Estimating and Accommodating Uncertainty

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Outline

- Some background and principles
- Single-species uncertainties
- Beyond the single-species
- Final thoughts

Some principles for uncertainty and MSE
MSE The Basics

MSE has three primary uses:

- development of the management strategy for a particular fishery;
- evaluation of generic management strategies;
- identification of management strategies that will not work and should be eliminated from further consideration

Key Note: The aim is to find management strategies that are robust to uncertainty rather than strategies that are optimal if a particular scenario is true.

"if a strategy does not perform adequately in computer simulations, would you expect it to perform adequately in the real world?"
MSE roles

Decision makers

- Specify objectives
- Assign priorities to the objectives?
- Define performance standards (or not)

Analysts

- Define performance statistics
- Select uncertainties & modelling stuff (✓)
- Plots and tables

Assign priorities to the objectives?
Key terminology for today

**Operating model (OM):** A mathematical–statistical model used to describe the modeled system in simulation trials and to generate resource monitoring data when projecting forward; the values for the parameters are determined through conditioning. Many OMs are considered to capture **uncertainty.**

**Simulation trial (or test):** A computer simulation to project the model system for a particular scenario forward for a specified period to ascertain performance.

**Hypotheses (or factors):** Aspects of the system that together determine the specifications of the operating model.

**Levels (of factors):** Choices for ways of parametering alternative hypotheses.

**Conditioning:** An operating model is “conditioned” on available information by adjusting its parameter values to ensure that it is consistent with this information, and hence reflects assumptions that are plausible—this process is similar (sometimes identical) to an assessment.

Based on Rademeyer et al. ICJMS (2007)
Uncertainty

How much uncertainty you decide to include in any particular analysis is as much an art as a science.

Uncertainty comes in several forms:

- **Estimation error**: differences between the actual values of the parameters of the OM and those provided by the estimator when fitting a model to available data;
- **Implementation error**: differences between intended management actions and those actually achieved;
- **Observation error** (or **measurement error**): differences between the measured value of some resource index and the corresponding actual value in the OM;
- **Process error**: natural variations in resource dynamics.
- **Model error**: difference between the model on which the management strategy is based and that on which the OM is based.
Find the Goldilocks spot

The “goldilocks spot” balances:
• Ignoring key uncertainties
• Considering trivial uncertainties or so many sources of uncertainty that it becomes impossible to conduct the work / interpret the results.

Dividing the trials into a **reference set** and a **robustness set** of the trials may assist in managing many trials, but will not reduce the workload caused by too many uncertainties.
References and Robustness Trials

- **Reference trials**: Trials that reflect the most plausible hypotheses – and hence used to identify the “best” management strategies.
- **Robustness trials**: used to assess whether the management strategy behaves “as expected” under unlikely, but still plausible, scenarios. Robustness trials often involve “nasty” crosses of factors, each of which is “somewhat plausible”.

Neither of these scenarios should be part of the reference set!
Operating models do’s and don’t

Do
• Be aware that the operating model(s) represent the uncertainties you will be examining.
• Follow the best practice guidelines.

Don’t
• Spend your entire project / budget developing the operating model.
• Focus on obvious uncertainties (and too many – minor – variations of the a single operating model).
• Focus too much on representing parameter uncertainty for one operating model variant, when model uncertainty is much more important.
Best practices related to uncertainties-I

• Consider a range of uncertainties, which is sufficiently broad that new information collected after the management strategy is implemented should **generally reduce** rather than increase this range.
• Include trials for each potential source of uncertainty (unless there is clear evidence that the source does not apply).
• Consider the need for spatial structure, multiple stocks, predator-prey interactions and environmental drivers on system dynamics.
• Divide trials into “reference” and “robustness” trials.
• Use Bayesian posterior distributions to capture the parameter uncertainty for each trial (if possible).

