Uncertainty in biological reference points and its management implication

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Outline

- Overview roles of biological reference point (BRP);
- Identify uncertainty associated with BRPs;
- Evaluate performance of BRPs and identify optimal BRPs.

Lobster fisheries in the Gulf of Maine (Homarus americanus) and California (Panulirus interruptus)

Tuna fisheries in the Indian Ocean
Biological reference points

Used as a *benchmark* or *guidepost* when:

- **Scientists describe stock status and recommend management options**
  - “Fishing mortality rates are above/below $F_{MSY}$…”
  - “Reduce/increase fishing mortality to levels below $F_{MSY}$…”

- **Managers describe goals and make decisions**
  - “Goal to maintain biomass near $B_{MSY}$…”
  - “Reduce/increase fishing effort to achieve $F_{MSY}$…”

- **Policy makers write laws that define policy**
  - “Optimum yield defined as MSY as reduced by relevant economic and social considerations…”

  - Related to a common management goal and calculated in a standard way
  - Often treated as exact but, but just another estimate with uncertainties of all kinds
  - The best reference points are “ball park” robust, easy to understand, easy and non-controversial to calculate
Target and threshold reference points

- **“Targets” for what managers want to achieve**
  - Like speed limit signs to achieve fast, safe transport (balancing speed and risk)

- **“Thresholds” for what managers want to avoid**
  - Like the yellow line on a highway (*you can cross them but...*)
  - Trigger attention and concern
  - Used increasingly because managers tend to stray from their targets, particularly in fisheries with excess capacity

- **“Limits” are special thresholds**
  - Like the “wrong way” sign on a ramp
  - Indicate need to take drastic action

Fishing mortality BRP vs. biomass BRP

- **$F$ reference points more important**
  - $F$ easier to control via catch, fishing effort, closed areas, seasons, etc.
  - The easiest way to affect biomass is by controlling $F$

- **$F$ limits and thresholds are more like “early warning” signals**
  - It’s already too late when biomass is low and you hit a biomass limit
BRPs without management actions have a technical meaning but no practical significance

BRPs imply management action

• What will managers do to move towards their target and to avoid limits?

• Related policy/technical questions:
  ➢ How quickly can/will managers react if a threshold/limit is crossed?
  ➢ What sort of measures are managers willing or capable of using?
Harvest Control Rule

More “traditional” HCRs (Steinshamn, 1998)

More “recent” HCRs (Deroba and Bence, 2008)

“Seven-Control-Area” Method (Zhang et al. 2012)

<table>
<thead>
<tr>
<th>Area</th>
<th>Next year decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$N_{y+1} = N_{th}$</td>
</tr>
<tr>
<td>2</td>
<td>$F_{y+1} = F_{1}$</td>
</tr>
<tr>
<td>3</td>
<td>$F_{y+1} = F_{1}$</td>
</tr>
<tr>
<td>4</td>
<td>$N_{y+1} = N_{y} + \frac{N_{th} - N_{y}}{10}$</td>
</tr>
<tr>
<td>5</td>
<td>$F_{y+1} = F_{th}$</td>
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<tr>
<td>6</td>
<td>$F_{y+1} = F_{y}$</td>
</tr>
<tr>
<td>7</td>
<td>$F_{y+1} = F_{sp}$</td>
</tr>
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</table>
Sources of uncertainty in BRPs

(1) Uncertainty associated with estimation of parameters (observational errors) used in calculating BRPs;

(2) Temporal variability (process errors) in key processes (e.g., growth, natural mortality, maturation, recruitment) resulting from temporal variability in ecosystem;

(3) Model misspecifications.

Potential consequences of uncertainty in BRPs

- **Random variability**
- **Temporal variability**
  - Different productivity scenarios
    Gulf of Mexico Atlantic bluefin tuna, high productivity scenario: overfished; low productivity scenario: not overfished (NMFS, 2012).
  - Inherent M vs. temporally induced M
    An increased M results in F BRP higher, more difficulty to conclude overfishing status.

