An agent-based model of fisher behavior and fish population dynamics in the Gulf of Mexico

How does fisher behavior affect stock assessment?

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Objectives

• Uncertainty in fisheries and human behavior.
• West Florida Shelf agent-based simulation model configuration and parameterization
• Model results.
• Stock assessment of simulation model results and comparison with “known” simulation system dynamics.
• Results, discussion, and implications.
• Future research.
Fisher Behavior: Key Source of Uncertainty in Fisheries

- Resource users sometimes respond to policies in an unintended way.
- Though uncertainty is widely accepted as a problem in fisheries management, attention has only focused on scientific uncertainty around the status of exploited resources.
- Uncertainty due to human responses to management has received much less attention.
- Human behavior dictates the spatial and temporal locations of fishery-dependent observations, often used to infer abundance trends in assessment models.

(See Fulton, et al. 2011 for review)
Catch per Unit Effort

Catch per unit effort (CPUE) is used as fishery dependent observations to determine a relative measure of population abundance if the following relation holds:

\[ U_i = \frac{C_i}{f_i} = qN_i \]

Where \( U \) is the catch per unit of fishing effort, \( f \) and \( q \) is the catchability coefficient, the proportion of the population captured by a unit of fishing effort.
Sources of Variation in CPUE

*CPUE is a stochastic process*

**Characteristics of animal population**
- Density (=abundance)
  - Spatial & temporal differences
- Behavior of animals
  - Aggregation behavior
  - Competition for gear space or bait
  - Physiological condition

**Fishing power of fishing unit**
- Gear characteristics
- Vessel characteristics
- Fishermen’s skills

**Environmental conditions**
- Affecting gear performance
- Affecting animal behavior

**Economic/management drivers**
- Regulated catches
- Reporting accuracy
- Market value of target species
CPUE Standardization

Ability to use CPUE as index of abundance depends on being able to adjust for (i.e. remove) the impact on catch rates of changes over time from factors other than stock abundance.

Relative abundance
- Spatially
- Temporally

Other sources of variation
Hypothesis Testing Through Simulation

- Reproduce fish population dynamics and fishing fleet behavioral dynamics – allow them to interact across space and time under realistic state conditions.
- Compare metrics derived from simulated fishing fleet observations, with the biological dynamics simulated in the system.
- Agent-based modeling well suited to simulate complex social and biological dynamics and their interactions.
- Fish and fishing vessels each modeled as individual agents.
Fishing Fleets and Fish Modeled

Long-line boat

Bandit boat

Buoy

Water depth: 120-900 feet

Line on bottom

Leaders
Hundreds of leaders clipped to each line

Bait
Squid, mackerel, skate, sardines

Main line
Heavy-duty monofilament or steel cable

Sources: National Oceanic and Atmospheric Administration
Times graphic - STEVE MADDEN
Simulation Spatial Definitions

- Grouped Strata ($\omega$): 3 groupings of Strata
- Strata ($\varphi$): areas of equal latitude where Florida’s coast runs north-south, areas of equal longitude where the coast runs east-west.
- Depth Sub-strata ($\delta$): 20m isobaths
- Grids ($\tau$): cells one minute latitude by one minute longitude
Spatial Distribution of Abundance

(Saul et al. 2013. Modeling the spatial distribution of commercially important reef fishes on the West Florida Shelf. Fisheries Research 143: 12-20)
Validation

Variogram Fits to 11 Areas

a) Gag Grouper

b) Mutton Snapper

c) Red Grouper
Biased Random Walk Migration Algorithm

- Develop pathway to simulate movement of an individual fish to offshore habitat.
- Important part of reef fish life history.
- Fishing effort removes migrating individuals in transit to offshore habitats.
- Establish an age structured population that is properly distributed across space and time.

Biased Random Walk Migration Algorithm
Tagging Simulation Results

Empirical Linear Speed

Simulated Linear Speed

\(\alpha = 0.7\)
\(\beta = 0.2\)

\(\alpha = 0.9\)
\(\beta = 0.1\)

(Wilcoxon rank sum test: \(P=0.3764\))
Tagging Simulation Results

Comparison of 350 randomly selected empirical and simulated red grouper recaptures from off the coast of Mote Marine Lab (location of half the releases)
Tagging Validation

a) Maturity at Age

b) Simulated Total Migration Time

c) Age and Stage of Tagging

- Sed. Adults
- Migrating
- Sed. Juv.

d) Simulated Recapture Age

- Sed. Adults
- Migrating

e) Commercial Catch at Age

- Discards
- Catch

f) Simulated Age at Arrival
Fish Population Parameterization

- Life history, starting age structure, and recruitment parameters taken from most recent stock assessment reports.
- Spatial distribution of fish abundance validated against the spatial distribution of fish habitat characteristics.
- Migration algorithm validated using tagging data.
Fisher Decision-Making

- Discrete choice models developed for three decisions: participation, site choice, and trip termination.

- Questionnaire completed by vessel captains determined factors to test in model.

- Panel dataset developed to fit models using commercial logbook data, weather, fish price, vessel characteristics, expected revenue, fuel price, and regulations.

