Evaluating Fishery Management
Reference Points in a Variable Climate

Melissa A. Haltuch\textsuperscript{1,2}, André E. Punt\textsuperscript{2}, Martin Dom\textsuperscript{3}

\textsuperscript{1} NOAA Northwest Fishery Science Center
\textsuperscript{2} School of Aquatic and Fishery Sciences, University of Washington
\textsuperscript{3} NOAA Alaska Fishery Science Center
What are Biomass Reference Points?

- A fishing mortality rate or level of stock biomass used by scientists to describe current stock status in relation to a management goal.
  - typically the desired level of a stock.

- Calculated in a standard way.

- Linked to stock productivity.
Example Control Rule: West Coast Groundfish

Control rules include goals, reference points, data, and expected management actions. Reference points are quantitative measures used in control rules.
Introduction

- Control rules require estimates of:
  - $B_0$ (average SSB @ F=0)
  - Current spawning biomass relative to $B_0$
  - $F_{MSY}$

- **Low frequency environmental variability, as well as fishing, can impact population abundance, often via recruitment.**

- 2 common ways to estimate $B_0$ depend upon:
  - Average Recruitment
  - Stock-Recruitment relationship

- BRPs are often treated as exact but realistically BRPs have some level of uncertainty.

- Need measures of BRPs which are robust to environmental forcing (i.e. unbiased and precise)
Previous Simulation Study:
Predicated upon a stationary stock-recruitment relationship
Fit the stock-recruitment model inside the stock assessment model

- **Factors**
  - Life history, Recruitment Variation
  - Data Quantity and Quality:
    - Observation Error, Age-composition sample size, length of the catch time series, and length of the survey.

- **Main Conclusion**
  - $B_0$ and stock depletion are best estimated with the stock recruitment estimators.
  - $B_0$ and stock depletion are poorly estimated with the average recruitment estimators.
Objective

- Explore the performance of alternative estimators given climate forcing via the stock-recruitment function:
  - $B_0$ (average unfished biomass)
  - Stock Depletion: Current biomass relative to $B_0 \left( \frac{B_{\text{last}}}{B_0} \right)$
  - $h$
  - $F_{\text{MSY}}$

- Groundfish life histories
  - Rockfish
  - Flatfish
  - Semi-pelagic Gadid
The Operating Model: Defining the True State of the System

- Age-structured
- B-H Recruitment (with variability & climate forcing)
- Biological Information –
  - Selectivity (logistic), Weight, and Fecundity at Age
  - Natural mortality (M)
  - Steepness (h)
  - Stock depletion (B_{curr}/B_{0})
- Burn-in = 400 years
- Sampling (with variability)
  - Survey Index of Abundance
  - Survey and Fishery Age Compositions
The Operating Model: Climate Forcing Function

- Deterministic
  - Sine or Step Function
  - Vary where data begin to be collected in relation to the climate forcing function
- 25 year period
- Calculate $B_0$ using 4 full cycles of the climate forcing function
The Operating Model: Climate Impact on Recruitment

- Allow the deviation about the stock-recruitment relationship to be a function of an environmental variable.

\[ N_{y,0} = \frac{4hR_0B_y}{(1-h)B_* + (5h-1)B_y} e^{\varepsilon_y - \frac{\sigma_R^2}{2}} \]

\[ \varepsilon_y = \bar{p}E_{y-1} + \eta_y \quad \eta_y : \ N(0, \sigma_R) \]

- Specify the total variance to be composed of two components:
  - Deterministic climate function
  - Random variability

\[ \sigma^2_\eta = \sigma^2_E + \sigma^2_R \]

- Each component contributes \( \frac{1}{2} \) of the total variance.
The Operating Model:
Example Population (without error)
The Estimation Model

- Age structured estimation model with an integrated stock-recruitment relationship
  (i.e. same structure as the operating model)

- Estimated quantities
  - $B_0$, $h$, environmental link to the stock-recruitment relationship, $F_{MSY}$
  - Time series of spawning biomass, recruitment and fishing mortality
  - Selectivity functions for the survey and fishery
Alternative Estimation Methods

Three alternative methods of stock assessment are considered:

1. Estimate the annual recruitments, use the estimates of spawning biomass and recruitment to estimate the parameters of a stock recruitment relationship external to the stock assessment. (abbreviation “M₀”)

2. Include the fit of a stock-recruitment relationship inside the stock assessment model. (abbreviation “M_{SR}”)

3. Include the fit to a stock-recruitment relationship which includes the environmental data inside the stock assessment model (Maunder and Watters 2003). (abbreviation “M_{SRE}”)
### Alternative Reference Point Estimators

<table>
<thead>
<tr>
<th>Estimator Description</th>
<th>$B_0$ and Depletion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock-recruitment relationship, $B_0$ equilibrium</td>
<td>SR</td>
</tr>
<tr>
<td>Average recruitment during the whole period of catches (* spawning biomass-per-recruit at $F_{MSY}$ for $B_{MSY}$)</td>
<td>$\bar{R}_{ALL}$</td>
</tr>
<tr>
<td>Average recruitment during the first 10 years of catches (* spawning biomass-per-recruit at $F_{MSY}$ for $B_{MSY}$)</td>
<td>$\bar{R}_{F10}$</td>
</tr>
</tbody>
</table>
### Simulation Trials:

