Toward a common understanding of MSE

What, Where, When, How, and Why?
What is MSE?

— using simulation to compare the relative effectiveness for achieving management objectives of different combinations of data collection schemes, methods of analysis and subsequent processes leading to management actions —

Fish and Fisheries (2016)
What is MSE?

“…uses simulation models within an adaptive framework that enables the comparison of alternative strategies in a virtual world under multiple (and often conflicting) objectives”

Why Conduct a MSE?

- “... to identify fishery rebuilding strategies and ongoing harvest strategies that are robust to uncertainty and natural variation, and that balance biological and socioeconomic objectives”

OECD (2010)
Types of Uncertainty Confronted

- Estimation
- Model (structural)
- Process
- Sampling
- Assessment
- Implementation
Types of Uncertainty Confronted in a MSE

- Estimation
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Ianelli et al. (2016) SAFE
Types of Uncertainty Confronted in a MSE

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Landsberg, S.
Types of Uncertainty Confronted in a MSE

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Hanselman et al. (2016) SAFE
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Types of Uncertainty Confronted in a MSE

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“Minimally, a MSE should consider…”

“Which uncertainty is most important will be case specific.”

Punt et al. (2016) Fish and Fisheries
Steps in the MSE Process

1. Identify management objectives and performance metrics*
2. Determine uncertainties to confront
3. Develop harvest strategies*
4. Build operating model
   • Conditioned on observed data
5. Simulate outcomes
6. Compare performance metrics across strategies*

* Minimum Stakeholder Involvement
MSE Framework

Operating Model

“True” Population Dynamics

Management Action (TAC, Input control, ...)

Sampling Model

Catch, length, age, effort, tagging, survey, ...

Management Model

Estimated Stock Status & Trends (Bo, SSB, ...)

Assessment Model

Estimated Stock Status & Trends (Bo, SSB, ...)

Operating Model
MSE Framework

Operating Model

Management Model

Sampling Model

Assessment Model

Management Action (TAC, Input control, ...)

“True” Population Dynamics

Catch, length, age, effort, tagging, survey, ...

Estimated Stock Status & Trends (Bo, SSB, ...)

Spawning Stock Biomass (SSB)

Steepness

Recruits

Unfished SSB

0.2 B₀

0.8 R₀

B₀

R₀
MSE Framework

Operating Model

“True” Population Dynamics

Management Model

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NOAA AFSC
MSE Framework

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Figure 3.17. Estimated sablefish total biomass (thousands t) and spawning biomass (bottom) with 95% MCMC credible intervals.

Hanselman et al. (2016) SAFE
MSE Framework

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Management Action (TAC, Input control, ...)

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Catch, length, age, effort, tagging, survey, ...

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Management Model

Cox et al. (2009) DFO Canada

Critical Zone

Cautious Zone

Healthy Zone

Limit Reference Point

Upper Stock Reference

Removal Reference

Removal Rate

Stock Status

Bo, SSB, ...
Challenges to MSE Implementation

• High costs
  • Full MSE requires development time and computational resources
• Obtaining stakeholder buy-in
  • Will short-term sacrifice result in long-term gain?
  • Necessary to ensure political pressure to accept/follow outcomes
• Identifying objectives can be difficult
• Uncertainty about future data collection process
• Requires knowledge of the system and sources of uncertainty
• Moving beyond single-species focus
MSE Case Studies

Multispecies MSE as a Tool for EBFM
Bio-economic Modelling within a MSE Framework
Confronting Environmental Change with MSE

Continuum of Complexity

Simulation Study  Full MSE
Multispecies MSE as a Tool for EBFM

- Impact of alternative finfish harvest rates
- Species interactions
- Incidental marine mammal mortality
- Multispecies biomass dynamics model
Species Interactions within an MSE Framework

\[
B_{i,t+1} = B_{i,t} + r_i B_{i,t} (1 - \frac{B_{i,t}}{K_i} - \sum_j \beta_{ij} B_{j,t} - \frac{H_i B_{i,t}}{K_{\sigma} - K_i})
\]

Competition Coefficient

Predator-prey Interaction

Harvest Rate


Fig. 1. Northeast US continental shelf Large Marine Ecosystem study area. White line represents the 200 m isobath

<table>
<thead>
<tr>
<th>Common names</th>
<th>12 Marine Mammals</th>
<th>15 Commercially Important Finfish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mysticetes</td>
<td>Fin whale, humpback whale, North Atlantic right whale, sei whale, minke whale</td>
<td></td>
</tr>
<tr>
<td>Odontocetes</td>
<td>Pilot whale, bottlenose dolphin, Atlantic white-sided dolphin, common dolphin, harbor porpoise</td>
<td></td>
</tr>
<tr>
<td>Pinnipeds</td>
<td>Gray seal, harbor seal</td>
<td></td>
</tr>
<tr>
<td>Small pelagic fish</td>
<td>Atlantic herring, river herring, saury, anchovies, Atlantic mackerel, jacks, scads</td>
<td></td>
</tr>
<tr>
<td>Flattfish</td>
<td>Yellowtail flounder, winter flounder, summer flounder, witch flounder, American plaice, Atlantic halibut, windowpane flounder</td>
<td></td>
</tr>
<tr>
<td>Gadids</td>
<td>Red hake, white hake, spotted hake, silver hake, rocklings, Atlantic cod, haddock, pollock</td>
<td></td>
</tr>
</tbody>
</table>
Species Interactions within an MSE Framework

