Economics and ACLs

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Main Points

- Maximum economic yield (MEY) could proxy OY
  - Reflects benefits to society more directly than MSY
  - Can be calculated subject to any constraints
  - Basis for estimating opportunity costs of constraints
  - Can reflect specific uncertainties and risk preferences
  - MEY proxies?

- Risk/uncertainty

- Ongoing work (4 case studies)
  1. Probabilistic forecasts: Revenue v. risk in ACLs for Alaska King Crab
  2. MSY/MEY for Eastern Bering Sea Snow Crab
  3. Robust harvest policy under parameter uncertainty
  4. Optimal investment in learning
National Standard 1

- “Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the United States fishing industry.”

- Preventing overfishing is a constraint
- OY is an objective
Optimum Yield

OY influenced by

- Risk preferences
- Harvest methods and institutions
  - Affect benefits and costs
  - Affect distribution of benefits and costs
  - Affect risk & uncertainty
OY & MSY

OY is defined by MSA Section 3(33) as “the amount of fish which—

[.....]

(B) is prescribed as such on the basis of the maximum sustainable yield from the fishery, as reduced by any relevant economic, social, or ecological factor; and

[.....]
OY & MSY

Is MSY a ‘good’ objective?

- Resource persistence
- Costs are not considered
- Yield can be a poor proxy for benefits
OY & MSY

OY = MSY/X

vs

OY = \max f(.) \text{ s.t. } B_{OY} \geq B_{MSY}

\text{s.t. etc.}

“…on the basis of the maximum sustainable yield from the fishery, as reduced by any relevant economic, social, or ecological factor…”
Maximum Economic Yield (MEY)

- MEY is harvest trajectory that yields greatest (net) economic benefits to society over time
- Subject to any constraints desired
- Often, $B_{MEY} > B_{MSY}$
  (If not, impose constraint $B_{MEY} \geq B_{MSY}$)
Risk and Uncertainty

- Cost of risk reduction
Case 1: Probabilistic Wholesale Revenue Projections (NPFMC Crab ACL Analysis)

Total Revenue = Random Catch x Product Recovery Rate x Price Forecast

\[ TR_{yi} = C_{yi} \times PRR_i \times P_y \]

\[ = C_{yi} \times [\bar{K} + (\eta_i \times \sigma_1)] \times [\bar{P}_y + (\eta_{2i} \times \sigma_2)] \]

\[ \eta_{1i}, \eta_{2i} \sim N(0,1) \quad i = 1, \ldots, 800 \]

Total Present Value = Discounted Sum of Total Revenues

\[ TPV_i = \sum_{y=1}^{y} \left( \frac{1}{1+r} \right)^{y-1} TR_{yi} \]

Sort \( TR_{yi}, TPV_i \) for \( i = 1, \ldots, 800 \):

- Median, lower/upper
- 5\textsuperscript{th} percentiles give 95\% prediction intervals for \( TR_y \) and \( TPV \)
Alaska Crab Wholesale Prices 1984-2008
Source: Commercial Operators Annual Reports

First Wholesale Price, Alaska Crab, by Species

Year

price

ws_p_RKC
ws_p_BKC
ws_p_GKC
ws_p_EBT
ws_p_EBS
Probabilistic Price Forecasts from Time Series Model

Red King Crab Price - COAR Data and Time Series Forecast

Snow Crab Price - COAR Data and Time Series Forecast

Golden King Crab Price - COAR Data and Time Series Forecast

Alaska King Crab (all Species) Price - COAR Data and Time Series Forecast
## Short-Run Implications for $P^*$

ACL defined by $P^*$ (additional uncertainty = 0.2)

<table>
<thead>
<tr>
<th>Alternative</th>
<th>$ABC_{tot}$</th>
<th>$ABC_{dir}$</th>
<th>Multiplier</th>
<th>Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Millions $</td>
<td>%Change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P^* = 0.5$</td>
<td>10,774 &amp;</td>
<td>9,559</td>
<td>1.0</td>
<td>142</td>
</tr>
<tr>
<td>$P^* = 0.4$</td>
<td>10,544</td>
<td>9,380</td>
<td>0.94</td>
<td>135</td>
</tr>
<tr>
<td>$P^* = 0.3$</td>
<td>9,952</td>
<td>8,821</td>
<td>0.89</td>
<td>127</td>
</tr>
<tr>
<td>$P^* = 0.2$</td>
<td>9,370</td>
<td>8,306</td>
<td>0.83</td>
<td>119</td>
</tr>
<tr>
<td>$P^* = 0.1$</td>
<td>8,565</td>
<td>7,559</td>
<td>0.76</td>
<td>109</td>
</tr>
</tbody>
</table>

& - set to the point estimate. Source: Chapter 6 (BBRKC) Table 6-1 (c)
Bristol Bay RKC:
Change in Forecasted Revenue from Baseline TPV (r=2.7%)
Case 2: Recent Scientific Interest in MEY

- *On implementing maximum economic yield in commercial fisheries*
  (Dichmont, Pascoe, Kompas, Punt, Deng, *PNAS* 2010)

- *Economics of overexploitation revisited*
  (Grafton, Kompas, Hilborn, *Science* 2007)

- *Limits to the privatization of fishery resources*
  (Clark, Munro, Sumaila, *Land Economics* 2010)

