MareFrame

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Deliverable D4.2

Common reporting procedures for model output

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Executive Summary

This report is a deliverable of Work Package 4 (WP4 – Ecosystem models and assessment models) of the FP7 MareFrame research project. It proposes a common procedure for reporting the outputs from the different ecosystem models employed in the MareFrame project. European fisheries are managed according to the Marine Strategy Framework Directive (MSFD) which is designed to protect European marine ecosystem and aims at achieving Good Environmental Status (GES) by 2020. GES is defined by eleven descriptors listed in this report. The aim of the MareFrame project is to apply a minimum of two ecosystem models on various case studies across Europe in order to identify management strategies which will achieve GES. As a result there is a need within MareFrame for a common reporting procedure to (i) produce indicators relating to the descriptors of GES and (ii) produce indicators comparable between different ecosystem models. This report investigates the common indicators related to the GES descriptors that can be derived from all different models considered in MareFrame in order to assess management strategies in regard of these descriptors. The six different ecosystem models to be used in MareFrame, described in this report, vary greatly from length-based (FishSUMS, Gadget, Simple Size Based Model) to age-based (Simplified Summary Model) and foodweb models (Ecopath with Ecosim, Atlantis). However, all six models return biomass and landings for each commercial species, from which it is possible to derive a variety of ecosystem indicators. A list of fourteen ecosystem indicators is proposed here. These indicators can be employed to assess the performance of management strategies simulated with different ecosystem models. To facilitate the comparison between ecosystem models it is suggested that, for each model, the value reached at the end of the simulation for each indicator should be reported in a summary table. To compare the variation in indicators across time, their values should also be displayed on traffic light plots, as exemplified in this report. On top of the procedure for displaying results proposed here, this report also suggests a common structure to follow when writing ecosystem model reports.

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Introduction

Marine fisheries are a resource of capital importance for the European Union due to their significant contribution towards the Member State's economy. It is therefore essential to protect the European marine environment in order to maintain its health and ensure sustainable production from fish stocks in the future. The Marine Strategy Framework Directive (MSFD) adopted in 2008 has been designed to effectively protect marine ecosystem across Europe (2008/56/EC). The overarching goal of the MSFD is to achieve Good Environmental Status (GES) for European fisheries by 2020. GES implies that fisheries are healthy, productive, ecologically diverse, free of pollution, and do not have negative implications for any other ecosystem component. One way to achieve GES is to: (i) build appropriate management strategies designed to achieve these criteria and (ii) test them in situ on a multispecies scale using ecosystem models to ensure that biological, ecological, environmental, economic and social targets will be met for all species and ecosystem component involved. This practice is known as Ecosystem Approach to Fisheries Management (EAFM). The MFSD provides the legislative framework for applying this EAFM to European fisheries.

The MareFrame EU research project (http://www.mareframe-fp7.org/) aims at applying and testing EAFM on eight worldwide-spread case studies offering a variety of ecological configuration, fisheries-related issues, and data availability. Contrary to the traditional monitoring of ecosystem indicators based upon observations, the tremendous advantage of the MareFrame approach to dealing with EAFM lies in performing forward simulations of any pressure applied to the ecosystem in order to forecast what will be the associated impact on ecosystem indicators, and ultimately, the ecosystem status. As a result, the modelling tools developed in MareFrame will allow developing management strategies to tackle specific issues using EAFM. Within the MareFrame project, a minimum of two ecosystems models will be applied in each case study in order to assess the robustness of EAFM despite the type of model employed. Therefore, a common reporting procedure is needed to compare outputs from different ecosystem models in order to fairly compare the performance of the management strategies tested. The need for these common methodological standards for assessing progress towards GES was recently highlighted by a workshop of ICES experts (ICES, 2014).