- **Inconsistency and incomparability between stock assessment F and B versus BRP F and B**
- **Inconsistency between BRP F and B**
American Lobster Fishery in the northeast USA

North Western Atlantic Ocean
National Marine Fisheries Service
Statistical Reporting Areas

American Lobster Fishery Management

1 15/16''

83-128 mm Carapace Length (CL)
American Lobster Fishery Management

BRP used prior to 2004:

- Survey data landings, M, and q
- Biological and fisheries parameters
- Catch-Survey Model
- Egg-per recruit model

Potential problems:
- Inconsistent with Magnuson-Stevens Act
- Large uncertainty in BRPs
- Inconsistency of BRP and Fcur
- Regime shift or changing system productivity
Different measures for the lobster stock

<table>
<thead>
<tr>
<th>Measures</th>
<th>Quantity Category</th>
<th>Population biomass/abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>weight</td>
<td>&gt;=53mm CL</td>
</tr>
<tr>
<td>12</td>
<td>weight</td>
<td>&gt;=83mm CL</td>
</tr>
<tr>
<td>13</td>
<td>weight</td>
<td>83-128mm CL</td>
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<td>21</td>
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<td>&gt;=83mm CL</td>
</tr>
<tr>
<td>23</td>
<td>numerical</td>
<td>83-128mm CL</td>
</tr>
</tbody>
</table>

![Graphs showing different measures for the lobster stock](chart.png)
MSE of American Lobster Fishery Management

Uncertainty: choice of BRPs

low \( F_{\text{target}} = 0.31 \) year\(^{-1}\) (ASMFC, 2000)

median \( F_{\text{target}} = 0.67 \) year\(^{-1}\) (ASMFC, 2006)

median high \( F_{\text{target}} = 0.93 \) year\(^{-1}\)

high \( F_{\text{target}} = 1.34 \) year\(^{-1}\)

low \( C_{\text{target}} = 30 \) million

median \( C_{\text{target}} = 40 \) million

median high \( C_{\text{target}} = 50 \) million (current catch level)

low \( N_{\text{target}} = 24.8 \) million (Median legal number 1982-2007)

median \( N_{\text{target}} = 37.2 \) million

high \( N_{\text{target}} = 49.6 \) million

\( N_{\text{limit}} = 0.5 \times N_{\text{target}} \)

\( F_{\text{limit}} = 1.5 \times F_{\text{target}} \)

\( C_{\text{limit}} = 1.5 \times C_{\text{target}} \)

F-BRPs + N-BRPs: 12 combinations

C-BRPs + N-BRPs: 9 combinations

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MSE of American Lobster Fishery Management

Uncertainty: choice of HCRs

“constant” HCR

“linear” HCR

“convex” HCR

“concave” HCR

“catch” HCR
Uncertainty: various errors and uncertainty of different processes

- Environmental variations (process error)
- Structural uncertainty (process error)
- Partial observability (observation error)
- Partial controllability (implementation error)

Evaluation of BRPs and HCRs

Performance measures
- Total catch
- Inter-annual catch variation
- Legal biomass at the end of management period
- Lowest legal biomass

Monte Carlo simulation
- 12 BRPs × 5 HCRs × 3 × 3 M = 540 scenarios
- 100 simulation runs for each scenario
- The same 100 random seeds were used for all simulation scenarios
Results

HCR + BRP

Scenario 203: $F_{\text{target}}=0.93 \text{ year}^{-1}$ $N_{\text{target}}=49.6 \text{ million} \ R_{\text{BHR}} \ M=0.15 \text{ year}^{-1} \times e^{20\% \text{CV}}$

![Graph showing the results for Scenario 203.]

Results

HCR + BRP

Scenario 219: $F_{\text{target}}=1.34 \text{ year}^{-1}$ $N_{\text{target}}=37.2 \text{ million} \ R_{\text{auto}} \ M=0.15 \text{ year}^{-1} \times e^{20\% \text{CV}}$

![Graph showing the results for Scenario 219.]

Results

HCR – “constant” HCR and “linear” HCR

Scenario 231: $F_{\text{target}} = 0.93 \, \text{year}^{-1}$, $N_{\text{target}} = 24.8 \, \text{million}$ $R_{\text{BHR}} \times e^{0.5C/V}$

Results

HCR – F-HCR and “Catch” HCR

Scenario 426: $C_{\text{target}} = 40 \, \text{million}$, $N_{\text{target}} = 37.2 \, \text{million}$ $R_{\text{min}} \times e^{0.2C/V}$
Results

