Management Strategy
Evaluation and the Gulf of Alaska walleye pollock fishery: incorporating climate variability

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18 May 2008
Outline

► Management Strategy Evaluation
► The Gulf of Alaska walleye pollock fishery
► The MSE for the GOA pollock fishery
► Simulation scenarios
► Results when including environmental variability
Management Strategy Evaluation

► Simulation testing of a management strategy with feedback
  ▪ Can account for process, observation, model, and implementation uncertainty

► Why perform an MSE?
  ▪ Assess the impact of error and uncertainty on the ability to achieve management goals and objectives

► This method is used in other countries, IWC
MSE Framework

Operating model

- Biological System, e.g., fish population(s)
- Exploitation System, e.g., commercial fleets

Observations (catch, CPUE)

Perception of the stock(s)

- Stock assessment, e.g., VPA, XSA, ASPM
- Management options, e.g., TAC, size limits

Implementation of rules and regulations

From Fromentin and Kell, 2007
The GOA walleye pollock fishery

- Directed fishing since 1964; fully domestic since 1989
- Managed by the NPFMC, with scientific advice provided by NOAA Fisheries - AFSC
- Current management strategy used since 2001
- Certified by the MSC in 2005
Components of the GOA pollock MSE

- **The operating model**
  - represents the “true” state of nature
  - applies management decisions to the “true” stock

- **The stock assessment model**
  - represents the “perceived” state of the stock
  - estimates stock status and biological reference points

- **The decision rule**
  - determines management decisions based on the results of the stock assessment

- **The performance measures**
  - statistics that quantify management goals and objectives
The models

- Statistical catch-at-age population dynamics models
- Fit fishery, survey, and biological data
- Estimate biological reference points
- Main difference is the age range
- Operating model
  - Estimates and projects process, observation, and model error
GOA pollock fishery management strategy

Annual stock assessment estimates $F_{40\%}$, $SB_{40\%}$, and current spawning biomass
Some results
Simulation scenarios

- **Base scenario**
  - 50 years, 2006 – 2055
  - No environmental or ecosystem forcing

- **Regime shifts**
  - 50 years, 2006 – 2055
  - Changes in average level of recruitment

- **Environmental variability**
  - 45 years, 2006 – 2050
  - Climate indices affect annual recruitment
Base scenario – management performance: SB/SB\textsubscript{40%}

Is the spawning biomass near the target level?

The stock is close to the target level on average.
Environmental forcing

Climate indices

Age-structured operating model

Link to recruitment

Data

TAC

Management Strategy

Years for defining the current regime

Climate Decision rule

Data

TAC

Management Strategy

Years for defining the current regime

Climate Decision rule
<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Index</th>
<th>Season</th>
<th>Source/Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary production</td>
<td>Precipitation</td>
<td>Winter</td>
<td>Bailey et al. 2005</td>
</tr>
<tr>
<td>Primary production</td>
<td>Wind mixing energy</td>
<td>Winter</td>
<td>Bailey et al. 2005</td>
</tr>
<tr>
<td>Concentration of prey and larvae</td>
<td>Eddy formation due to freshwater input – Precipitation</td>
<td>Spring</td>
<td>FOCI</td>
</tr>
<tr>
<td>Concentration of prey and larvae</td>
<td>Upwelling and transport – Wind mixing energy</td>
<td>Spring</td>
<td>FOCI</td>
</tr>
<tr>
<td>Stage duration</td>
<td>Temperature</td>
<td>Spring</td>
<td>FOCI</td>
</tr>
<tr>
<td>Water column turbulence, eddies, transport, advection, upwelling</td>
<td>Precipitation</td>
<td>Spring</td>
<td>Ciannelli et al. 2004, Bailey et al. 2005</td>
</tr>
<tr>
<td>Water column turbulence, eddies, transport, advection, upwelling</td>
<td>Wind mixing energy</td>
<td>Spring, Summer</td>
<td>Ciannelli et al. 2004, Bailey et al. 2005</td>
</tr>
<tr>
<td>Temperatures affect amount of prey and amount of pelagic habitat for juveniles and age-0 animals</td>
<td>Sea surface temperature (may interact with other environmental factors)</td>
<td>Summer, Autumn</td>
<td>Bailey 2000, Bailey et al. 2005</td>
</tr>
</tbody>
</table>
Environmental variability