Reported Mar. Mammal Mortality 10x Reported Mortality

Groundfish Harvest

Pelagic Harvest

Smith et al.: Management trade-offs among marine mammals, fishing fleets, and finfish
Species Interactions within an MSE Framework

Reported Mar. Mammal Mortality 10x Reported Mortality

Graph A: Groundfish Harvest

Graph C: Pelagic Harvest

Legend:
- Current Fishing
- No Fishing
- x 0.25
- x 0.5
- x 2
- x 4
- x 8
- x 15

Mysticetes (B/B_{MSY})
Odontocetes (B/B_{Current})
Pinnipeds (B/B_{Current})
Flatfish (B/B_{MSY})
Gadids (B/B_{MSY})
Species Interactions within an MSE Framework

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**Groundfish Harvest**

- **Reported Mar. Mammal Mortality**
- **10x Reported Mortality**

**Pelagic Harvest**

- **Flatfish (B/B_{MSY})**
- **Gadids (B/B_{MSY})**
- **Pinnipeds (B/B_{Current})**
- **Odontocetes (B/B_{Current})**
- **Mysticetes (B/B_{Current})**

- **Current Fishing**
- **No Fishing**
- **x 0.25**
- **x 0.5**
- **x 1**
- **x 2**
- **x 4**

- **Small pelagic fish (B/B_{MSY})**
Bio-economic Modelling within a MSE Framework

- Evaluate economic outcomes of
  - Effort allocation among target species
  - Changes in fleet size
- Stochastic multispecies bio-economic model
Economic MSE: Australian Northern Prawn Fishery

Laird (2015), NPF Industry Pty Ltd
Northern Prawn Fishery Schematic

Gourguet et al. (2014) Ecological Economics
Northern Prawn Fishery Schematic

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Economic MSE: N. Australian Prawn Fisheries

Effort Allocation

<table>
<thead>
<tr>
<th>Effort combinations</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₀</td>
<td>( \infty \text{tig} = 0 % )</td>
</tr>
<tr>
<td>T₁₀</td>
<td>( \infty \text{tig} = 10 % )</td>
</tr>
<tr>
<td>T₅₀</td>
<td>( \infty \text{tig} = 50 % )</td>
</tr>
<tr>
<td>T₉₀</td>
<td>( \infty \text{tig} = 90 % )</td>
</tr>
<tr>
<td>T₁₀₀</td>
<td>( \infty \text{tig} = 100 % )</td>
</tr>
</tbody>
</table>

Vessel Participation

- SQ: fleet size
- K⁻: fleet size
- K⁺: fleet size

Effort Tradeoff

- banana prawn sub-fishery
- white banana prawn
- blue endeavour prawn
- grooved tiger prawn
- brown tiger prawn
- tiger prawn sub-fishery
- NPF trawlers

S. Gourguet et al. / Ecological Economics 99 (2014) 110–120
More banana prawn effort

Equal or variable effort

More tiger prawn effort

Higher Profit

Higher Variability

Gourguet et al. (2014)
Ecological Economics
Economic MSE: N. Australian Prawn Fisheries

Gourguet et al. (2014)
Ecological Economics
Confronting Environmental Change with MSE

Evaluating management strategies for eastern Bering Sea walleye pollock (Theragra chalcogramma) in a changing environment

James N. Ianelli, Anne B. Hollowed, Alan C. Haynie, Franz J. Mueeter, and Nicholas A. Bond

1Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 7600 Sand Point Way NE, Seattle, WA 98115, USA
2School of Fisheries and Ocean Sciences, 315 Lena Point, 17101 Pt. Lena Loop Rd, Juneau, AK 99801, USA
3Joint Institute for the Study of Atmosphere and Ocean, University of Washington, Box 354925, Seattle, WA 98195, USA

*Corresponding Author: tel: +1 206 526 6510; fax: +1 206 526 6723; e-mail: jim.ianelli@noaa.gov.


Received 19 July 2010, accepted 6 January 2011; advance access publication 11 April 2011.
Simulating Future Recruitment

1) 82 IPCC Climate Models

2) Recruitment ~ SST

3) Simulated Future Recruitment Under Climate Change

Ianelli et al. (2011) ICES JMS
Alternative Management in a Changing Climate

Stationary Climate

Changing Climate

Adjust F down as B target approaches
Gradual Changes in Carrying Capacity
Changing the 1.5 MT TAC Cap

Ianelli et al. (2011) ICES JMS
MSE of the Sockeye Salmon Fishery in Bristol Bay, Alaska

*NOTE: This does not represent NOAA/NMFS research.

