Assessment for All initiative(a4a)
The a4a Management Strategies Evaluation algorithm

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Abstract

This document presents the Management Strategies Evaluation algorithm developed in the JRC Assessment For All (`a4a`) initiative. Management Strategy Evaluation (`MSE`) is a complex simulation and forecasting procedure that takes into account structural and observational uncertainty on stock dynamics (growth, recruitment, maturity) and on its exploitation by fishing fleets (selectivity, effort). The `MSE` paradigm can lead to to the articulation of the central part of a decision making framework for fisheries management under uncertainty. The `a4a` approach to `MSE` is to develop a set of common methods and procedures to build a minimal standard `MSE` algorithm. This has the most common elements of both uncertainty and management options. Such a toolset should allow for the development of `MSE` simulations for many fisheries in an operational time frame. The `a4a` `MSE` design uses a two step approach. The first step defines the 'standard' components of an `MSE` while the second step sets the details, for example the `HCR` or the `OM` conditioning.

Contents

1 Introduction

Management Strategy Evaluation (MSE) is a complex simulation and forecasting procedure that takes into account structural and observational uncertainty on stock dynamics (growth, recruitment, maturity) and on its exploitation by fishing fleets (selectivity, effort). The MSE paradigm can lead to to the articulation of the central part of a decision making framework for fisheries management under uncertainty. The algorithms for development and application of MSE simulations are currently fairly diverse across different fora and fisheries, despite the obvious common elements and a shared overall structure.

Figure 1 shows the major components in the fisheries system, how they relate and interact, and their position in the the fisheries management cycle. The industry, in most cases comprising private companies, manage fleets of fishing vessels exploiting the public marine resources. Scientific institutions then collect data on both the activity of the industry and the biological resources, in order to build a model representing both fleets and stocks dynamics. These models form the basis for scientific advice to the corresponding management body on how distinct policy options will affect the whole system, fleets and stocks. This management body (government, international institution or RFMO) has the institutional responsibility of managing these public marine resources for the common good. This requires the setting of appropriate regulations to steer and limit the activity of fishing.

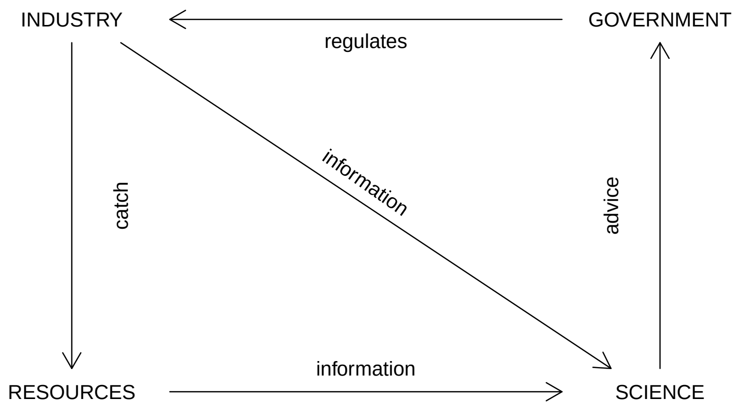

Figure 1: Management cycle

Figure 2 places the MSE components on top of the management cycle. The fleet and the stocks are embedded in an operating model, which is the representation of the natural and fishery systems. On the other side, the management procedure includes the stock assessment process, carried out by scientific institutions and experts, and the management process, carried out by the governmental institutions based on scientific advice. Two other important components are the observation error, which represents the process of collecting information for scientific purposes, and the implementation error, which accounts for differences between the intended results of the regulatory processes and the observed results, and incorporates the way the actors implement regulations and perceive the management objectives behind them.

The a4a approach to MSE is to develop a set of common methods and procedures to build a minimal standard MSE algorithm. This has the most common elements of both uncertainty and management options. Such a toolset should allow for the development of MSE simulations for many fisheries in an operational time frame.

The a4a MSE design uses a two step approach. The first step defines the 'standard' components of an MSE while the second step sets the details, for example the HCR or the OM conditioning.

