

A modular framework for the generic application of fisheries Management Strategy Evaluation (MSE)

Ernesto Jardim¹, Finlay Scott¹, Iago Mosqueira¹, Paris Vasilakopoulos¹, Alessandro Mannini¹, Cecilia Pinto¹, Christoph Konrad¹, and ...¹

¹European Commission, Joint Research Centre, Sustainable resources directorate,
Water and Marine Resources unit, 21027 Ispra (VA), Italy

*Corresponding author ernesto.jardim@ec.europa.eu

November 22, 2018

Abstract

This document presents the Management Strategy Evaluation framework developed in the EC 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 leads naturally to articulation 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 which has the most commonly considered elements of uncertainty and options for management. Such a toolset allows for the development of MSE simulations for many fisheries within a reasonable operational time frame. The presented framework builds on tools of the Fisheries Libraries in R project (FLR) and R language.

Contents

1	Introduction	3
2	Notes on modularity	7
3	Methods	8
3.1	Notation and Definition of variables	9
3.2	Timeline	10
3.3	Operating model	11
3.4	Observation error model (OEM)	13
3.5	Management procedure (MP)	13
3.5.1	Estimator of stock statistics or stock assessment	14
3.5.2	Parametrization of the Harvest Control Rule	14
3.5.3	Harvest Control Rule (HCR)	15
3.5.4	Technical measures (TM)	15
3.5.5	Implementation system	15
3.6	Implementation error model (IEM)	16

1 Introduction

Management strategies evaluation (MSE) is a process to develop management options, which includes several interactions with stakeholders and policy makers, to collect and identify objectives, constraints, limitations, etc. Integrating all these elements when testing management options allows tuning evidences to reality, or reply to relevant questions. Additionally it has the advantage of buying-in stakeholders and policy managers by sharing the ownership of proposed solutions.

Evidence or support to each management option, is built using simulation algorithms which try to capture uncertainty of the most relevant processes. The analysis of results is based on a set of performance indicators, discussed and agreed with stakeholders and policy makers, which summarize risks and trade-offs of the different management options.

HCR here ?

The quantitative side of MSEs are complex simulation and forecasting models that consider the structural and observational uncertainty on stock dynamics (growth, recruitment, maturity, etc) and exploitation by fishing fleets (selectivity, effort, etc), as well as the management decision making process and implementation of management measures. A key feature of MSE is the consideration of multiple types of uncertainty (REFs). As such the MSE paradigm can be a central part of a decision making framework for fisheries management under uncertainty. **Mention risk based management**

MSE was introduced in Europe through the ICES Working Groups on Long-Term Management Measures (ICES, 1994, 1995) and a meeting funded by the European Community (Horwood, 1994). These studies used MSEs to evaluate the impact of including inter-annual constraints on catch limits of NE Atlantic flatfish (Kell et al. (2005a)) and evaluate the ICES procedure for managing some roundfish stocks (Kell et al. (2005b), Kell et al. (2006)).

Building on this work, three expert working groups (EWGs) of the EC's Scientific, Technical and Economic Committee for Fisheries were held that focused on the development of 'generic' harvest control rules (HCR), based on a broad range of stocks and situations (e.g. data availability, life history, stock status etc.) (STECF (2007b),

STECF (2007c), STECF (2008)).

These HCRs could be applied to the large number of EU fisheries that were managed through catch limits, bypassing the need to develop and test an impractical number of individual HCRs for each stock i.e. if an HCR was deemed to be robust enough (after simulation testing with hypothetical stocks) then it could be applied ‘off the shelf’ to an appropriate stock.

During this period, there were a series of EU projects¹ that provided the background for MSE related activities including developing management plans for specific stocks, developing software for performing MSE (e.g. FLR Kell et al. (2007)) and for testing alternative management approaches (e.g. the use of multi-annual plans, data poor stocks, inclusion of ecosystem interactions). One of the main results of these projects was the development and adoption of the management plan for the Northern hake stock based on MSE analysis STECF (2007a).