(Saul et al. Accepted. Modeling the decision making behavior of fishers in the reef fish fishery on the West Coast of Florida. Human Dimensions of Wildlife.)
Fisher Decision and CPUE Analysis

20 Year Projection
From 2005/2006 State of Fishery (pre-IFQ)

Return to port

When to fish
Where to fish

Simulated Logbook Data

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<th>Species Name</th>
<th>Code</th>
<th>Guttered-lbs</th>
<th>Whole-lbs</th>
<th>Gear</th>
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Model Validation

Source: Strelcheck and Farmer (2012), Personal Communication, NOAA Southeast Regional Office
CPUE Standardization

**Typical Standardization**

Red Grouper CPUE and Biomass

**Additional Factors**

Red Grouper CPUE and Biomass

Longline
Catch at Size

Length Distribution of Catch

Red Grouper Year 20

Length Distribution of Population

Red Grouper Year 20

Red Grouper HL Selectivity

Used in Saul Simulation Model as Derived from SEDAR 9
Findings with Stock Synthesis

**Numbers Over Time: Red Grouper**

**Biomass Over Time: Red Grouper**
Findings with Stock Synthesis

Numbers Over Time: Red Grouper

Biomass Over Time: Red Grouper
Findings with Stock Synthesis

**Numbers Over Time: Red Grouper**

- Simulation
- Base Model
- Perfect CPUE, init F 1/3 SEDAR

**Biomass Over Time: Red Grouper**

- Simulation
- Base Model
- Perfect CPUE, init F 1/3 SEDAR
Findings with Stock Synthesis

**Numbers Over Time: Red Grouper**

- **Simulation**
- **Base Model**
- **Perfect CPUE**
- **Perfect CPUE, est. init. F**
- **Perfect CPUE, init F half SEDAR**
- **Perfect CPUE, SEDAR init F**
- **Perfect CPUE, init F 1/3 SEDAR**

**Biomass Over Time: Red Grouper**

- **Simulation**
- **Base Model**
- **Perfect CPUE**
- **Perfect CPUE, est. init. F**
- **Perfect CPUE, init F half SEDAR**
- **Perfect CPUE, SEDAR init F**
- **Perfect CPUE, init F 1/3 SEDAR**
Findings with Stock Synthesis

Control Rule Plot: Simulated Red Grouper

MSY_{proxy} = SPR_{30%}

- **Base Model, MSY Reference**
- **Base Model, SPR Reference**
- **Perfect Index, MSY Reference**
- **Perfect Index, SPR Reference**
- **SEDAR 12**
- **SEDAR 12 Update**
- **SEDAR 42**
Findings with Stock Synthesis

Red Grouper MSY Based Projections

- SS Yield
- Base Model - OFL
- Base Model - OY
- Base Model - Fcurrent
- Perfect CPUE - OFL
- Perfect CPUE - OY
- Perfect Index - Fcurrent
Findings with Stock Synthesis

Red Grouper SPR$_{30\%}$ (MSY Proxy) Based Projections

- SS Yield
- Base Model - OY
- Base Model - Fcurrent
- Perfect CPUE - OFL
- Perfect CPUE - OY
- Perfect CPUE - Fcurrent
Results and Implications

• Direction and magnitude of CPUE index matters and drives biomass trend estimation in stock assessment models.

• An index that perfectly fits biomass produces results that estimates nearly identical biomass trends.

• Accurately anchoring fleet fishing mortality at the beginning of the time series in stock assessment models is critical to obtaining properly scaled results.
Results and Implications

• Historical data such as landings can be useful in tuning the early phases of a fishery.

• Runs with higher fishing mortality at the start underestimated spawning stock biomass, and therefore estimated less biomass and numbers of fish, and vice versa.
Spatial Distributions of Fishing Effort and Biomass

Fishing Effort Simulation Year 20

Biomass at Simulation Start

Latitude

Longitude

Handline

Red Grouper
Results

• Fishing effort spatially and temporally affected by weather: less fishery dependent observations during times and at locations of high wind.

• Trip duration sometimes limited by hold size (filled vessel to capacity) which suggests effort saturation effect on CPUE.

• Spatial and temporal fishing effort distributions driven by closures indicate stock level catchability cannot be constant in space and time.

• Local depletion - spatial distribution of fishing effort and fish populations not uniform.
  —People tend to have their fishing sites that they know work and only exploratory fish a fraction of the time if at all (survey responses suggest 25%).
Fisher Behavior and Oil Spill

Simulated Handline Fishing Effort

Simulated Longline Fishing Effort
Where did the fishing effort go?
Full Model

Evaluate socioeconomic and fisheries assessment and management affects

Source: The Sea Around Us Project, University of British Columbia
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“Managing fish is managing people”
-Ray Hilborn, 2007

Gulf Fisherman’s Association
Southern Offshore Fishing Assn.
Reef Fish Shareholder’s Alliance

A.P. Bell and Starfish Market
Abrahm’s Seafood
Ariel Seafood
Buddy Gandy Seafood
Cox Seafood
Fish Busterz (Madeira Beach)
Holiday Seafood
Jenson Tuna
Little Manatee Fish House
Madeira Beach Seafood
Sammy’s Seafood
Save On Seafood
Water Street Seafood

Glen Brooks
David Krebs
Jason de la Cruz
Bobby Spathe