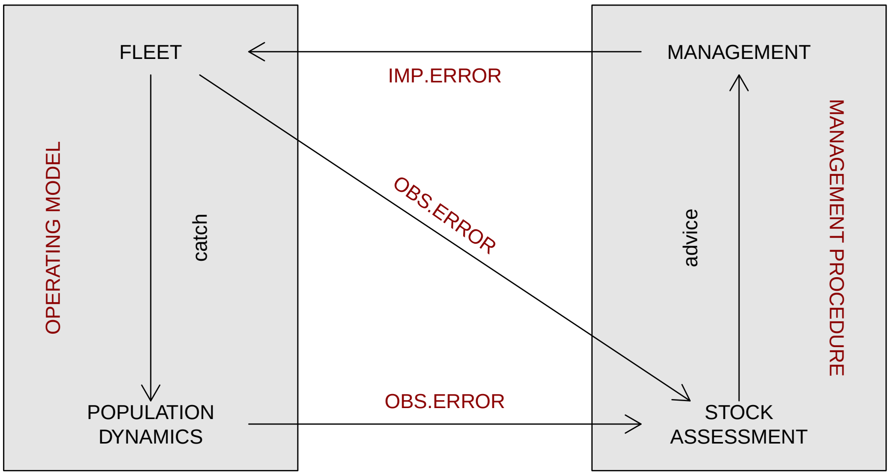

Figure 2: Management Strategies Evaluation

For background information on `a4a` check the `FLa4a` introductory vignette[1].

For more information on the `a4a` methodologies refer to Jardim, et.al, 2014, Millar, et.al, 2014 and Scott, et.al, 2016.

2 Notation and Definition of variables

The following notation will be used for the defined variables, functions and indices. Variables in the Operating Model (OM) are always uppercase, whiles variables in the Management Procedure (MP) are lowercase, *e.g.* catch C in OM c in the MP. Quantities estimated within the MP, *e.g.* fishing mortality by a stock assessment model, will use the uppercase with a hat, *e.g.* $\hat{F}$. The same will apply to functions which are estimated within the MP, *e.g.* the stock-recruitment function[2]. The target value that results from a decision process, *e.g.* the application of a harvest control rule, is identified by a tilde, $\tilde{F}$. Indices will always use lowercase, with their maximum value represented by the corresponding uppercase letter, *e.g.* ages as $a = 1 \ldots A$. Table 1 presents the variables used in this document.

[1] `vignette("introduction", package="FLa4a")`

[2] The S/R estimation means not only the parameters but also the choice of the functional form, which depends of the perception of the stock on that moment.

[3] Either in terms of catch-per-unit-effort and abundance or fishing mortality and effort.

Subject	Notation	Description
Variables		
	N	population abundance in number of individuals
	R	recruitment in number of individuals
	F	fishing mortality rate
	M	natural mortality rate
	B	mature biomass in weight
	W	individual mean weight
	P	percentage of mature fish
	C	catch in number of individuals
	Y	yield in weight
	Q	fleet catchability
	S	fleet selectivity
	E	fleet effort
	V	indicator of stock status
	D	abundance index
Functions		
	g	stock-recruitment function
	j	hyper(hypo)stability function [3]
	f	stock assessment model or indicator
	h	management decision function (aka harvest control rule)
	k	implementation function
	w	technical measures function
	l	implementation error function
	o	observation error function
Other		
	μ	expected value
	σ^2,Σ	variance or covariance matrix
	θ	set of parameters
	ϕ	median
	LN	lognormal probability density distribution
Indices		
	$a = 1 \dots A$	age
	$t = 1 \dots T$	years
	$i = 1 \dots N$	iterations
	trg	target

Table 1: Variables, indices and function, and the notation used to refer to them in the text.

3 Operating model

The operating model includes the population dynamics of the stock

$$N_{a+1,t+1} = N_{a,t} \exp(-F_{a,t} - M_{a,t})$$

while for the first age, recruitment is estimated following some function of the adult biomass $G(B)$

$$N_{0,t} = R_t = g(B_t)$$

which is in turn dependent on the proportion of mature individuals at age (P_a) and the mean weight at age in the stock (W_a)

$$B_t = \sum_{a=1}^{A} W_{a,t} N_{a,t} P_{a,t}$$

Calculation of catch at age in numbers follows the standard Baranov equation

$$C_{a,t} = \frac{F_{a,t}}{F_{a,t} + M_{a,t}} N_{a,t}(1 - \exp(-F_{a,t} - M_{a,t}))$$

while total yield in weight is calculated as

$$Y_t = \sum_{a=1}^{A} W_{a,t} C_{a,t}$$

Fishing mortality at age is related to effort through selectivity-at-age, catchability and the (possibly non-linear) function (j)

