Aquaculture and Capture Fisheries: Toward An Integrated Economic-Ecological Analysis

Di Jin
Marine Policy Center
Woods Hole Oceanographic Institution
Acknowledgements

* Porter Hoagland, Eric Thunberg, John Steele, Andy Solow, Mike Fogarty, Tracy Dalton, Scott Steinback

* NOAA Saltonstall-Kennedy Grant Program

* NOAA MARFIN Grant Program

* NOAA NEFSC Social Sciences Branch

* NOAA Narragansett Lab

* WHOI Marine Policy Center
Outline

• Ecosystem-based management
• The Economic-Ecological Framework
• Economic Interactions between Commercial Fishing and Aquaculture
• Ecological Interactions between Commercial Fishing and Aquaculture
• Summary
Sustaining Marine Fisheries  (NRC 1999)

• Goal of sustainability in fishery management requires an understanding of larger ecosystem processes
• We cannot manage ecosystems per se
• EBM is: “...an approach that takes all major ecosystem components and services into account in managing fisheries...”
• Humans are integral parts of the ecosystem
• We can attempt to manage human activities (e.g., fishing and aquaculture)
EBM Framework (NRC 1999)

- **Stresses**
  - Harvesting single fish species
  - Harvesting multiple fish species
  - Habitat degradation
  - Deterioration of environmental quality

- **Responses**
  - Single-species stock effects
  - Trophic linkages
  - Food web models

- **Benefits**
  - Commercial surpluses
  - Commercial surpluses
  - Recreational fisheries
  - Subsistence fisheries
  - Other non-market benefits

Aquaculture
Ecosystem-Based Management
(normative aspects)

• Place-based
• Humans are a component
• Science-based
  – Maintains ecosystem integrity
  – Enhances ecosystem resilience
  – Adaptive
• Integrated (species, sectors):
  – Accounts for intra- and inter-system linkages
  – Considers feedbacks between natural and social systems
• Considers cumulative impacts
• Engages multiple stakeholders
  – Collaborative problem-solving and solution-finding
EBM Challenges
(Leslie and McLeod 2007)

• To implement EBM, a society needs:
  – A common vision to define the preferred ecosystem state(s)
  – **Methods of evaluation** and adaptation
  – Ocean governance frameworks (*e.g.*, property right assignments)
  – Successful examples
The Economic-Ecological Framework
An Integrated Economic and Ecological Framework

Ecosystem “Value”

Accounting price

Biomass

Economy

Ecosystem
Some Possible Economic Models

**Bio-economic**: captures the complexity of non-linear systems but incorporates only 1-2 species and 1-2 industry impacts

**Input-output (I-O)**: includes numerous species and industries, but all coefficients (e.g., prices) are fixed

**Computable General Equilibrium (CGE)**: captures key non-linear interactions and develops estimates of welfare changes
Input-Output Model Applications

- Evaluation of economic impacts:
  - Fishery management alternatives
  - Distribution across fishing communities
  - Distribution across industry sectors
  - Fleet rationalization efforts:
    - American lobster
    - Sea scallops
Major Features of a CGE Model

1. Multiple sectors, nonlinear, subject to resource constraints.

2. Supply and demand are derived from the behavior of profit-maximizing producers and utility-maximizing consumers.

3. Supply and demand for goods and production factors are equated by adjusting prices so that markets clear in equilibrium.
Basic Components of a CGE Model

- **Capital**: $K$
- **Labor**: $L$
- **Composite Factor**: $Y$
- **Intermediate Input**: $X$
- **Output**: $Z$
- **Imports**: $M$
- **Domestic Sales**: $D$
- **Exports**: $E$
- **Armington Composite Commodity**: $Q$
- **Utility**
  - **Household**: $X_C$
  - **Government**: $X_G$
  - **Investment**: $X_V$
  - **Intermediate Input**: $X$

Production, Trade, Consumption
Economic Interactions between Commercial Fishing and Aquaculture

Example: An increase in fish biomass
## New England Coastal Regional Economy
### Baseline Economic Value

<table>
<thead>
<tr>
<th>Sector/Commodity</th>
<th>Output</th>
<th>Total Supply*</th>
<th>Imports**</th>
<th>Exports**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>2,428</td>
<td>7,107</td>
<td>5,305</td>
<td>626</td>
</tr>
<tr>
<td>Aquaculture</td>
<td>127</td>
<td>684</td>
<td>565</td>
<td>7</td>
</tr>
<tr>
<td>Fishing</td>
<td>870</td>
<td>653</td>
<td>42</td>
<td>259</td>
</tr>
<tr>
<td>Fish Processing</td>
<td>1,124</td>
<td>543</td>
<td>126</td>
<td>708</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>194,703</td>
<td>247,123</td>
<td>90,029</td>
<td>37,608</td>
</tr>
<tr>
<td>Other</td>
<td>750,325</td>
<td>673,199</td>
<td>131,211</td>
<td>208,336</td>
</tr>
</tbody>
</table>