Taken from: Punt et al. Fish Fish. 2016
My process:

- I start by identifying “broad factors” - based on the list of what I have done previously.
- For each factor, I identify levels (including “none”) and highlight one (or more) **base levels**.
- I then create the reference trials based on combinations of the levels (usually the “base” levels).
- I then create robustness trials.
- I try to avoid too many “almost unrealistic” trials.

https://www.linkedin.com/pulse/how-conquer-impossible-task-jimmy-woodard
Philosophy of Conditioning
Notes on conditioning-I

Conditioning is (traditionally) a major component of single-species operating models.

However: operating models are caricatures of scenarios so perfection is not essential.

This is sufficiently close for an operating model scenario!
Ideally conditioning should be conducted by fitting (using Bayesian methods!) the operating model to the available data. However, other approaches have been used:

- **Bootstrapping** (e.g. the trials developed by the IWC)
- **Sampling parameter values from a variance-covariance matrix**
- **Just using the best estimates of the parameters.**

For data-poor situation (or evaluation of generic management strategies) “conditioning” is setting the values of the parameters of the operating model to “capture plausible scenarios” – often for a set of “representative” species-types.
Notes on conditioning-III

There is a temptation to “weight” models (rather than parameters within models) based on likelihood. This should be done very carefully, because AIC-type approaches can reject models because either:

• They fit the data worse some other models [OK!]
• They do not fit the data better than a simpler model [bad because we lose a scenario that is plausible but we have not “gone there yet” (e.g. some of the impacts of climate change and OA).]
Final Note: What is not an MSE

MSE is focused on uncertainty. Hence, any MSE that assumes that management has perfect information about stock size, productivity, etc, is not an MSE.

http://www.icge.co.uk/languagesciencesblog/wp-content/uploads/2014/04/you_shall_not_pass1.jpg
Single-species considerations
Before we go to far

Although MSE can be designed to achieve multi-species or ecosystem objectives, most MSEs are focused on single-species considerations.

Note: some of ecosystem and multi-species considerations can be approximated using single-species operating models (but the set of performance statistics is obviously consequently limited).
Unforgettable factors-I

**Productivity:**
- Form and parameters of the stock-recruitment relationship
- Presence of depensation
- Extent of variation and correlations in recruitment about the stock-recruitment relationship
- Regime shifts in recruitment
- Occasional catastrophic mortality or recruitment events

Szuwalski PNAS 2013
Unforgettable factors-II

Non-stationarity:
• Changes in the stock-recruitment relationship
• Time-varying natural mortality
• Time-varying carrying capacity
• Time-varying growth and selectivity

In principle, these factors could be explored using ecosystem models that “realistically” create such behaviour, but similar behaviour can be obtained using trends (linear, cyclic, etc) in, for example, natural mortality and growth rate.
Non-stationarity is realistic (climate change, etc.). However, it does challenge specification of performance statistics (what does $B/B_0$ mean when $B_0$ changes over time?).

Potential solutions include:

- *Avoiding performance statistics based on $B_0$ (and its friends $0.2B_0$, $B_{MSY}$, etc.)*
- *Run the model with no fishing and calculate “dynamic $B_0$” (this is the “solution” adopted by the IWC)*
Unforgettable factors-IV

Data-related issues:
• CVs and effective sample sizes
• Changes in the relationship between catchability and abundance
• Changes in survey bias (fishery-independent data)
• Survey and sample frequency
• Ageing error
• Historical catch inaccuracy (bias)

General note: Most data generation processes lead to data that are far “too good”. Apply “Punt’s Turing Test”
Unforgettable factors-V

Outcome (Implementation) uncertainty:
• Decision makers adjust or ignore management advice
• Realized catches differ from total allowable catches due to mis-reporting black market catches, etc.
• Errors in the location of the catches from that intended.
• “Strategic” monitoring.
Unforgettable factors-VI

Other factors:
• Spatial and stock structure
• Technical interactions
• Time-varying selectivity, movement and growth
• Initial stock size

You’ve got to be very careful if you don’t know where you are going, because you might not get there.