$$F_{a,t} = S_{a,t} Q_t j(E_t)$$

4 Observation error model

4.1 Catch in number of individuals, $c_{a,t}$

Catch in numbers-at-age[4] are observed with error

$$c_{a,t} = C_{a,t} \exp \epsilon_c$$

where ϵ_c is log-normally distributed

$$\epsilon_c \sim LN(\mu_c, \sigma_c^2)$$

4.2 Index of abundance, $d_{a,t}$

The index of abundance is observed with error, through catchability, which defines its relationship with the stock abundance-at-age

$$d_{a,t} = N_{a,t} q_{a,t} \exp \epsilon_d$$

where ϵ_d is log-normally distributed

$$\epsilon_d \sim LN(\mu_d, \sigma_d^2)$$

5 Management procedure

5.1 Assessment/Estimator of stock statistics

Input into the decision rule includes the indicator of current status ($\hat{V}$), given the available information, in this case catches (c) and an index of abundance (d)

$$\hat{V} = f(c_{a,t}, d_{a,t} | \theta_f)$$

where

$$V = \sim LN(\mu_v, \Sigma_v)$$

transformed through some suitable function (f), for example a stock assessment. The precise inputs, and the elements in θ will depend on the precise form of the HCR. In an age based system, for example, these would be estimates of F_t, B_t and C_t[5].

The stock assessment component of the status estimator might include an stock-recruitment relationship

$$\hat{N}_{0,t} = \hat{g}(\hat{B}_t)$$

$\hat{g}$ is the stock recruitment relationship estimated within the MP and represents the perceived dynamics, which differs from G, included in the OM.

5.2 Management Decision/Harvest Control Rule

In this code it is assumed that management is carried out through changes in F, although the implementation of those changes can be done through a combination of systems: input control, output control and/or technical measures. A first decision is made about the target fishing mortality for next year. The result of this decision is afterwards translated into an *implementation variable*.

$$\tilde{F}_{a+1,t+1} = h(\hat{F}_{a-1,t-1}, \hat{F}_{trg}, t_{trg})$$

[4] Generally derived from sampling of numbers-at-length and a growth model or age-length key

[5] Which in our notation would be represented by $\hat{F}_t$, $\hat{B}_t$ and $\hat{C}_t$.

5.3 Management system

This process translates the management decision into a regulation, for example fishing opportunities, or days at sea. It mimics the process used to formulate the advice from the scientific estimates of likely effects of different fishing mortality levels.

5.3.1 Input/effort management

$$\tilde{E}_{t+1} = k(\tilde{F}_{a+1,t+1}|\theta_k) \exp \epsilon_{\tilde{E}}$$

$$\epsilon_{\tilde{E}} \sim LN(\mu_{\tilde{E}}, \sigma^2_{\tilde{E}})$$

5.3.2 Output/TAC management

$$\tilde{C}_{t+1} = k(\tilde{F}_{a+1,t+1}|\theta_k) \exp \epsilon_{\tilde{C}}$$

$$\epsilon_{\tilde{C}} \sim LN(\mu_{\tilde{C}}, \sigma^2_{\tilde{C}})$$

5.3.3 Technical measures

Technical measures affect the exploitation by imposing a shift in the age structure of the catch. Both gear selectivity or availability can be mimicked using shifts in the age structure of the exploitation. The overall level of exploitation is dealt by the input or output controls and technical measures are seen as a complement.

$$\tilde{S}_{a,t+1} = w(\hat{S}_{a,t}|\theta_w) \exp \epsilon_{\tilde{S}}$$

$$\epsilon_{\tilde{S}} \sim LN(\mu_{\tilde{S}}, \sigma^2_{\tilde{S}})$$

6 Implementation error model

$$F_{a,t+1} = l(\{\tilde{E}_{t+1}, \tilde{C}_{t+1}\}, \tilde{S}_{a,t+1}|\theta_l) \exp \epsilon_F$$

$$\epsilon_F \sim LN(\mu_F, \sigma^2_F)$$

7 Summary

Flexible framework to run single species MSE analysis. Each MSE element and process has a function that allows the user to set its own approach:

- Fleet dynamics - $j()$
- Stock-recruitment relationship - $g()$
- Observation error model - $o()$
- Stock assessment model or status indicator - $\{f(), \hat{g}()\}$
- Harvest control rule - $h()$
- Management system - $k()$
- Technical measures - $w()$
- Implementation error model - $l()$