Modeling Recruitment Responses of Striped Marlin (Tetrapturus audax) and Swordfish (Xiphias gladius) to Environmental Variability in the North Pacific

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Overview

- Current North Pacific Stock Assessments
  - Striped Marlin
  - Swordfish

- Evidence of Environmental Forcing
  - Early Life History Survival is Important Process
  - Consider Effects of Key Climate Processes:
    - Pacific Decadal Oscillation Index
    - Southern Oscillation Index

- Results and Future Research
  - Are There Significant Effects?
  - How Can We Address Model Uncertainty?
Striped Marlin Growth, Distribution, and Food Habits

- Inhabits surface waters $\geq 20\,^\circ\text{C}$ with 75% of time $<10$ m depth
- Generalist predator (scombrids, squids,...) with rapid growth
- Highly vulnerable to shallow set longline gear

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1. Striped Marlin (LJ)
2. Pacific Sardine (TL)
3. Market Squid (ML)
4. Yellowfin Tuna (FL)
5. Dover Sole (TL)
6. Pacific Cod (TL)

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Size at Age

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Parameter estimation and state dynamics for integrated assessment models (Stock Synthesis)

State dynamics Model $N$

Process errors Observation errors

Parameter $N_0$

Parameter $q$

$N_{t+1} = N_t - C_t$

$y_t = qN_t$

$-\frac{n}{2} \ln[\sum (y_t - \hat{y}_t)^2]$
Recruitment dynamics modeled using 2 hypotheses

- Moderately Resilient SR Curve, Steepness is $h=0.7$
- Environmentally-Driven Recruitment, Steepness is $h=1$
Alternative Stock Assessment Scenarios:
What is the value of steepness, the fraction of unfished recruitment expected at 20% of unfished biomass?

• Formulate multiple working hypotheses about how alternative causal factors influence recruitment

• Select best hypothesis using model selection criteria or if multiple hypotheses are supported use model averaging

\[ R = \frac{4 h R_0 B}{B_0 (1 - h) + B (5 h - 1)} \]
Results: Trends in Spawning Biomass

- Fishery yield (thousand mt):
  - 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20
- Spawning biomass (thousand mt):
  - 0, 10, 20, 30, 40, 50, 60, 70
- Catch: 
- Moderately Resilient SR Curve
- Environmentally-Driven Recruitment

In the diagram, the trends of fishery yield and spawning biomass are depicted over the years from 1955 to 2000. The catch is represented by a shaded area, while the moderately resilient survival ratio (SR) curve is shown as a solid black line. The environmentally-driven recruitment is indicated by a dotted line.
Measuring Recruitment Success: Accounting for Maternal Effects

North Pacific Striped Marlin Recruits Per Spawner Anomalies
Moderately Resilient Stock-Recruitment Curve Scenario

Predicted R/S
Observed R/S

R/S Anomaly
Western and Central North Pacific Swordfish Relative Stock Status

Spawning Biomass Sub-Area 1

- $F$ (Fishing Mortality)
- $-2\times se$
- $+2\times se$
- $S_{MSY}$

Spawning Biomass (mt)

Fishing Mortality Sub Area 1

- $F$
- $-2\times se$
- $+2\times se$
- $F_{MSY}$
Measuring Swordfish Recruitment Success: Accounting for Maternal Effects

Western and Central North Pacific Swordfish
Recruits Per Spawner Anomalies

- Spawning Biomass (mt)
  - 16000 18000 20000 22000 24000 26000 28000 30000

- Recruits per spawner (R/S in kg)
  - 0.00 0.01 0.02 0.03 0.04 0.05 0.06

- Predicted R/S
- Observed R/S

R/S Anomaly
Indices of Environmental Forcing Effects on Striped Marlin Recruitment Success

Seasonal Indices of Environmental Forcing for Early Life History Stage Survival During Striped Marlin Spawning Season, May to August

<table>
<thead>
<tr>
<th>Year</th>
<th>Average Monthly Southern Oscillation Index (May-Jun)</th>
<th>Average Monthly Pacific Decadal Oscillation (May-Jun)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>-30</td>
<td>-3</td>
</tr>
<tr>
<td>1970</td>
<td>-20</td>
<td>-2</td>
</tr>
<tr>
<td>1980</td>
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<tr>
<td>1990</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>10</td>
<td>2</td>
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<tr>
<td>2010</td>
<td>20</td>
<td>3</td>
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</table>
Striped Marlin Moderately Resilient Stock-Recruitment Steepness Scenario
Association Between PDO and Recruits Per Spawner Ratio

Pacific decadal oscillation index (May-Aug)

Log10 transform of striped marlin recruits per spawning biomass

\[ \rho = 0.32 \]

P-value = 0.04
Striped Marlin Moderately Resilient Stock-Recruitment Steepness Scenario Association Between PDO and Recruits Per Spawner Anomaly Ratio

Pacific decadal oscillation index (May-Aug)

Log10 transform of striped marlin recruits per spawning biomass anomaly

\[ \rho = -0.06 \]

P-value = 0.72
Striped Marlin Environmental Forcing Stock-Recruitment Steepness Scenario
Association Between PDO and Recruits Per Spawner Anomaly Ratio

Pacific decadal oscillation index (May-Aug)

Log10 transform of striped marlin recruits per spawning biomass anomaly

$\rho = 0.11$

P-value = 0.51
Western and Central North Pacific Swordfish
Association of Recruits Per Spawner Anomalies and Southern Oscillation Index

\[ (R / S)^{PREDICTED} = 25.589 \cdot 10^{-3} - 5.085 \cdot 10^{-4} \cdot SOI_{Apr-Jul} \]

\[ \Delta_{AIC} \approx 10^2 \]
Results and Conclusions

- Limited Evidence for Strong Environmental Effects on Striped Marlin Recruitment Success
- Evidence Exists That the Southern Oscillation Index Influences Swordfish Recruitment Success Was Found
- Striped Marlin Will Likely Be More Vulnerable to Climate Change Than Swordfish Due to More Intensive Fishery Exploitation and Lower Stock-Recruitment Resilience
Future Work

- **How Can Stock Forecasts Include Model Uncertainty for Recruitment Predictions?**
  - Use Fitted Environmental Forcing Functions

- **Use Fitted Stock-Recruitment Curves**
  - Resample Fitted Error Distributions
  - Resample Empirical CDF of Residuals

- **Use Empirical Cumulative Distribution Functions**
  - Recruitment
  - Recruits Per Spawner
  - Recruits Per Spawner Anomalies

- **Apply Model Averaging When Several Scenarios are Supported by the Data**
Thank You Very Much