Collaborators:
Ray Hilborn
Chris Anderson
Jocelyn Wang
Michael Link

Funding provided by the Bristol Bay Science and Research Institute, and the Bristol Bay Regional Seafood Development Association
Bristol Bay Run Size (millions)

- Ugashik
- Egegik
- Naknek–Kvichak
- Nushagak
- Togiak

2010 Value: $165 Million ($390)
Commercial Sockeye Salmon Fishery in Bristol Bay, Alaska
Commercial Sockeye Salmon Fishery in Bristol Bay, Alaska
Commercial Sockeye Salmon Fishery in Bristol Bay, Alaska
Purpose of MSE

- Simulate catch, escapement, and run size
  - Under alternative management strategies
- 100 years forward in time (2014+)
- Account for
  - Estimation uncertainty
  - Stochastic recruitment
  - Shifting production regimes
  - Implementation uncertainty
- Components
  - Biological (OM)
    - Simulate recruitment
  - Management
    - Daily effort allocation decisions
Trial Management Strategies

- Current escapement goals
- ADFG proposed escapement goals (2012)
- ADFG BEG (Smsey) estimates Fair et al. (2012)
- TR-based escapement goals with in-season assessment

<table>
<thead>
<tr>
<th>Stock</th>
<th>Current SEG</th>
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<tbody>
<tr>
<td>Igushik</td>
<td>225</td>
</tr>
<tr>
<td>Wood</td>
<td>1,100</td>
</tr>
<tr>
<td>Nushagak</td>
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<tr>
<td>Kvichak</td>
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<th>TR-based EG</th>
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<tr>
<td></td>
<td>Lower</td>
<td>Upper</td>
<td>Breakpoint</td>
<td></td>
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Simulating Recruitment Regimes

- Single Regime
- Fixed Breakpoint
- Regime Transition
Hidden Markov Ricker

- Bayesian Ricker model
- Estimate regime-specific parameters
  \[ \hat{\alpha}_r, \hat{\beta}_r, \hat{\sigma}_r \]
- Treat regime (state) transition as a 1st order Markov process
  - Regime_t conditioned on Regime_{t-1}
- Estimate state transition probability matrix
  \[ \pi_{i,j} = \begin{bmatrix} p_{i=1,j=1} & p_{i=1,j=2} \\ p_{i=2,j=1} & p_{i=2,j=2} \end{bmatrix} \]
- Prior on \( \beta_r \) (equilibrium/unfished abundance)
  - Paleolimnological data

- Reconstructed salmon abundance from lake sediment isotopes
  - Schindler et al. (2005) Ecology
Low: 2.5 RpS
High: 9.4 RpS

Egegik River

Median

- alpha: 0.93 beta: 8.72
- alpha: 2.24 beta: 9.73

Recruitment (millions)

Spawning Abundance (millions)

Probability of Regime

Median

DIC: 1440.9
Egegik Ricker Parameters

![Egegik Ricker Parameters Diagram](image-url)
Egegik Transition Probability Matrix, DIC: 1440.89

Transition FROM

1 - 1

Low

1 - 2

Low

2 - 1

High

2 - 2

High

name

- 1 - 1
- 1 - 2
- 2 - 1
- 2 - 2

0.00 0.25 0.50 0.75 1.00

0.00 0.25 0.50 0.75 1.00

Low

High
Operating Model

- Generate future regime states for 100 years based on TPM
- Simulate future recruitment
  - State-specific Ricker parameters
    - Drawn from joint posterior in each realization
  - Adding random lognormal recruitment deviations
Implementation Uncertainty

Mixed-stock Harvest

Interception Catch

Variation in Arrival

2015 Run Size

\[ P_{t,p,s,d} \]
Management Model

- Simulate in-season management process
  - Difficulty in achieving escapement goals
  - Districts open/closed
    - Depending on whether stock is ahead/behind target \( \text{day} \)
  - Simulated manager receives partially-delayed information

**Inputs**
- \( \text{Arrivals}_\text{day} \)
- Esc Goal
- \( \text{Esc Target}_\text{day} \)

**Outputs**
- \( \text{Harvest}_\text{day} \)
- \( \text{Esc}_\text{day} \)
Management Model Realism
Escapements: 1963 - 2008

Predicted Esc. > Obs. Esc
Management Model Realism
Escapements: 1963 - 2008

Predicted Esc. > Obs. Esc

Predicted Esc. < Obs. Esc
The Complete MSE Framework

- Simulate recruitment, escapement and catch
  - Over 100 years, 100x
Concluding Thoughts on MSE

• MSE is an important tool for identifying optimal practices
  • By explicitly including multiple sources of uncertainty and variability
• MSE may be useful to address a broad range of questions
  • Assessment model design, climate change readiness, EBFM, value of information and survey design
• MSE must be conducted as a collaborative process with stakeholders
  • Determine value functions and alternative performance metrics
  • Ensure public understanding and support
• Tighter integration with economic modelling is necessary
  • Fully assess management outcomes
  • Quantify drivers of behavior that lead to implementation uncertainty
• Careful consideration of goals and uncertainty is necessary from the outset
Thank you for listening...

Contact:
curry.cunningham@noaa.gov