- *Limits to the privatization of fishery resources: Comment*
  (Grafton, Kompas, Hilborn, *Land Economics* 2010)

- *Limits to the privatization of fishery resources: Reply*
  (Clark, Munro, Sumaila, *Land Economics* 2010)
Maximum Sustainable Rent (MSR): Static MEY in a Gordon-Schaefer Bioeconomic Model

MSR Tangency: Marginal Cost = Marginal Revenue

MSR Profit = TR-TC

MSR, UR = 0, ∞ discount rate cases bound dynamic MEY

Unregulated (UR) Bioeconomic Equilibrium: Total Revenue=Total Cost

Key result: $B_{MSR} > B_{MSY}$ unless Marginal Cost = 0 then $B_{MSR} = B_{MSY}$

If and only if: $C_{MSR} < C_{MSY}$ unless MC = 0 then $C_{MSR} = C_{MSY}$
Fig. 1. (A) BMEY and BMSY of Western and Central Pacific big eye tuna. (B) BMEY and BMSY of Western and Central Pacific yellowfin tuna. (C) BMEY and BMSY of Australian northern prawn fishery. (D) BMEY and BMSY of Australian orange roughy fishery.

Source: Grafton et al. 2007, Economics of Overexploitation Revisited, Science 318:1601
Bioeconomic Model = Optimal Control Problem

\[
\begin{align*}
\text{Max } & \mathbb{E} \left\{ \sum_{t=0}^{\infty} \beta^t \left( V_t' C_t - \frac{1}{2} (C_t - C_{t-1})' A (C_t - C_{t-1}) \right) \right\} \\
\{C_t \geq 0\}
\end{align*}
\]

subject to:

\[
\begin{align*}
N_t &= GMN_{t-1} - GM^2 C_{t-1} + R_t \\
V_t &= P_t - \theta - \Psi C_t + \Phi N_t
\end{align*}
\]

- Prices \( P_t \) and recruitment \( R_t \) are \textbf{exogenous} stochastic processes.
- \( \theta \) is a vector of cost parameters; \( G, M \) are growth, net mortality.
- Except for matrices (in bold), variables are random vectors.
- Baranov, Pope’s approx give pop dynamics in catch-explicit form.
- Selectivity vector implies a scalar control problem in \( F \).
- Solution is summarized by an intertemporal decision rule.
Population Dynamics and Demand-Side Effects:
Static MEY Alternative to Gordon-Schaefer

- $C_{UR}$ not sustainable!
- $C_{MSY} = C_{MSR}$ by construction!
- If MC decreases then $C_{MSY} < C_{MSR}$
Stochastic Dynamic MEY & Bioeconomic Equilibrium

- Intertemporal decision-rule implies time series $F_t(\omega)$
- $F_t(\omega) > F_{MSY}$ or $F_t(\omega) < F_{MSY}$ are possible events
- Probability function $\Pr(\omega | \square)$ measures likelihoods

Optimal dynamics to $F_{MSY}$ from different initial conditions

Simple example (5-size classes):
1. Deterministic (easily relaxed)
2. Constant recruitment = $1.9 \times 10^6$
3. Constant price = $2$/crab
4. Constant direct cost = $1.65$/crab
5. No stock externality or bycatch
6. Small price elasticity of demand
Optimal Dynamics of Unfished Population to MSY

**Dynamic** $F_{MEY}$ and Numbers of crab

**Simple example (5-size classes):**
1. Deterministic (easily relaxed)
2. Constant recruitment = $1.9 \times 10^6$
3. Constant price = $2$/crab
4. Constant direct cost = $1.65$/crab
5. No stock externality or bycatch
6. Small price elasticity of demand
Factor characteristic polynomial to solve the model
Shape driven by parameter estimates of population model

5-1 stable roots (<1) and 1 unstable (>1)
Roots govern system dynamics, optimal speed-of-adjustment to fluctuations in recruitment, prices

$z - M$ plot (point-estimate yellow): Characteristic polynomial with variation in natural mortality $M$

Real Roots = Stable Solution!
Case 3: Risk, Uncertainty, and Robust Control

- Risk
- Uncertainty
  - Parameter uncertainty
  - Model uncertainty
  - Observation uncertainty
  - Stationarity uncertainty
How can we capture parameter uncertainty in control rules?

Uncertainty Bounds

<table>
<thead>
<tr>
<th>$x_t$</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_{t+1}$</td>
<td>1</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Observed transitions

![Diagram showing uncertainty bounds]
How can we capture parameter uncertainty in control rules?

Source: Based on data presented in Walters (1975) and Hilborn and Walters (1992)
How can we capture parameter uncertainty in control rules?
Case 4: Optimal investment in learning

How can we think about whether to invest in

   a) cheaper, lower quality information vs.

   b) more expensive, higher quality information?
Choice of learning protocol

How can we think about the tradeoff b/w harvesting strong fish stocks vs. protecting weak stocks when we observe the degree of mixing with error?
Conclusions

OY is objective, MSY can be treated as a constraint in control problem

MEY can proxy OY … constrain MEY any way you like

MEY calculated appropriately implies ACL or ACT

Information is part of the value of catch, so part of OY

Various work to capture risk and uncertainties is underway