The adoption of long-term management plans (LTMP) in the EU was affected by the Lisbon Treaty which came into force in 2009 (REF). Article 43 of the Treaty implied that the European Council was solely responsible for setting fishing opportunities. This led to an inter-institutional disagreement within the EU about the use of the HCRs in LTMPs which was not resolved until 2014 (REF). During this period MSE research and development was undertaken, for example for the Baltic Sea (REF), but the resulting LTMPs were not adopted until 2017 (REF) when the conflict was sorted out.

[The resolution is that fisheries cannot be managed by HCR. However, given the objectives and framework of the Common Fisheries Policy (e.g. achieving FMSY by 2020 and the use of upper and lower bounds for FMSY) it is possible to construct an implicit HCR using an envelope approach STECF (2016).]

As mentioned above, the full MSE process involves close communication with policy makers and stakeholders to agree on the options to be tested, performance indicators for the evaluation of those options and details of the decision process. MSE simulations are the quantitative side of this process and typically have a number of common elements and a shared overall structure [REFS]. However, the frameworks for development and

¹EFIMAS (2004 - 2008), COMMIT (2004 - 2007), UNCOVER (2006 - 2010), PRONE (2006 - 2009), CAFE (2006 - 2009), AFRAME (2007 - 2009)

application of MSE simulations are currently fairly diverse across different fora and fisheries.

Figure 1 shows the major components in a fisheries management system, how they relate and interact, and their position in the fisheries management cycle. The industry, in most cases comprising private companies, manage fleets of fishing vessels exploiting the fisheries resources. Scientific institutions then collect data on both the industry activity and 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. The management body (government, international institution or regional fisheries management organization - RFMO) has the institutional responsibility of managing the resources, in most cases public, for the common good, which requires the setting of appropriate regulations to steer and limit the activity of fishing.

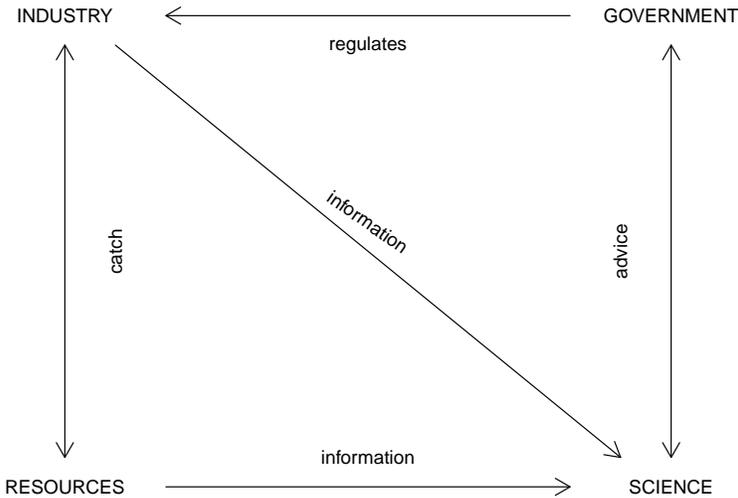


Figure 1: Management cycle

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. The two blocks are connected through two important components: 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 actors implement regulations and perceive the management objectives behind them.