There are known knowns. These are things we know that we know. There are known unknowns. That is to say, there are things that we know we don't know. But there are also unknown unknowns. There are things we don't know we don't know.
Spatial and stock structure are the quickest way to:
- **Make virtually any management system fail**
- **Spend many years developing operating models**
- **Do something that actually matters!**
Stock and spatial structure-I

Selecting numbers of stocks:
• Consider genetic and non-genetic methods (but be careful not to confuse stocks with spatial variation in biological characteristics).
• Avoid the temptation to “create stocks” in the absence of data, without clear guidelines on what to do with performance statistics for “cryptic” stocks.

Key considerations for multi-stock operating models
• Where are they found (and when)?
• Is there dispersal among the stocks (if so how much)?
• What are performance statistics for multi-stock cases (all stocks must be above the LRP; the sum of all stocks must be above the LRP, etc.)?
Stock and spatial structure-II

Best practices for spatial models:

- The number of spatial areas in the operating model should never be known exactly to the management strategy (i.e. there should be boundary errors).
- Is there movement among spatial regions (if so at what ages / levels)?
- How does density-dependence relate to the spatial structure of the operating model?
Beyond single-species
Technical Interactions:

‘Multispecies Y/R’ (MSYPR)

Remember NO biological interactions!
Larger mesh sizes = higher predation
see MSVPA

Total (summed) Y/R for 4 species and 2 mesh sizes. Arrows correspond to max Y/R for each species, plus actual fishing effort. After Murawski (1984)


http://slideplayer.com/slide/7993288/
Technical Interactions-I

Technical interactions can occur:
• between species within one (or more fleets) (i.e. true technical interactions); or
• between fleets fishing for the same species (i.e. gear competition); or
• with protected or endangered species (i.e. unintentional technical interactions).

Technical interactions can lead to byproduct landings which can actually impact overall profits.

We will focus on the first of these reasons for technical interactions.
Quick Note

Multispecies technical interactions are much easier to include in operating models than multispecies biological interactions because:

- The interactions are due to fishing and do not require major changes to the basic population dynamics equations.
- There is direct data on technical interactions (bycatch and discards) that are available in the many cases.
- Many algorithms exist for identifying the metiers that should form the basis for the operating model.
How to include in operating models

1. First decide on a fleet-structure
   - Fleets are usually groups of vessels fishing in the same area at the stage time
   - But the fleet-structure could be the same vessels at different times of the year (e.g. for sardine and anchovy off South Africa).

2. Extract the species-composition of the catch by each fleet, which will be used for conditioning

3. Include fits to the species-composition as part of the conditioning.
Technical Interactions-III

The simplest operating models assume that technical interactions are static, but some:

- **allow for a full effort dynamics models where vessels select areas and times to fish to maximize revenue, minimize bycatch etc.**
  - This is approach taken in Atlantis
  - Such a model can be fitted “outside” the conventional conditioning process given it will likely be (very) slow.
- Allow for a simpler process (e.g. Ono et al., in press) that fits an empirical model to bycatch rates so that the future mimics the past.
BIOLOGICAL INTERACTIONS

http://stuartwestmorland.com/stock/concepts/


http://greatnessborealforest.weebly.com/symbiosis.html
There are three “levels” associated with modelling biological interactions:

- **Outside of model predators** ("extended single-species operating models")
- **MICE operating models**
- **End-to-end operating models**

http://content.time.com/time/health/article/0,8599,2070599,00.html
Outside of model predators-I

Here we extend the basic population dynamics equations to include time-varying predation, but the predators are not “dynamic”. For example:

\[ N_{y+1,a+1} = N_{y,a} e^{-M_0 - M_y} \]

where

\[ M_y = M_A e^{\sin(2\pi(y-10)/5)} \]
Outside of model predators-II

Advantages:
• Very simple to code (and to condition the operating model).
• Easy to include as a sensitivity test as in a single-species.
• One can replace simple functions by actual (predicted) predator trends, even with predator suitability.