The aim of this report is to develop such a common reporting procedure and provide a basis for reporting the results obtained from the various ecosystem models employed in MareFrame. The report focuses on GES descriptors. It investigates what common indicators can be derived from all different models considered in MareFrame, described in here, in order to assess management strategies in regard of these descriptors. It also provides a common format to report and compare indicators across models, and proposes a report template for writing results from each model.

Measuring Good Environmental Status

In order to assess whether GES is met or not, ecosystem models employed in MareFrame should ideally provide information on all following criteria:

- Descriptor 1**:** Biodiversity is maintained
- Descriptor 2**:** Non-indigenous species do not adversely alter the ecosystem

- Descriptor 3: The population of commercial fish species is healthy
- Descriptor 4: Elements of food webs ensure long-term abundance and reproduction
- Descriptor 5: Eutrophication is minimised
- Descriptor 6: The sea floor integrity ensures functioning of the ecosystem
- Descriptor 7: Permanent alteration of hydrographical conditions does not adversely affect the ecosystem
- Descriptor 8: Concentrations of contaminants give no effects
- Descriptor 9: Contaminants in seafood are below safe levels
- Descriptor 10: Marine litter does not cause harm
- Descriptor 11: Introduction of energy (including underwater noise) does not adversely affect the ecosystem

While it is virtually impossible to get all this information from a single marine ecosystem model, it is important to ensure that a maximum of indicators can be obtained or derived from models outputs.

Modelling approaches

When deciding which ecosystem model to employ to address a specific question, the type of ecosystem to be simulated must be considered. Marine ecosystems vary greatly in complexity and can cover small or large areas, include few or numerous species, contain one or several fish communities (demersal and pelagic), and can also be subject to complex oceanography requiring a spatial modelling component. However, deciding which model is the most appropriate often comes down to the availability of data for the ecosystem considered. Data-rich ecosystems support the use of complex models while data-poor ecosystem may only offer enough information for the parameterisation of simpler, less elaborated models. As a result, different ecosystems are often simulated with different models. Ecosystem model vary in type (food web model, size- or age-based model, individual-based model), are built differently, rely on different assumptions, and will consequently return different outputs and indicators. While this is not an issue when assessing the performance of a management system in a particular ecosystem, it can be problematic when comparing management strategies applied across several ecosystems, or when comparing outputs from different models. It is therefore important to investigate what are the common indicators that can be developed from the outputs from each ecosystem model. Comparing these common indicators will be critical in assessing management strategies simulated with different models and/or applied in different ecosystems.

Ecosystem models and their outputs

Six ecosystem models are to be employed in the MareFrame project:

- Ecopath with Ecosim
- Gadget
- Atlantis
- FishSUMS
- Simple size-based model
- Simplified summary model

Ecopath with Ecosim

Ecopath with Ecosim (EwE) is a food-web production model used to analyse aquatic ecosystems. It combines software for ecosystem trophic mass balance analysis (Ecopath) with a dynamic modelling capability (Ecosim) (Christensen *et al.*, 2005). The ecosystem as modelled is represented by functional groups which can be composed of species, groups of species with ecological similarities or ontogenetic fractions of a species. Ecopath uses two equations to parameterise models: one for the energy balance of each group and one to describe the production (Christensen *et al.*, 2005). EwE is well-established and has already been used to study the implementation of ecosystem-based fisheries management (Heymans *et al.*, 2011). EwE also includes an Ecospace component which allows for spatial modelling

Species modelled in EwE can be broken down in two or more functional groups of different body size when for instance, a predator species switches prey as it grows. However, it is not a length or age-based and the outputs regarding commercial species are expressed in total biomass only.