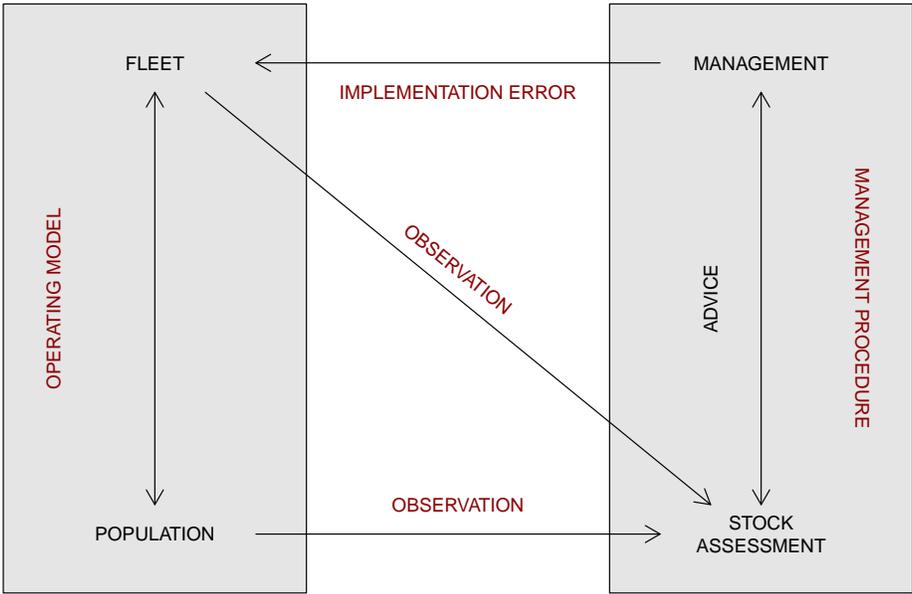


Figure 2: Management Strategies Evaluation

The European Commission Joint Research Centre (JRC) started its 'Assessment for All' Initiative (a4a) in 2012, with the aim to develop, test, and distribute methods to assess a large numbers of stocks in an operational time frame, while including the major sources of uncertainty in scientific advice, and to build the necessary capacity/expertise

on stock assessment and advice provision. Since its inception a series of papers have been published, mainly focused on adding uncertainty to stock assessment and ways of incorporating it in the advisory process (Jardim et al., 2015; Citores et al., 2018; Jardim et al., 2018; Millar et al., 2015; Scott et al., 2016).

The aim of this paper is to describe the a4a MSE algorithm and show results of its application to both data rich and data limited stocks. With a focus on the modular design of the MSE algorithm, which provides a framework that can be parametrized and setup to deal with a wide range of situations occurring in scientific advice to fisheries management.

2 Notes on modularity

Modularity links software implementation with the processes one is trying to model, making it easier to develop extensions of the model but also to communicate one's implementation of a specific process.

From <https://en.wikipedia.org/wiki/Modularity>

Modularity is the degree to which a system's components may be separated and recombined.

In ecology, modularity is considered a key factor – along with diversity and feedback – in supporting resilience.

In modular programming, modularity refers to the compartmentalization and interrelation of the parts of a software package.

In software design, modularity refers to a logical partitioning of the "software design" that allows complex software to be manageable for the purpose of implementation and maintenance. The logic of partitioning may be based on related functions, implementation considerations, data links, or other criteria.

The term modularity is widely used in studies of technological and organizational systems. Product systems are deemed "modular", for example, when they can be decomposed into a number of components that may be mixed and matched in a variety of configurations.[1][2] The components are able to connect, interact, or exchange resources (such as energy or data) in some way, by adhering to a standardized in-

terface. Unlike a tightly integrated product whereby each component is designed to work specifically (and often exclusively) with other particular components in a tightly coupled system, modular products are systems of components that are "loosely coupled." [3]

3 Methods

The a4a approach to MSE is to develop a set of common methods and procedures to build a standard MSE algorithm which includes the most common elements of both uncertainty and management options, allowing the development of MSE algorithms in an operational time frame.

To implement the MSE framework we used a modular design and the FLR platform (Kell et al., 2007). A modular design allows the break down of the system components in smaller, independent, parts. It bares resemblances to the object oriented programming and the agile paradigms of software development applied to ecological modeling (Silvert, 1993; Holst, 2013).

A modular algorithm fosters the reuse of code, improves communications among modelers, reduces maintenance and, foremost, improve the understanding of the algorithm. In that sense the a4a MSE modules link back to the model parts, so that each element of the model maps to a single module, allowing the practitioner to focus on each part of the model without having to constantly check and build new interactions with other relevant parts.

