, 2004): $35

• Meta-analysis of values (Fredrick et al. (2006)) for Southeast US: $18 mean, $7 median (across all value types, including improved recreational opportunities)

Caveats (among others)

• Uncertainty, thresholds, habitat interactions

• Not a marginal value; quarters with high fishery value likely correlated with value for agriculture, other uses
Discussion

A lower bound?

• Simulation represents small proportion fishery, other harvests could be considered to occur in outflow areas, but not included
• Unable to generate observed spikes in adult abundance
• Shrimp also depend on estuaries and moderate salinity
• Massive marsh dieback in 2000-2002 linked to elevated salinity, led to significant loss of land, reduced storm and erosion protection
• Recreational crabbing not considered at all, potentially more valuable than commercial fishery (Evans, 1996)

Georgia currently does not consider coastal resources in water management plans

• Common practice, water resource managers dominated by historical concern for agriculture, municipal needs
• Fishery interests far less coordinated… second-order “tragedy”
Thank you

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