Ecosystem recovery following the DWH oil spill evaluated using an end-to-end model

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COLLEGE OF MARINE SCIENCE
- Funded by the Gulf of Mexico Research Initiative since late 2011
- One of 15 funded centers nationwide, one of five in Florida
- 20 academic institutions in seven states and six countries
Modeling objectives

• Impacts:
  • Fisheries value
  • Fish community structure
  • Ecosystem biodiversity
  • Recovery time
• Evaluate impact of mitigation decisions (fisheries closures and dispersants)
• Socioeconomic analysis
• Evaluating in parallel DWH (2010) and IXTOC I (1979) oil spills
Atlantis summary

• Atlantis Gulf of Mexico model and a SWGOM model
• Major methodological papers so far on biomass distributions (2), diet matrix (2), larval connectivity, and oil dose-response
• 3D Irregular polygon geometry for computational efficiency
Bacteria to apex predators ("end-to-end")

Ocean chemistry & physics (1º coupling to GOM HYCOM, NCDDC)

12 hour time step

Features

- Age structured
- Larval transport
- Biogenic & physical habitat associations
- Nutrient and waste cycling
- Fisheries accounting

1st diet study

- ~1200 stomachs analyzed
- Some from C-IMAGE longline surveys
- Literature: Fishbase (235 spp.), SeaLifeBase (15 spp.), FWC FWRI (905 spp.)

Food web analysis

- Fit to a Dirichlet distribution (multivariate Beta) using MLE
- Provides diet estimates (modes of marginal Beta) and error range
- Diet error now being used in sensitivity analysis of Atlanits (Masi, in prep)

2nd diet study

- +1000 additional stomachs (including CIMAGE)
- GOM Trophic Interactions Database (TAMUCC)

Improvement in Atlantis fit
- 2/3rd of groups improved
- 23% reduction in SS
- 28% reduction in bias
- Comparison with 10 published food webs
  - Just published last week in Fish. Res.
GAM for biomass

GAM

- Predicting biomass distributions for ~ 50 species groups using generalized additive modeling
- First paper (Drexler) used negative binomial GAM; revision (Gruss) used Delta method

Predictor variables

Bot. temp  Bot. oxy  Depth  Sediment  Chl A

GAM abundance modeled w/neg. binomial & log link

GAM for biomass

\[ g(\eta) = s(\text{depth}) + s(\text{chl a}) + s(\text{temperature}) + s(\text{DO}) + \text{factor (sediment type)} \]

- \( \eta \) is probability of presence or abundance
- Logit-link/binomial and log-link/quasi-Poisson
- Uses SEAMAP groundfish trawl: includes validation to 1/3 of data set
- Automated model selection
- Methodology has spawned a Restore Act project (UM, Babcock)
- OSMOSE, Ecospace, Atlantis

Diagnostics

Equilibrium catch & biomass

Historical reconstruction 1990-2010

Effects included so far...

- Vertebrate direct mortality
- Vertebrate growth
- Vertebrate recruitment
- Fisheries closures
- Uptake-depuration dynamics
- Mode of uptake (ingestion or absorption)

Fish toxicology

In progress...

- Invertebrate toxicology
- Benthic oxygen limitation
- Zooplankton bloom
Dynamic oil concentrations

- Consults Lagrangian particle model for oil concentrations (Paris, UM)
- Includes microbial degradation (Müller, Valladares, Schedler, TUHH)
Dose response

Growth and mortality functional responses

- AIC model selection
- Dornberger et al. *in revisions*
- CIMAGE responses (otolith/lesion) & literature

Lesion frequency (mortality proxy)

Otolith growth rates
Vertebrate growth & mortality effects

\( \varphi_t \)  
Bioavailable oil concentration

\( E_t \)  
\# oiled grid points

\( O_{i,t} \)  
Oil conc. at gridpoint \( i \), time \( t \)

\( \rho \)  
Depuration rate

\( \mu \)  
Uptake rate (\textit{benthic or pelagic})

\( \alpha, \beta \)  
Mortality model parameters

\( \gamma, \delta \)  
Growth model parameters

\( K \)  
Sediment-to-water ratio

\( B \)  
Benthic diet fraction

Uptake-depuration dynamics

\[
\varphi_t = O_{i,t-1} \cdot \frac{E_t}{I} \cdot \sum_{i} (\mu \cdot O_{i,t}) \cdot e^{-\rho}
\]

(ecotoxicology experiments forthcoming)

Mortality & growth dose-response

\[
m_t = \alpha \cdot \log \left[ K \varphi_t \cdot \frac{1}{\beta} \right] \cdot \omega^{-1}
\]

\[
g_t = 1 + (K \varphi_t)^\gamma - \delta
\]

Ingestion / absorption uptake mode

\[
M_t = m_{t\text{pelagic}} \cdot (1 - B) + m_{t\text{benthic}} \cdot B
\]

\[
G_t = g_{t\text{pelagic}} \cdot (1 - B) + g_{t\text{benthic}} \cdot B
\]
Invertebrate response