Recovering figure 2 and mapping the MSE modules becomes clearer how the algorithm is designed.

It's of major importance to keep in mind that the MSE works as a whole, which requires the different elements to be consistent with each other. For example an HCR that requires BRPs, like F_{MSY} , must rely on an estimator which provides the necessary information to compute it, which in itself relies on an OEM that produces the input data for the stock assessment model to run. On the other hand, a 'model-free' HCR that uses survey information to compute fishing opportunities, requires an estimator that computes trends and an OEM that samples biomass.

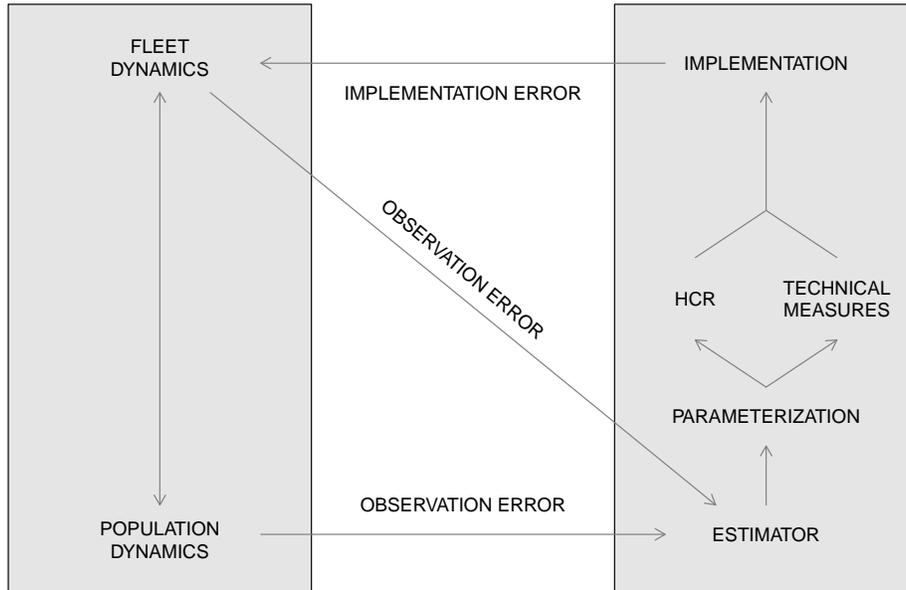


Figure 3: The a4a MSE algorithm

3.1 Notation and Definition of variables

Table 1 presents the variables used in this document. The following notation will be used for the defined variables, functions and indices. Variables related to the Operating Model (OM) are uppercase, while variables in the Management Procedure (MP) are lowercase, *e.g.* catch is C in OM and c in the MP. Management values that result from a decision process, *e.g.* the application of a HCR, are identified by a tilde, \tilde{c} . Functions will be represented with lower case letters. Indices will always use lowercase, with their maximum value represented by the corresponding uppercase letter, *e.g.* ages as $a = 0 \dots A$.

3.2 Timeline

Figure 4 presents the timeline used in the algorithm. The algorithm moves in time steps of 1 year. In each time step the MP is run to provide the conditions to project the OM, which are based on policy options being tested and the perception of stock status.

The OM, in any given time step, extends from t_0 up to t_a . During the analysis it will be projected up to t_f taking into account the conditions set by the MP in the relevant time step.

Stock assessment or estimation of indicators is carried out in moment t_a . In which moment the MP has available, through sampling defined by the OEM, data between t_1 and t_a . If the full time series is sampled then $t_1 = t_0$. Usually the MP doesn't have access to the complete information of the OM ($t_0 : t_a$), although in some situations partial information can be available. For example, if a survey is carried out during t_a it can be included in the estimation process.

Year t_m refers to the time step when management decisions will be applied to the fleet.

