Louisiana Coastal Area Delta Management Ecosystem Modeling

Delta Management Fish and Shellfish Ecosystem Model

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Question: How do a select combination of river diversions affect fish and shellfish in the receiving basins?

Tool: Food web model that accounts for effects of environmental changes, fishing, and predator-prey interactions

- Simulates changes in biomass (tonnes km\(^{-2}\)) and catch (t km\(^{-2}\) yr\(^{-1}\)) of fish and shellfish species over 50 years
- Makes use of end-to-end model construction:
  Output of the Delft3D hydrodynamic model drives the fish and shellfish model
Ecopath with Ecosim and Ecospace

Ecopath: Mass-balance “snapshot” of an ecosystem (initial conditions of the model)

Ecosim: Temporal dynamic simulations (used for model calibration)

Ecospace: Spatial-temporal modeling (framework of the model)
Model development: Ecopath

Key inputs:

• Average biomass of species representative of Louisiana estuaries
• Parameters quantifying turnover and growth: P/B, Q/B, EE, age at maturity, von Bertalanffy growth parameters
• Representative fishing fleets and annual landings
• Diet matrix
## Groups in the model

<table>
<thead>
<tr>
<th>Fish</th>
<th>Fish</th>
<th>Invertebrates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic croaker</td>
<td>silver perch</td>
<td>mud crabs</td>
</tr>
<tr>
<td>bay anchovy</td>
<td>silversides</td>
<td>other shrimp</td>
</tr>
<tr>
<td>black drum</td>
<td>southern flounder</td>
<td>oyster drill</td>
</tr>
<tr>
<td>blue catfish</td>
<td>spot</td>
<td>white shrimp</td>
</tr>
<tr>
<td>coastal sharks</td>
<td>spotted seatrout</td>
<td>zoobenthos</td>
</tr>
<tr>
<td>gizzard shad</td>
<td>striped mullet</td>
<td>zooplankton</td>
</tr>
<tr>
<td>Grey snapper</td>
<td>sunfishes</td>
<td></td>
</tr>
<tr>
<td>Gulf menhaden</td>
<td>threadfin shad</td>
<td></td>
</tr>
<tr>
<td>Gulf sturgeon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>killifishes</td>
<td>Invertebrates</td>
<td></td>
</tr>
<tr>
<td>largemouth bass</td>
<td>benthic crustaceans</td>
<td></td>
</tr>
<tr>
<td>pinfish</td>
<td>blue crab</td>
<td></td>
</tr>
<tr>
<td>red drum</td>
<td>brown shrimp</td>
<td></td>
</tr>
<tr>
<td>sand seatrout</td>
<td>eastern oyster</td>
<td></td>
</tr>
<tr>
<td>sea catfishes</td>
<td>grass shrimp</td>
<td></td>
</tr>
<tr>
<td>sheepshead</td>
<td>mollusks</td>
<td></td>
</tr>
</tbody>
</table>

1Juvenile and adult, 2spat, seed, and sack, 3submerged aquatic vegetation

- **Primary producers**
  - Gulf sturgeon
  - phytoplankton
  - SAV
- **Invertebrates**
  - benthic crustaceans
  - benthic algae
- **Other**
  - Kemp Ridley sea turtle
  - dolphins
  - detritus
  - seabirds
Model development: Ecospace

**Key inputs:**
- Ecopath model
- Basemap of model area with 1 km² grid
- Ecosim fishing effort (annual pattern kept constant for future)
- Spatial and temporal dynamic environmental drivers: values per grid cell, per month for each decadal simulation
- Habitat features (can be dynamic when habitat changes through time)

**Key outputs:**
- Monthly estimated biomass and catch projections for each km² grid cell for every 50-year simulation
- Used to determine if/where increases and/or decreases in biomass and catch can be expected under selected diversion operation scenarios relative to a future without action
Environmental driver and habitat input

- **Delft3D environmental drivers**
  - Monthly salinity, temperature, and Chl \(a\) per Ecospace grid cell (1 km\(^2\)) of target years between 1995-2020
  - Decadal percent wetland per Ecospace grid cell between 1995-2020
- **OECLs (oyster environmental capacity layers)**
  - Based on daily Delft3D output of sal, temp, and TSS
  - Creates capacity (suitability) per grid cell per month
- **Oyster cultch map**

Response curves determine the effect of each of these drivers on individual species
Response curves

The response curves describe the suitability of the parameter values to each species on a scale from 0-1 based on the species tolerance range.

Movement to unsuitable cell reduced by multiplier based on all parameters affecting a species.