<table>
<thead>
<tr>
<th>BRP</th>
<th>Total catch</th>
<th>Catch variation</th>
<th>Minimum biomass</th>
<th>Terminal biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F&lt;br&gt;target = 0.31 year&lt;br&gt;–1; N&lt;br&gt;target = 24.8 million</td>
<td>1</td>
<td>10</td>
<td>1</td>
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<tr>
<td></td>
<td>F&lt;br&gt;target = 0.67 year&lt;br&gt;–1; N&lt;br&gt;target = 24.8 million</td>
<td>4</td>
<td>6</td>
<td>4</td>
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<tr>
<td></td>
<td>F&lt;br&gt;target = 0.67 year&lt;br&gt;–1; N&lt;br&gt;target = 37.2 million</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>F&lt;br&gt;target = 0.67 year&lt;br&gt;–1; N&lt;br&gt;target = 49.6 million</td>
<td>2</td>
<td>8</td>
<td>2</td>
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<tr>
<td></td>
<td>F&lt;br&gt;target = 0.93 year&lt;br&gt;–1; N&lt;br&gt;target = 24.8 million</td>
<td>8</td>
<td>1</td>
<td>8</td>
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<tr>
<td></td>
<td>F&lt;br&gt;target = 0.93 year&lt;br&gt;–1; N&lt;br&gt;target = 37.2 million</td>
<td>7</td>
<td>3</td>
<td>7</td>
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<tr>
<td></td>
<td>F&lt;br&gt;target = 0.93 year&lt;br&gt;–1; N&lt;br&gt;target = 49.6 million</td>
<td>5</td>
<td>4</td>
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<td>F&lt;br&gt;target = 1.34 year&lt;br&gt;–1; N&lt;br&gt;target = 37.2 million</td>
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<td>9</td>
<td>6</td>
</tr>
</tbody>
</table>

"linear" HCR long-term R<br>BRP, M=0.15 year<br>–1 × e<br>20%CV

Design of Management Strategy Evaluation for California spiny lobster
MSE for the Indian Ocean Tuna Fisheries  
(Zhang et al. 2013)

Evaluate performance of a given set of BRPs for different HCRs

<table>
<thead>
<tr>
<th></th>
<th>SSB\text{target} (’000 t)</th>
<th>F\text{target} (year\textsuperscript{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>bigeye tuna</td>
<td>460</td>
<td>0.29</td>
</tr>
<tr>
<td>yellowfin tuna</td>
<td>960</td>
<td>0.47</td>
</tr>
</tbody>
</table>
Evaluate performance of a given set of BRPs for different HCRs

**Uncertainty**
- Initial stock abundance
- Age-composition
- Initial fishing mortality
- Recruitment dynamics
- Age-specific M
- Imperfect HCR implementation

**Performance measures**
- Total catch
- Inter-annual catch variation
- Total biomass at the end
- Lowest value of total biomass

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**Results**

**HCR – bigeye tuna**

[Diagram showing the results of HCR implementation for bigeye tuna]
Performance of the given BRPs for different HCRs

**HCR - yellowfin tuna**

- Total catch
- Annual catch variation
- Lowest biomass
- Terminal biomass

Search for optimal BRPs for a given set of HCR

**BRP - yellowfin tuna**
Results

BRP – yellowfin tuna

BRP – bigeye tuna

Biomass performance
819 BRPs

Catch performance
38 BRPs
Summary

It is important to consider different types of uncertainty associated with BRPs.

MSE can be very helpful in

- Evaluate the performance of BRPs;
- Identify optimal BRPs for a given set of HCR;
- Identify optimal HCR for a given set of BRPs

The whole BRP package

- Policy and goals
  - Attitudes towards risk
- Targets for management goals
- Threshold & limit reference points
  - For what managers want to avoid
- Data collection and stock assessments
- Management actions

All tailored to biology
  - Resiliency and uncertainty
All built around logistics
  - What is practical
BIG QUESTION

Will the whole BRP package help managers go where they want to be and help them stay there?

MANY SMALL QUESTIONS

- How do the reference points relate to management targets and goals?
- Are uncertainties considered?
- Are the benchmarks measurable?
- Are the data/estimates sufficiently precise?
- Is the work load reasonable?
- Are legal requirements addressed?
- Does the package require management actions that are unrealistic (too frequent, too drastic, too expensive, too unpopular)?

Figure 2: Relationship between OFL, ABC, ACL and ACT
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