The distance between t_a and t_d , will be referred as 'data gap', between t_a and t_m as 'management lag' and between t_d and t_m as 'scientific gap'.

These time windows can be of any number of years. The most common approach in ICES is to have a data gap and a management lag of 1 year, while in the case of ICCAT it's more common to have ... [IAGO].

In the descriptions that follow, for the sake of simplicity, ψ is used in a loose way referring to any time lag without specifying its length.

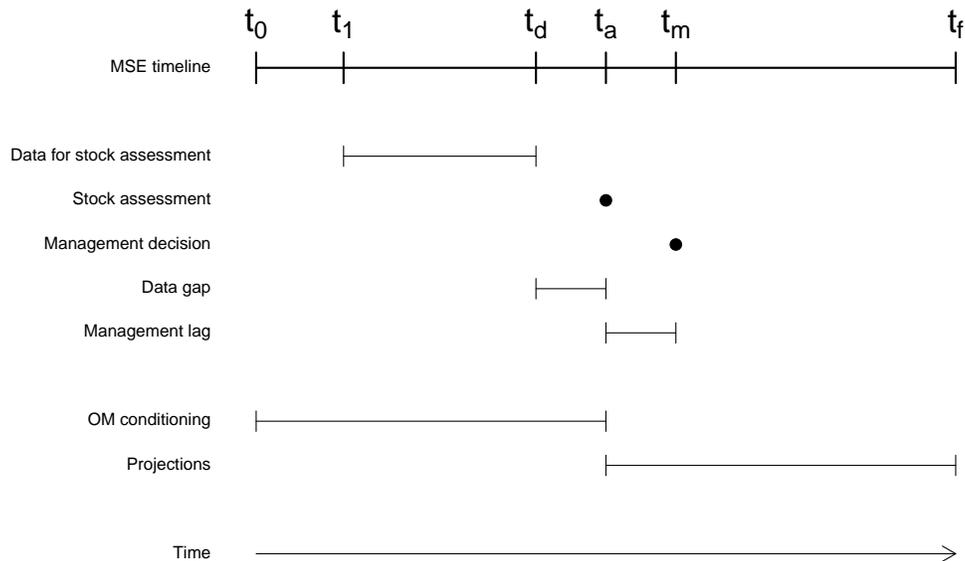


Figure 4: Time line of events occurring during the algorithm loop (time flows from left to right). t represents time, in years; subscripts 0 refers to the first year in the time series, f stands for the final year of the time series, 1 refers to the first year of data while d refers to the last, a refers to the year when the assessment or indicator estimation is carried out, m refers to the year for which management options are being set.

3.3 Operating model

An operating model represents the scientific perception of the natural and human system. It is commonly generated by formally conditioning on the available sources of data, through statistical fitting of a fishery and population model. Other sources of information, such as expert knowledge, or data obtained from other stocks and fisheries, are often also used (REF). The complexity of an operating model can vary widely, from biomass dynamics models (REF) to multi-stock and multi-fleet age-structured model with spatial components and seasonal time steps (REF). **[The complexity of the operating model will have a direct influence on the complexity of the management options that can be explored with it, and on the range of future robustness scenarios they can be tested against.]**

The type of operating model for which this framework has been initially designed

is of intermediate complexity: a single stock, age-based, yearly population model, exploited by an aggregated fleet. However, extensions of this structure can be developed in various ways. This could include, for example, consideration of multiple fleets, or seasonal dynamics for both stock and fleets. Very often the limits to complexity are set by the availability of data and information for parameterizing any extra processes, rather than the ability of the platform to incorporate them.