►► Climate indices

- precipitation (on Kodiak Island)
- wind mixing energy (Shelikof Strait)
- sea surface temperature (Shelikof Strait)
- North Pacific PDO anomaly

►► Jan 1962 – Dec 2005 (historical data)
►► Jan 2001 – Dec 2050 (data from IPCC model output)
Incorporating climate indices

\[ R_{y+1} = \bar{R}_1 \exp \left( \sum_{i=1}^{n} a_i I_{i,y} \right) e^{\varepsilon_y - \sigma_R^2/2}; e_y \sim N(0, \sigma_R^2) \]

► Multiple scenarios for climate forcing on age-1 recruitment
  - Model selection using AIC

► Accounts for some of the process error using the climate indices
  - \( \sigma_R \) decreased from 1.0 to 0.6

► Two management strategies were evaluated
## Operating models

### Model 1
- **Winter precipitation**
  - $+0.339 \pm 0.119$
- **Spring SST**
  - $-0.833 \pm 0.180$
- **Summer precipitation**
  - $-0.140 \pm 0.095$
- **Summer SST**
  - $+0.570 \pm 0.187$
- **Autumn SST**
  - $-0.405 \pm 0.130$

### Model 2
- **Winter precipitation**
  - $+0.310 \pm 0.117$
- **Spring SST**
  - $-0.776 \pm 0.176$
- **Summer SST**
  - $+0.531 \pm 0.185$
- **Autumn SST**
  - $-0.394 \pm 0.130$

*Match existing hypotheses*
Management strategies

\[ SB_{40\%} = SBPR(F = F_{40\%}) \times \bar{R}_y \]

► Current management strategy

\[ \bar{R}_y = \frac{1}{y - 1978} \sum_{y' = 1978}^{y-1} N_{y',1} \]

► Dynamic \( B_0 \) management strategy

\[ \bar{R}_y = \sum_{a=1}^{15} m_a w_a N_{y-a,1} / \sum_{a=1}^{15} m_a w_a \]

► CPA algorithm management strategy

\[ \bar{R}_y = \frac{1}{y - \text{Regime Year}} \sum_{y' = \text{Regime Year}}^{y-1} N_{y',1} \]
Current MS – SB/SB\textsubscript{40%}
Current MS - spawning biomass

ccsm31

- SB_{40%}
- SB_{20%}

gfdl201

gfdl211

mirocH1

mirocM1

mirocM2

mirocM3

ukhadcm31

Spawning biomass (million mt)
Dynamic $B_0$ MS - SB/SB$_{40\%}$
Dynamic $B_0$ MS – spawning biomass

Spawning biomass (million mt)

ccsm31

- SB$_{40\%}$
- SB$_{20\%}$

Year

Spawning biomass (million mt)

gfdl201

Year

Spawning biomass (million mt)

gfdl211

Year

Spawning biomass (million mt)

mirocH1

Year

Spawning biomass (million mt)

mirocM1

Year

Spawning biomass (million mt)

mirocM2

Year

Spawning biomass (million mt)

mirocM3

Year

Spawning biomass (million mt)

ukhadcm31

Year

Spawning biomass (million mt)
Current mgmt strategy

$\text{Prob}(SB_y < SB_{20\%})$
Dynamic $B_0$ MS

\[ \text{Prob}(SB_y < SB_{20\%}) \]
Results for Model 2 - ccs3m31

ccsm31 - current mgmt strategy

ccsm31 - dynamic B0

ccsm31 - current mgmt strategy

ccsm31 - dynamic B0
Results for Model 2 - ukhadcm31

**ukhadcm31 - current mgmt strategy**

- Year: 2010 to 2050
- Spawning biomass (million mt): 0 to 5

**ukhadcm31 - dynamic B0**

- Year: 2010 to 2050
- Spawning biomass (million mt): 0 to 5

**SB / SB40%**

- Year: 2010 to 2050
- Spawning biomass (million mt): 0 to 5

**SB40%**

- Year: 2010 to 2050
- Spawning biomass (million mt): 0 to 5

**SB20%**

- Year: 2010 to 2050
- Spawning biomass (million mt): 0 to 5
Conclusions

► The current management strategy meets management goals

► The current management strategy has uneven performance when regime shifts or climate variability are incorporated