*Millions of 2006*

* Composite Commodity
** Including both domestic and foreign trade
## Foreign and domestic imports and exports
(2006 $ millions)

<table>
<thead>
<tr>
<th>Sector/Commodity</th>
<th>Foreign Imports</th>
<th>Domestic Imports</th>
<th>Foreign Exports</th>
<th>Domestic Exports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>1,118</td>
<td>4,187</td>
<td>161</td>
<td>465</td>
</tr>
<tr>
<td>Aquaculture</td>
<td>99</td>
<td>466</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Fishing</td>
<td>42</td>
<td>0</td>
<td>259</td>
<td>0</td>
</tr>
<tr>
<td>Fish Processing</td>
<td>28</td>
<td>98</td>
<td>66</td>
<td>643</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>30,537</td>
<td>59,491</td>
<td>37,608</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>341</td>
<td>130,870</td>
<td>15,532</td>
<td>192,804</td>
</tr>
</tbody>
</table>
Linking of a CGE model with a marine ecosystem model for fisheries policy analysis

**Diagram**

- **Food Web Model**
  - Fish Stock $B$
  - Capital $K$
  - Labor $L$
  - Intermediate Input $X$
- Fish Stock $B$
  - Composite Factor $Y$
- Output $Z$

**Flow**
- Fish Stock $B$ to Utility
- Capital $K$ to Composite Factor $Y$
- Labor $L$ to Composite Factor $Y$
- Intermediate Input $X$ to Output $Z$

**Boxes**
- Fisheries Management
- CGE Model

**Terms**
- CGE: Computable General Equilibrium
- Fisheries Management
- Food Web Model
- Utility

**Variables**
- $B$: Fish Stock
- $K$: Capital
- $L$: Labor
- $Y$: Composite Factor
- $X$: Intermediate Input
- $Z$: Output
Ecosystem Productivity Scenarios
Collie et al. (2009); Steele et al. (2007)

- Baseline: 1993-2002 foodweb configuration
- \( P_{III} = \) reduce the role of invertebrate pelagic predators → increases the abundance of all fish guilds (1971-1990 foodweb)
# Feeding Guilds

*(Steele et al. 2007)*

<table>
<thead>
<tr>
<th>Piscivores</th>
<th>Planktivores</th>
<th>Benthivores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spiny dogfish</td>
<td>Smooth dogfish</td>
<td>Atlantic herring</td>
</tr>
<tr>
<td>Winter skate</td>
<td>Barndoor skate</td>
<td>Butterfish</td>
</tr>
<tr>
<td>Silver hake</td>
<td>Little skate</td>
<td>Acadian redfish</td>
</tr>
<tr>
<td><strong>Atlantic cod</strong></td>
<td>Thorny skate</td>
<td>Northern sandlance</td>
</tr>
<tr>
<td>Pollock</td>
<td><strong>Haddock</strong></td>
<td>Atlantic mackerel</td>
</tr>
<tr>
<td>White hake</td>
<td>Red hake</td>
<td>Windowpane</td>
</tr>
<tr>
<td>Spotted hake</td>
<td>American plaice</td>
<td>Loligo squid</td>
</tr>
<tr>
<td><strong>Atlantic halibut</strong></td>
<td><strong>Yellowtail flounder</strong></td>
<td>Illex squid</td>
</tr>
<tr>
<td>Summer flounder</td>
<td>Winter flounder</td>
<td>Smooth skate</td>
</tr>
<tr>
<td>Bluefish</td>
<td>Witch flounder</td>
<td></td>
</tr>
<tr>
<td>Sea raven</td>
<td>Longhorn sculpin</td>
<td></td>
</tr>
<tr>
<td>Goosefish</td>
<td>Cunner</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ocean pout</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fourspot flounder</td>
<td></td>
</tr>
</tbody>
</table>
### Percent changes associated with ecosystem changes

#### An increase in fish biomass

<table>
<thead>
<tr>
<th>Sector/Commodity</th>
<th>Output</th>
<th>Supply</th>
<th>Imports</th>
<th>Exports</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>0.00</td>
<td>0.02</td>
<td>0.03</td>
<td>-0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Aquaculture</td>
<td>-1.25</td>
<td>0.86</td>
<td>1.28</td>
<td>-3.34</td>
<td>0.21</td>
</tr>
<tr>
<td>Fishing</td>
<td>10.33</td>
<td>6.35</td>
<td>-3.43</td>
<td>17.87</td>
<td>-4.70</td>
</tr>
<tr>
<td>Fish Processing</td>
<td>9.96</td>
<td>2.27</td>
<td>-4.35</td>
<td>13.21</td>
<td>-3.28</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.03</td>
<td>0.04</td>
<td>0.04</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Other</td>
<td>0.04</td>
<td>0.04</td>
<td>0.05</td>
<td>0.03</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Millions of 2006 $
Distributional Effects