The operating model includes the population dynamics of the stock, which is described by the survival equation,

$$N_{a+1,t+1} = e^{(-F_{a,t}-M_{a,t})} N_{a,t}$$

Recruitment is estimated following some function of the reproductive biomass

$$N_{0,t+\psi} = R_{t+\psi} = g(B_t)$$

where g is a stock-recruitment model and B_t is reproductive biomass, that depends 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,

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

with total yield in weight calculated as

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

Fleet dynamics are modeled through changes in fishing mortality at age, which is related to effort through selectivity-at-age (S), catchability (Q) and effort (E) by

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

All variables above can, in theory, be treated as random and have a probability distribution associated with it.

3.4 Observation error model (OEM)

The observation error model (OEM) mimics the data collection process, setting the interface between the OM and MP. The outcome of an OEM is a dataset, u , composed of the variables needed to inform management, most of the times after using a model to estimate relevant variables for management.

A common setup for the OEM is to generate observations of catch numbers and abundance indices, both aggregated by age or length. Catch in numbers-at-age are defined by

$$c_{a,t} = C_{a,t}e^{\varepsilon_c}$$

where ε_c is log-normally distributed $\varepsilon_c \sim LN(\mu_c, \Sigma_c)$. The index of abundance samples the stock numbers or biomass,

$$d_{a,t} = N_{a,t}q_{a,t}e^{\varepsilon_{a,t}}$$

where catchability, q , defines the relationship between the index and stock abundance-at-age or biomass, also considered log-normally distributed with $\varepsilon \sim LN(\mu_q, \Sigma_q)$.

Note that for cases which don't use analytical assessments the OEM will sample age aggregated indicators, for example biomass or catch. The mechanics are similar, the data function mimics the sampling process to generate observations, and uncertainty is added through an error term that follows a specified probability distribution.

3.5 Management procedure (MP)

The MP is the system's part that mimics advisory and decision processes. It's split into a sequence of smaller processes which replicate the flow of information and decisions made during the management process. Namely estimate stock status, estimate reference points, decide about future fishing opportunities, and convert the decision into an implementation measure. In parallel it can include decisions about complementary

measures like changes in mesh sizes, effort limitations, marine protected areas, etc.

The MP considers that management is carried out through changes in F or C . The implementation of those changes can be done through a combination of systems: input control, output control and/or technical measures.

3.5.1 Estimator of stock statistics or stock assessment

The first step after collecting and processing sample data is to estimate the stock status,

$$v = f_{est}(u; \theta_{est})$$

where f_{est} is a stock assessment model or a method to compute a "model-free" indicator.

For an analytical stock assessment $u_{a,t-\psi} = \{c_{a,t-\psi}, d_{a,t-\psi}\}$, and variables like fishing mortality, spawning stock biomass, recruitment, will be estimated. In such case a stock-recruitment component may exist $n_{0,t-\psi} = g(b_t - \psi)$, where g is the stock recruitment relationship used within the MP and represents the perceived dynamics, which may differ from the OM.

In a "model-free" framework other indicators are estimated, *e.g.* the survey trend. In that case $u_{a,t-\psi} = \{d_{a,t-\psi}\}$ where f_{est} now is the methodology to compute the trend.

Error in v , if needed, can be included. Although there are a large number of procedures to add uncertainty to the model fit, the most common approach is to use estimation uncertainty and propagate it into stock status.

Note that the elements of θ_{est} depend on the HCR shape. For example, in the common ICES HCR these would be $f_{t-\psi}$, $b_{t-\psi}$, $c_{t-\psi}$ and/or $s_{a,t-\psi}$.

3.5.2 Parametrization of the Harvest Control Rule

This process sets the management references that will be used by the HCR to set exploitation levels in the future conditional on policy objectives,

$$\theta_{hcr} = f_{ph}(\theta_{est}|\xi)$$

Once more, the elements of θ_{hcr} depend on the HCR's shape.

When a stock assessment exists, this process is linked with the estimation of biological reference points (BRP). BRPs are afterwards translated, or transformed, into management reference points which set the objectives and limits of the HCR, for example $\theta_{hcr} = \{f_{trg}, t_{trg}\}$. The computation of these references may take place yearly or within a pre-specified period.