► The dynamic $B_0$ management strategy has better performance for regime shifts, but significant tradeoffs for climate variability
Acknowledgements

► Funding through NOAA Fisheries
► Anne Hollowed and Jim Ianelli
► Allen Macklin, Nick Bond, Phyllis Stabeno, Muyin Wang, Kevin Bailey, and Jim Overland (NOAA/PMEL)
► The Punt lab
► UW QERM and SAFS
MSE Framework

From Fulton et al., 2007
MSE Framework

From Kell et al., 2003

Operating Model
Computer simulation of complex "Reality"

Process errors are generated in the operating model.

Management Procedure
Assessment
Computer simulation of sampling and assessment process
Estimation errors arise due to the assessment procedures.

Management Controls
Computer simulation of management based on perception of the system

Performance Statistics

Feedback
Schematic of the framework

- Stock assessment
  - Estimate current state of population
- MCMC process
- Projections
  - Project population $i$ forward with management strategy
  - Each MCMC parameter vector represents a simulated population
The ‘true’ and estimated values are stored by year and simulation.
Base scenario – estimation performance: ABC

Annual management decision based on assessment results and decision rule

\[ \text{Error}_y = 100(\text{Est}_y - \text{True}_y)/\text{True}_y \]
Regime shifts

**Scenario 1**

**Scenario 2**

The graphs illustrate the average level of recruitment (in billions) from 2010 to 2050 for two different scenarios. The x-axis represents the years, and the y-axis represents the average level of recruitment. The data shows a consistent pattern for both scenarios, with the recruitment levels remaining relatively stable over the years.
Regime shifts

►► All forcing is on age-1 recruitment

►► Fixed regime shifts
  - the average level of recruitment changes in specific years during the projection period

►► Random regime shifts
  - probability of an annual change in the average level of recruitment and recruitment variability
  - modelled using a homogeneous Markov process

►► Four management strategies were evaluated
Management strategies

\[ SB_{40\%} = SBPR(F = F_{40\%}) \times \bar{R}_y \]

► Current management strategy

\[ \bar{R}_y = \frac{1}{y - 1978} \sum_{y' = 1978}^{y-1} N_{y',1} \]

► Dynamic \( B_0 \) management strategy

\[ \bar{R}_y = \sum_{a=1}^{15} m_a w_a N_{y-a,1} / \sum_{a=1}^{15} m_a w_a \]

► Sliding window management strategy

\[ \bar{R}_y = \frac{1}{25} \sum_{y' = y-25}^{y-1} N_{y',1} \]

► CPA algorithm management strategy

\[ \bar{R}_y = \frac{1}{y - \text{RegimeYear}} \sum_{y' = \text{RegimeYear}}^{y-1} N_{y',1} \]
Results for regime shift scenarios

- Current management strategy and dynamic $B_0$ management strategy performed similarly
- The sliding window MS and the CPA algorithm MS did not perform as well
- Catches
  - dynamic $B_0$ MS $>$ current MS during periods of lower productivity
  - dynamic $B_0$ MS $<$ current MS during periods of higher productivity
Results for regime shifts

Fixed regime shifts - scenario 1

Current

Dyn $B_0$

Fixed regime shifts - scenario 2
Results for regime shifts

Scenario 1
Prob($SB_y < SB_{20\%}$)

- Current mgmt strategy
- Dynamic B0

Scenario 2

Year
Percent

0 5 10 15 20

2010 2020 2030 2040 2050
Current MS – Catch applied

- ccsm31
- gfdl201
- gfdl211
- mirocH1
- mirocM1
- mirocM2
- mirocM3
- ukhadcm31

Year

Catch (thousand mt)

2010 2020 2030 2040 2050

0 100 200 300 400 500
Dynamic $B_0$ – Catch applied
Model 2 – ukhadcm31

ukhadcm31 - current mgmt strategy

Year

ukhadcm31 - dynamic B0

Year