The outputs from the EwE model are:

- Biomass
- Mortality
- Prey consumption
- Catches
- Landings
- Discards
- Revenue

FishSUMS

FishSUMS (Speirs *et al.*, 2010) is a length-structured partial ecosystem model in which the species of interest are modelled with full length structure from egg to adult together with a highly simplified representation of the rest of the ecosystem (hence the name partial ecosystem model) in three components: zooplankton, benthos and other fish. FishSUMS is not a production model but a mortality model: food requirements for growth, maintenance and reproduction, together with length-based prey preferences, are used to calculate predation mortalities on the prey. FishSUMS does not have a spatial component and assumes that the ecosystem is homogenous across its area (expressed in km^2). Being a length-based model, FishSUMS produces not only biomass outputs but also length-specific outputs

The outputs from the FishSUMS model are:

- Biomass (both total stock biomass and spawning stock biomass)
- Catches/Landings (no over quota discards)
- Recruitment
- Mortality
- Numbers at length
- Numbers at age
- Length distribution
- Fluxes of biomass
- Large Fish Indicator (LFI)

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Gadget

Gadget is shorthand for the "Globally applicable Area Dis-aggregated General Ecosystem Toolbox", which is a statistical model of marine ecosystems (previously known as BORMICON (Stefánsson and Pálsson, 1997) and Fleksibest). Gadget is an age-length structured forward-simulation model, coupled with an extensive set of data comparison and optimisation routines. Processes are generally modelled as dependent on length, but age is tracked in the models, and data can be compared on either a length and/or age scale. The model is designed as a multi-area and multi-fleet model capable of including predation and mixed fisheries issues, but it can also be used on a single species basis. The structure of the model is described in Begley and Howell (2004), and aformal mathematical description is given in Frøysa et al. (2002).

The outputs from the Gadget model are:

- Total biomass (for all stocks/stock components)
- Biomass by age, length, area, time step and stock component
- Catches and landings (both total and by model dimensions)
- Predation (both total and by model dimensions)
- Recruitment (by length, area, time step and stock component)
- Mortality
- Numbers by any model dimension (i.e. by age, length, area, time step and stock component)
- Length distributions
- Stock (component) proportions
- Fitted values on the same dimensions as the observations

Atlantis

Atlantis (Fulton et al., 2004) is an ecosystem box-model intended for use in Management Strategy Evaluation. It has been applied to multiple marine systems (from single bays to millions of square kilometres) in Australia and the United States (Fulton et al., 2011; Kaplan et al. 2012). Atlantis is composed by a set of sub-models. It features a deterministic biophysical sub-model that is spatially-resolved in three dimensions using a map made up of polygons and vertical layers. It follows tracks the nutrient flow through the main biological groups found in the marine ecosystem of interest. The primary ecological processes considered in the model are consumption, production, waste production and cycling, migration, predation, recruitment, habitat dependency, and mortality. Lower trophic levels (invertebrates) are modelled as biomass pools (although cephalopods and prawns may have some age structure), while the vertebrates are represented using an age- and stock-structured formulation (which tracks the condition of average individuals). The physical environment is also represented explicitly - via a set of polygons matched to the major geographical and bioregional features of the simulated marine system. Physical forcing fields (currents, temperature and salinity) are included using results of an external hydrodynamic model. The exploitation sub-model allows for multiple fleets, each with its own characteristics (regarding gear selectivity, habitat association, targeting, effort allocation and management structures).

The outputs from the Atlantis model include:

- Spatial and temporal distribution of biomass of all functional groups, including age class abundance and weight of all vertebrate groups
- Mortality
- Prey consumption
- Pelagic to demersal biomass ratio
- Piscivore to planktivore biomass ratio
- Infauna to epifauna biomass ratio
- Catch of fish and by-catch groups
- Total landed catch
- Landings
- Profit per fishery

Simple Size Based Models

Of these the simplest is the Charmingly Simple Model (CSM) (Pope *et al.* 2006). These are length-structured partial ecosystem models in which species are modelled by a range of L_∞ groups. This allows most other variables to be assumed using the Beverton and Holt and the Charnov life history invariants. Consequently in the case of the CSM 12 species were modelled with only 15 parameters (hence the name the Charmingly Simple Model). In its original form the CSM was a long term equilibrium model. Recent developments under MareFrame have created an enhanced transient form of the CSM model (ECSM) which is a based upon the Proto-Moment approach of Pope (2003), and Hallfredsson and Pope (2007). Such approaches to size based model have a potential to greatly increase the scope of problem tackled by this approach but are as yet in an early stage of development.