3.5.3 Harvest Control Rule (HCR)

The HCR is composed by a rule or set of (f_{hcr}), which based on the perceived status of the stock (v) and policy objectives (ξ), defines the exploitation levels for the future

$$\tilde{h}_{t+\delta} = f_{hcr}(v_{a,t-\psi}|\theta_{hcr})$$

The result of this decision together with possible complementary measures is afterwards translated by the implementation system into a management action.

3.5.4 Technical measures (TM)

Technical measures affect the exploitation by imposing a shift in the age structure of the catch

$$\tilde{s}_{a,t+\delta} = f_{tm}(\hat{s}_{a,t-\psi}|\xi)$$

Both gear selectivity changes through mesh size regulation, or population availability through the implementation of MPAs, 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.

3.5.5 Implementation system

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

If an input/effort management process is tested

$$\tilde{F}_{a,t+\psi} = f_{is}(\tilde{h}_{t+\psi}, \tilde{s}_{a,t+\psi})$$

While if an output/TAC management system is considered

$$\tilde{C}_{a,t+\psi} = f_{is}(\tilde{h}_{t+\psi}, \tilde{s}_{a,t+\psi})$$

Note that in both cases the enforcement of technical measures has to be taken into account considering intended shifts in selectivity.

3.6 Implementation error model (IEM)

The IEM is the interface/link/... between the MP and the OM, which transfers into the OM the decisions made during the management process. It allows testing deviances from the original decision, for example over-catching fishing opportunities.

$$\{C_{a,t+\psi}, F_{a,t+\psi}\} = f_{iem}(\tilde{C}_{a,t+\psi}, \tilde{F}_{a,t+\psi}; \theta_{iem})$$

In the case of an input system

$$F_{a,t+\psi} = \tilde{F}_{t+\psi} e^{\varepsilon_{a,t+\psi}}$$

while in the case of an output system

$$C_{a,t+\psi} = \tilde{C}_{t+\psi} e^{\varepsilon_{a,t+\psi}}$$

where $\varepsilon \sim LN(\mu_F, \sigma_F^2)$ or $\varepsilon \sim LN(\mu_C, \sigma_C^2)$, although other distributions can be used.

References

- Citores, L., Ibaibarriaga, L., Jardim, E., 2018. Uncertainty estimation and model selection in stock assessment models with non-parametric effects on fishing mortality. *ICES Journal of Marine Science* 75 (2), 585–595.
- Holst, N., 2013. A universal simulator for ecological models. *Ecological Informatics* 13, 70–76.
- Horwood, J., 1994. Modelling of fisheries management strategies. dublin, ireland. Tech. Rep. Privately published.
- ICES, 1994. Report of the working group on long-term management measures. 18–27 january 1994, miami, usa. Tech. Rep. ICES CM 1994/Assess:11.
- ICES, 1995. Report of the working group on long-term management measures. 4–12 april, lowestoft, uk. Tech. Rep. ICES CM 1995/Assess:15.
- Jardim, E., Eero, M., Silva, A., Ulrich, C., Pawlowski, L., Holmes, S. J., Ibaibarriaga, L., Oliveira, J. A. A. D., Riveiro, I., Alzorritz, N., Citores, L., Scott, F., Uriarte, A., Carrera, P., Duhamel, E., Mosqueira, I., 2018. Testing spatial heterogeneity with stock assessment models. *PLOS ONE* 13 (1).
- Jardim, E., Millar, C., Mosqueira, I., Scott, F., Osio, G., Ferretti, M., Alzorritz, N., Orio, A., 2015. What if stock assessment is as simple as a linear model? The a4a initiative. *ICES J Mar Sci* 72 (1), 232–236.
- Kell, L., Pastoors, M., Scott, R., Smith, M., Van Beek, F., O’Brien, C., Pilling, G., 2005a. Evaluation of multiple management objectives for northeast atlantic flatfish stocks: sustainability vs. stability of yield. *ICES Journal of Marine Science* 62 (6), 1104–1117.
- Kell, L., Pilling, G., Kirkwood, G., Pastoors, M., Mesnil, B., Korsbrekke, K., Abaunza, P., Aps, R., Biseau, A., Kunzlik, P., Needle, C., Roel, B., Ulrich, C., 2006. An evaluation of multi-annual management strategies for ices roundfish stocks. *ICES Journal of Marine Science* 63 (1), 12–24.