Disadvantages:
• Not clear how realistic the trends in natural mortality are.
• Provides no way to address questions regarding prey-on-predator effects
MICE models-I

The principles of MICE

- **Keep it simple (3-10 species / species-groups)**
  - Allows parameters to be estimated from data
  - Allow multiple projections to be conducted “quickly”
- **Focused on a particular issue (or a small number of issues).**
- **Includes of some “ecosystem” context or impact.**
- **Need to be careful to include a “sufficient” number of species (prey and predator)**
- **MICE can be fitted formally to data (aka single-species conditioning)**
Examples of MICE-based MSEs:

- *The South African hake-seal model (aka the original)*
- *Pollock, cod, halibut, and arrowtooth flounder in the Gulf of Alaska (A’mar et al. 2010)*
- *Sardine, anchovy and predation off the US west coast*
- *Sharks and prawns off southern / northern Australia*
- *Flatfish in the North Sea*

Note that most MICE have involved fixed-F / perfect information projections so are not ‘real’ MSEs
MSE in the Gulf of Alaska

Stochastic biomass dynamics model

Arrowtooth flounder → Pollock → Pacific cod → Pacific halibut

Age-structured model with Type I, II and III functional forms for the interactions among species
Natural mortality for pollock

Type I

Type II

Type III
Conditioned operating model-I

The operating model is fitted to diet data (proportions and in absolute terms).

This is the posterior mode fit.
Conditioned operating model-II

Estimated (conditioned) biomass and recruitment trajectories for cod.

The biomass trajectories for the predators were fitted to the model output (somewhat naughty)
Management Strategy

The management strategy is based on the actual strategy applied.

Assessment method: Age-structured single-stock integrated assessments.

Harvest control rule:
Results-I

Projections under Type I functional relationship

Columns show sensitivity to the fishing mortality on the predators:
- Status quota $F$
- $F_{MSY}$
- $1.5 \times F_{MSY}$
Results-II

Projections under Type III functional relationship

Columns show sensitivity to the fishing mortality on the predators:
• Status quota $F$
• $F_{MSY}$
• $1.5 \times F_{MSY}$
End-to-End models

End-to-end models (e.g. Atlantis, EwE) can be used as operating models (not estimation models, unlike MICE).

Advantages:
• More realistic, often provide more performance metrics than other operating models
• Some have standard estimation integrated already
• Include vessel dynamics models

Disadvantages:
• Some (e.g. Atlantis) computational intensive
• Conditioning these models remains difficult
• Generating data can be a challenge (e.g. age, length conditional at-age length data).
Final thoughts

https://www.researchgate.net/profile/Peter_Bayliss/publication/314537432/figure/AS:470520337571840@1489192198028/Figure-5-The-Catchment-to-coast-Management-Strategy-Evaluation-approach-whereby-the-MSE.png

http://store.metmuseum.org/content/ebiz/themetstore/invt/80010981/80010981_01_l.jpg
Best practices related to uncertainties

A minimalist MSE:
• Some process error: normally variation about the stock-recruitment relationship
• Parameter uncertainty related to the two major determinants of performance:
  • Productivity; and
  • overall size of the resource being managed
• Observation error related to monitoring.

Note that the **most important uncertainty** is often quite different among applications – don’t copy and paste operating model specifications.
Finally

Do not assume that you will ever be able to capture every uncertainty (even in a single-species context). The management system should understand that it is likely the set of uncertainties will evolve over time.

The IWC (and other jurisdictions, South Africa, CCSBT, IWC) have implemented a scheme where every “few” years, a check is made (an “Implementation Review”) to ensure that the tested uncertainties are still plausible and adequate.
The Giants on whose shoulder we stand

Questions