Work in progress

Macrofaunal Density Post Spill

Recruitment effects

- Overlap between oil and ichthyoplankton provides recruitment impact

### Relative losses

<table>
<thead>
<tr>
<th>Fish Family</th>
<th>Relative Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bothidae - Bothus spp.</td>
<td>0.1</td>
</tr>
<tr>
<td>Clupeidae - Etrumeus teres</td>
<td>0.2</td>
</tr>
<tr>
<td>Clupeidae - Brevoortia spp.</td>
<td>0.3</td>
</tr>
<tr>
<td>Clupeidae - Sardinella aurita</td>
<td>0.4</td>
</tr>
<tr>
<td>Coryphaenidae - Coryphaena spp.</td>
<td>0.5</td>
</tr>
<tr>
<td>Engraulidae</td>
<td>0.0</td>
</tr>
<tr>
<td>Lutjanidae - Lutjanus campechanus</td>
<td>0.1</td>
</tr>
<tr>
<td>Lutjanidae - Lutjanus griseus</td>
<td>0.2</td>
</tr>
<tr>
<td>Lutjanidae - Rhomboplites aurorubens</td>
<td>0.3</td>
</tr>
<tr>
<td>Mugilidae</td>
<td>0.4</td>
</tr>
<tr>
<td>Myctophidae</td>
<td>0.5</td>
</tr>
<tr>
<td>Paralichthyidae - Etropus spp.</td>
<td>0.0</td>
</tr>
<tr>
<td>Pomatomidae - Pomatomus saltatrix</td>
<td>0.1</td>
</tr>
<tr>
<td>Rachycentridae - Rachycentron canadum</td>
<td>0.2</td>
</tr>
<tr>
<td>Sciaenidae - Cynoscion spp.</td>
<td>0.3</td>
</tr>
<tr>
<td>Sciaenidae - Cynoscion nebulosus</td>
<td>0.4</td>
</tr>
<tr>
<td>Sciaenidae - Sciaenops ocellatus</td>
<td>0.5</td>
</tr>
<tr>
<td>Sciaenidae - Bairdiella chrysoura</td>
<td>0.6</td>
</tr>
<tr>
<td>Sciaenidae - Micropogonias undulatus</td>
<td>0.7</td>
</tr>
<tr>
<td>Sciaenidae - Leistostomus xanthurus</td>
<td>0.8</td>
</tr>
<tr>
<td>Scombridae - Scomber collas</td>
<td>0.9</td>
</tr>
<tr>
<td>Scombridae - Thunnus thynnus</td>
<td>1.0</td>
</tr>
<tr>
<td>Scombridae - Katsuwonus pelamis</td>
<td>0.1</td>
</tr>
<tr>
<td>Scombridae - Acanthocybium solandri</td>
<td>0.2</td>
</tr>
<tr>
<td>Scombridae - Scomberomorus maculatus</td>
<td>0.3</td>
</tr>
<tr>
<td>Scombridae - Euthynus alletteratus</td>
<td>0.4</td>
</tr>
<tr>
<td>Scombridae - Scomberomorus cavalla</td>
<td>0.5</td>
</tr>
<tr>
<td>Serranidae - Hemanthias spp.</td>
<td>0.6</td>
</tr>
<tr>
<td>Serranidae - Serranulus pumilio</td>
<td>0.7</td>
</tr>
<tr>
<td>Stromateidae - Peprius paru</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Fishery closures

- Complex history of closures updated daily in the model
DWHOS simulations

Averaged ‘super’ groups

100 day exposure

Only a few percent change for most groups under conservative scenario

Most affected groups
- Elasmobranchs
- Gag, Red snapper
- Other Lutjanidae
- Other Demersals
Recovery time

Bimodal

Recovery time

Functional group fate

Does Not Decrease 28%
Recovers within 25 years 39%
Does Not Recover 8%
Recovers within 10 years 25%
Model validation

- Significant post-spill shifts in fish community structure (PERMANOVA \( p<0.001 \)) (fewer planktivores, more invertivores)
- Poor recruitment apparent for some reef fishes (e.g., red snapper)
- PAHs persist in liver tissue samples into 2012; 2013 analyses ongoing
- Within species shifts observed in trophic position; smaller size-at-age
- Some recovery in community structure apparent by spring/summer 2013
**Outputs**

**Improved socioeconomics**
- David Yoskowitz (Harte)
- Shore-based industry impacts & indicators
  - Commercial harvesters
  - Primary dealers and processors
  - Seafood wholesalers and distributors
  - Grocers
  - Restaurants
  - Fuel service
  - Equipment retailers
  - Marinas
  - Hotels/motels/bed & breakfast
  - Boat building and repair

**Virtual Ecosystem Simulator**
Acknowledgements

U South Florida (Murawski, Hollander, Romera)
Mote (Wetzel, Main)
U South Alabama (Patterson)
SEFSC-NOAA (Schirripa, Kelble, Zimmerman)
NWFSC-NOAA (Levin, Kaplan)
NEFSC-NOAA (Link)
University of Miami (RSMAS) (Die, Babcock, Paris)
Florida State University (Coleman, Gosnell)
FWRI (Mahmoudi, Chagaris)
CSIRO (Fulton, Gorton)
NCDDC (Beard, Parsons, Carleton)
UNAM (Gracia)
CICIMAR-IPN (Arreguin-Sanchez)
ICIMAP, UAM, & many others