- Kell, L., Pilling, G., Kirkwood, G., Pastoors, M., Mesnil, B., Korsbrekke, K., Abaunza, P., Aps, R., Biseau, A., Kunzlik, P., Needle, C., Roel, B., Ulrich-Rescan, C., 2005b. An evaluation of the implicit management procedure used for some ices roundfish stocks. *ICES Journal of Marine Science* 62 (4), 750–759.
- Kell, L. T., Mosqueira, I., Grosjean, P., Fromentin, J.-M., Garcia, D., Hillary, R., Jardim, E., Mardle, S., Pastoors, M. A., Poos, J. J., Scott, F., Scott, R. D., 2007. Flr: an open-source framework for the evaluation and development of management strategies. *ICES J Mar Sci* 64 (4), 640–646.
- Millar, C. P., Jardim, E., Scott, F., Osio, G. C., Mosqueira, I., Alzorriz, N., 2015. Model averaging to streamline the stock assessment process. *ICES Journal of Marine Science: Journal du Conseil* 72 (1), 93–98.
- Scott, F., Jardim, E., Millar, C. P., Cerviño, S., 2016. An Applied Framework for Incorporating Multiple Sources of Uncertainty in Fisheries Stock Assessments. *PLOS ONE* 11 (5).
- Silvert, W., 1993. Object-oriented ecosystem modelling. *Ecological Modelling* 68 (1), 91–118.
- STECF, 2007a. Northern Hake Long-Term Management Plan Impact Assessment (SGBRE-07-05). No. EUR 23643 EN. Publications Office of the European Union, Luxembourg, 106 pp.
- STECF, 2007b. Report of the SGMOS-07-01 Working Group on the Evaluation of Policy Statement Harvest Rules. No. EUR 23656 EN. Publications Office of the European Union, Luxembourg, 67 pp.
- STECF, 2007c. Report of the SGMOS-07-07 Working Group on the Follow Up Meeting: Evaluation of Policy Statement Harvest Rules. No. EUR XXXXX EN. Publications Office of the European Union, Luxembourg, 56 pp.
- STECF, 2008. Report of the Working Group on Harvest Control Rules (SGRST 08-02). No. EUR 23641 EN. Publications Office of the European Union, Luxembourg, 87 pp.

STECF, 2016. Multiannual plan for demersal fisheries in the Western Mediterranean (STECF-16-21). No. EUR 27758 EN. Publications Office of the European Union, Luxembourg, 130 pp.

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
	U	dataset
H	set of decisions	
Functions	f	function
	g	stock-recruitment
Indices	$a = 0 \dots A$	age
	$t = 1 \dots T$	years
	$j = 1 \dots J$	iterations
	trg	target
	oem	observation error model
	est	estimator
	ph	parametrization of the harvest control rule
	hcr	harvest control rule
	tm	technical measure
	is	implementation system
Timeline	t_0	first year in the time series (OM)
	t_1	first year of data (OEM)
	t_d	last year of data (OEM)
	t_a	year when the assessment or indicator estimation is carried out (MP)
	t_m	year for which management options are being set (MP)
	t_f	final year of the time series (OM)
Other	μ	expected value
	σ^2, Σ	variance or covariance matrix
	θ	set of parameters
	ξ	policy objectives
	ψ	data gap
	δ	management lag
LN	lognormal probability density distribution	

Table 1: Variables, indices and functions notation used in this paper.