- Productivity scenario: $P_{III}$
- Region comprises the New England coastal fishing communities
- Benefits are EV surplus gains ($) per household
- Distribution is skewed, reflecting seafood consumption habits
- Could map across communities

Welfare changes (equivalent variations) associated with changes in fishery stock (2006 $ millions) by household Income categories

Total 131.02
Ecological Interactions between Commercial Fishing and Aquaculture

Example: The management of forage fish
An integrated economic-ecological analysis of forage fish management
A framework by Hannesson et al. (2009)

Let species $j$ be the commercially harvested small pelagic species, and species $i$ be a predator of species $j$.

\[ \Delta B_i = \frac{a_i}{C_i / P_i} \Delta B_j \]

Capture fisheries  
Aquaculture

where $\Delta B$ is the change in biomass, $a_i$ is the share of $\Delta B_j$ eaten by species $i$, $C$ is consumption, and $P$ is production.
EMAX model of Georges Bank by Link et al. (2008)

Fig. 3. Network diagram from EMAX. The two fishery nodes are not modeled directly as nodes in this network analysis; rather they are treated as direct (landings) and indirect (bycatch and discards) removals of other nodes. The dashed lines indicate that those nodes are part of the microbial loop.
Ecosystem effects of a change in small commercial pelagic stock*

<table>
<thead>
<tr>
<th>Compartment</th>
<th>$B$</th>
<th>$P/B$</th>
<th>$D$</th>
<th>$C/P$</th>
<th>$a$</th>
<th>$s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small pelagic-squid</td>
<td>0.962</td>
<td>0.95</td>
<td>1.4</td>
<td>2.89</td>
<td>0.0084</td>
<td>0.0029</td>
</tr>
<tr>
<td>Medium pelagic</td>
<td>0.1928</td>
<td>0.45</td>
<td>53.5</td>
<td>5.4</td>
<td>0.0568</td>
<td>0.0105</td>
</tr>
<tr>
<td>Demersals-benthivores</td>
<td>5.02</td>
<td>0.45</td>
<td>10.1</td>
<td>2.04</td>
<td>0.1054</td>
<td>0.0517</td>
</tr>
<tr>
<td>Demersals-omnivores</td>
<td>3.779</td>
<td>0.45</td>
<td>12</td>
<td>1.84</td>
<td>0.0850</td>
<td>0.0462</td>
</tr>
<tr>
<td>Demersals-piscivores</td>
<td>4.254</td>
<td>0.45</td>
<td>24.3</td>
<td>5.42</td>
<td>0.5710</td>
<td>0.1054</td>
</tr>
<tr>
<td>Sharks-pelagics</td>
<td>0.0244</td>
<td>0.1</td>
<td>21</td>
<td>5.55</td>
<td>0.0006</td>
<td>0.0001</td>
</tr>
<tr>
<td>Highly migratory species</td>
<td>0.0352</td>
<td>0.68</td>
<td>14.4</td>
<td>3.01</td>
<td>0.0023</td>
<td>0.0008</td>
</tr>
<tr>
<td>Baleen whales</td>
<td>0.4167</td>
<td>0.04</td>
<td>5.8</td>
<td>118.36</td>
<td>0.0259</td>
<td>0.0002</td>
</tr>
<tr>
<td>Odontocetes</td>
<td>0.122</td>
<td>0.04</td>
<td>35.2</td>
<td>360</td>
<td>0.1401</td>
<td>0.0004</td>
</tr>
<tr>
<td>Sea birds</td>
<td>0.0144</td>
<td>0.28</td>
<td>27.3</td>
<td>15.92</td>
<td>0.0040</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

* Ecological parameters are from Link et al. (2008). Units for biomass ($B$) are in g m$^{-2}$; and units for production ($P$) and consumption ($C$) are in g m$^{-2}$ yr$^{-1}$. 

Percent changes in predator biomass resulting from one unit (g m$^{-2}$) change in prey biomass (small commercial pelagic species)
Next Step

• To develop an integrated model that is useful for analyzing policies related to aquaculture development

• To improve the resolution of fishing and aquaculture related sectors in the CGE model

• To develop model links between the ecosystem (e.g., forage fish biomass) and relevant aquaculture productions
Summary

• EBM involves understanding intra-system linkages and the feedbacks between natural and human systems.

• Aquaculture and commercial fisheries may interact in a complex way throughout economic system (e.g., may compete in downstream markets).

• The culturing of one species could affect the status of a range of species or the characteristics of an entire ecosystem.

• The economic-ecological framework is a useful tool in EBM implementation.