**Parameters constant between simulations**

<table>
<thead>
<tr>
<th>Species</th>
<th>Rockfish</th>
<th>Flatfish</th>
<th>Semi-pelagic Gadid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of catch time series</td>
<td>50 years</td>
<td>50 years</td>
<td>50 years</td>
</tr>
<tr>
<td>Extent of observation error</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Age-composition sample size</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Period of Climate Function</td>
<td>25 years</td>
<td>25 years</td>
<td>25 years</td>
</tr>
<tr>
<td>Amplitude of Climate Function</td>
<td>½ total</td>
<td>½ total</td>
<td>½ total</td>
</tr>
<tr>
<td>Natural mortality (yr⁻¹)</td>
<td>0.12</td>
<td>0.2</td>
<td>0.23</td>
</tr>
</tbody>
</table>
### Simulation Trials:
Parameters varying between simulations

<table>
<thead>
<tr>
<th>Species</th>
<th>Rockfish</th>
<th>Flatfish</th>
<th>Semi-pelagic Gadid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depletion</td>
<td>0.2, 0.4, 0.6</td>
<td>0.2, 0.4, 0.6</td>
<td>0.2, 0.4, 0.6</td>
</tr>
<tr>
<td>Steepness (h)</td>
<td>0.2, 0.3, 0.5</td>
<td>0.6, 0.8, 1</td>
<td>0.55, 0.75, 0.95</td>
</tr>
<tr>
<td>Extent of recruitment variation</td>
<td>0.2, 0.4, 0.6</td>
<td>0.3, 0.5, 0.7</td>
<td>0.9, 1.13, 1.3</td>
</tr>
<tr>
<td>Shape of the environmental function</td>
<td>Step, Sine</td>
<td>Step, Sine</td>
<td>Step, Sine</td>
</tr>
<tr>
<td>Position of the environmental function at the start of data collection</td>
<td>Peak, Middle, Trough</td>
<td>Peak, Middle, Trough</td>
<td>Peak, Middle, Trough</td>
</tr>
</tbody>
</table>

- **Full Factorial Design**
- **100 simulations for each trial.**
Performance Evaluation

- Estimates of $B_0$, stock depletion, $h$, and $F_{\text{MSY}}$ are compared to the true values from the operating model.

- Performance statistics:
  - For Each Simulation Within A Trial

\[
\text{Percent Relative Error} = \left( \frac{O - T}{T} \right) \times 100
\]
Preliminary Individual Trial Results

- All life histories
- Lowest level of both recruitment variability and observation error.
- Middle value for steepness.
- Target level of stock depletion (40% $B_0$).
- Sine shaped climate forcing function.
- Collection of data beginning at the peak of the climate forcing function.
Estimation of Spawning Biomass

Rockfish

Flatfish

Semi-pelagic Gadid

Spawning Biomass

Year

MSR & MSRE
Estimation of Virgin Spawning Biomass

- $M_0$ - Estimation ability is worst for rockfish

- $M_{SR}$ & $M_{SRE}$
  - Estimation improves with inclusion of S-R model in assessment
  - Fitting the stock-recruitment model is similar to using average recruitment over the full time period of catches
  - Average over 10 years more variable and typically poorer
  - Estimation is less variable with inclusion of environmental parameter
Estimation of Stock Depletion

- $M_0$
  - Estimation ability is worst for rockfish
  - using average recruitment during the first 10 years of catches generally better than using the fit of the SR

- $M_{SR}$ & $M_{SRE}$
  - Estimation improves with inclusion of SR model in assessment for rockfish
  - Estimation ability improves for rockfish
  - Negatively bias for flatfish and gadid
  - Less variable than the $M_0$ model
  - Estimation is less variable with inclusion of environmental parameter
  - Average recruitment better for gadid
The ability to estimate $F_{MSY}$ is directly linked to the ability to estimate $h$.

Fitting the SR generally underestimates $h$ and $F_{MSY}$.

Using average recruitment to calculate $F_{MSY}$ always overestimated $F_{MSY}$.
Estimation of Stock-Recruitment Steepness & $F_{MSY}$

- $M_0$
  - Estimation ability is poor for rockfish, better for flatfish and gadid
  - Using average recruitment results in a huge positive bias for estimates of $F_{MSY}$

- $M_{SR}$ & $M_{SRE}$
  - Improved estimation of h
  - $M_{SRE}$ slightly improves estimators for the flatfish and gadid
  - $M_{SRE}$ greatly improves the estimator performance for rockfish
Preliminary Conclusions

- Estimation of $F_{MSY}$ most conservative using the fit of the stock-recruitment relationship and can be grossly overestimated using average recruitment, depending upon the model structure.

- Unclear if fitting S-R model or average recruitment over the observed time series is better for estimating virgin biomass.

- Using the fit of the S-R model to estimate stock depletion is generally better than using average recruitment (same as the previous study).

- $M_0$ - worst for the long-lived unproductive rockfish

- $M_{SR}$ - showed improved estimation of most quantities of interest

- $M_{SRE}$
  - Preferred for estimating stock depletion, better estimation of recruitment at the end of the time series.
  - Preferred for estimation of $h$ and $F_{MSY}$
Acknowledgments

Northwest Fisheries Science Center -
Fisheries Resource Assessment and Monitoring Division

Participants in the Pacific Fishery Management Council
SSC December 2006 B-zero Workshop

Punt and Hilborn Labs, U of W