Unsuitable cells will have reduced availability of prey.
Test operation plan:
- Open 4 diversions for 50 years
- Compare against future without action
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- Open 4 diversions for 50 years
- Compare against future without action
Brown shrimp Year 50

Future w/o Action June  

4 Diversions Open June
Brown shrimp Year 50

Future w/o Action October

4 Diversions Open October
Biomass change from initial conditions

- **Brown Shrimp Middle Barataria**
  - Production Run 6
  - Production Run 2 (FWOA)

- **Brown Shrimp Middle Breton Sound**
  - Production Run 6
  - Production Run 2 (FWOA)

- **Brown Shrimp Lower Barataria**
  - Production Run 6
  - Production Run 2 (FWOA)

- **Brown Shrimp Lower Breton Sound**
  - Production Run 6
  - Production Run 2 (FWOA)
Biomass year 50 relative to FWOA
Catch year 50 relative to FWOA
Operation plan summary

Decreases in species that prefer higher salinities on a sub-basin level, increases in (few) species that prefer lower salinities

Magnitude of change dampened on a larger spatial scale; redistribution of species

Spatial pattern suggests two lower diversions mostly responsible for the changes

Location of diversions in tested operation plan

Example: brown shrimp year 50
Questions?
Approach

Ecospace

- **Basemap**: grey cells inactive, all other cells active
- **Grid cell size**: 1-km$^2$
- **Ecosim in every cell, monthly time step**
- **Movement**: does not represent species-specific swimming speed or seasonal migration, but prevents entrapment of nektonic species in unsuitable habitat using a generic rate of 300 km yr$^{-1}$. Movement is also needed to not have a spatial disconnect between juvenile and adult groups that may have different habitat preferences.
- **What determines if habitat is suitable?**
  - Habitat: cultch, percent wetland, depth
  - Environmental drivers: Chl $\alpha$, salinity, temperature, TSS
Approach
Ecospace: Habitat capacity model

Capacity $C$ affects the size of the foraging arena area in a grid cell; low capacity reduces consumption.

The habitat capacity of a cell affects movement as well, such that movement towards unsuitable habitat is slowed as a function of the habitat capacity ($C$) of that neighboring cell.

$C = Y_1 \cdot Y_2 \cdot Y_3 \cdot Y_4; \quad C \in [0,1]$
Approach
Ecospace: Habitat capacity model

For each group capacity maps are created

These are comparable to HSIs

Fishing, trophic interactions, and changes in capacity over time will determine group biomass during simulation runs

Example capacity map sack oysters
Example capacity map juv. brown shrimp
Approach

Special handling: oysters

Oysters may be affected by specific sal, temp, and TSS values that persist for shorter periods than a month, which may be masked by monthly averages of those values.

TroSim Oyster Environmental Capacity Layers (OECLs)

Input: daily sal, temp, TSS

Daily sal*temp*TSS OEC averaged by month (0-1)

Output: monthly ascii files with OEC per Ecospace model grid cell

The layer is loaded into Ecospace as an environmental driver with a linear response curve.
How habitat capacity changes the foraging arena equation:

\[ V_{ij} = \frac{v_{ij} \cdot B_i}{2 \cdot v_{ij} + a_{ij} \cdot B_j} \]

\[ V_{ij} = \frac{v_{ij} \cdot B_i}{2 \cdot v_{ij} + a_{ij} \cdot B_j / C_{rcj}} \]

\( V_{ij} \) = vulnerable portion of the prey
\( v_{ij} \) = vulnerability exchange rate
\( B_i \) = prey biomass
\( a_{ij} \) = effective search rate
\( B_j \) = predator biomass
\( C_{rcj} \) = relative habitat size or habitat capacity of the cell

In effect, low habitat capacity for a predator in a grid cell reduces the foraging arena area, and the vulnerable portion of the prey (so the predator is not eating less, but running out of available food)

Christensen et al. 2014
How habitat capacity affects movement:

For each border between cells, for example between cell \((r,c)\) and cell \((r,c+1)\) to its right, Ecospace assumes instantaneous mixing rates \(m_{1j}B_{rcj}\) to the right and \(m_{2j}B_{rcj}\) to the left. This movement is affected by the habitat capacity of the neighboring cell

\[
\frac{m_{1j}}{m_{2j}} = \frac{C_{rc+1j}}{C_{rcj}}
\]

Ecospace sets the exit rate to \(m_j\) (user supplied dispersal rate; 300 km yr\(^{-1}\)) for whichever cell has lower capacity \(C_{rcj}\), then adjusts the exit rate for the cell with higher \(C_{rcj}\) to \(M_j\) times the capacity ratio.