Presently the outputs from the ECSM model (for a series of L_∞ Trait based pseudo-species):

- Steady State Biomass (both total stock biomass and spawning stock biomass)
- Catches and landings
- Predation Mortality
- Numbers at length
- Length distribution by pseudo-species and for the fish in ecosystem
- Size spectrum slope and intercept (or potentially LFI)

Further developments of the Proto-Moment approach might reasonably allow a far wider range of outputs.

Simplified Summary Models

Simplified Summary Models are models that fit to and emulate the results of more complicated models. The most obvious example is the Amoeba model of Collie *et al* (2003). This is a multispecies Schaeffer model fitted to the long term output of models age based multispecies models such as MSVPA/MSFOR. Fitting is done by using the age based model to estimate the Jacobian of change in yield of species (s) from fleet (f) with respect to change in the effort of fleet (g) at the long term yield situation at status quo fleet sizes. This together with the values of catch by species at status quo fleet sizes provides sufficient information to fit the Multispecies Schaefer Model. The virtues of this are that the resulting model of long-term yield is quick to run, seems to closely mirror results from the more complex model and because it is a simple quadratic model its biological reference points may be calculated directly using linear algebra. Many other outputs can be bolted on to this simple model as a mean of providing a simple tool for stakeholders to explore trade-offs for factors associated directly with the fishing effort of the different fleets.

The outputs from such a model could include

- Biomass (both total stock biomass and spawning stock biomass)
- Catches and landings
- Economic and social consequences of changes in effort
- Environmental effects directly associated with intensity of effort types (e.g. by catch of marine mammals in gill nets, bottom impact by beam trawls)

Limitations are the inability to predict the effect of mesh changes

Common reporting: comparable indicators from different models

As reported above, the ecosystem models used in the MareFrame project vary greatly in their type, outputs, and also the number of species involved depending on which ecosystem they are applied on. While it is not possible to provide indicators for all description needed for GES, the similarities between models can be used to calculate standard indicators which can be compared between models and ecosystems.

All the aforementioned models return biomass and landings for each commercial species. These two criteria can already be used to compare outputs from two models applied to the same ecosystem and assess the repeatability of results. Several biomass and landings based ecosystem indicators can also be derived from these two results:

- Trends in biomass: do all species in the ecosystem reach a stable and sustainable status (% of species stabilised at the end of simulation)
- Abundance trends of functionally important species/groups
- Trends in landings: is economic sustainability achieved
- Fishing revenues: using mean price/kg
- Fishing mortality (species specific)
- Catch to biomass ratio
- Number of overfished stocks (assessed stock only)
- Proportion in weight of large species
- Number of species with significant landings (Gascuel *et al.*, 2014): landings higher than a minimum level (to be set for all models/ecosystem to be compared)
- Shannon's diversity index (Shannon, 1948): biodiversity index based on the proportion of species in the landings
- Mean Maximum Length (MML) (ICES, 2009): based on maximum asymptotic length L_∞ from Fishbase (www.fishbase.org) and the weight (biomass) of species

- Mean Trophic Level (MTL) (Pauly *et al.*, 1998): based on the mean trophic level from Fishbase (www.fishbase.org) and the weight (biomass) of species
- Marine Trophic Index (MTI) (Pauly and Watson, 2005): MTL of predatory fish i.e. species with a trophic level of 3.25 or higher
- Pelagic to demersal ratio: indicator of nutrient input and quality of benthic habitat (de Leiva Moreno *et al.*, 2000)

Before comparing parameters between models it is essential to check that this is feasible for all indicators. Some models may allow for deriving an indicator which will not have exactly the same meaning than the same indicator from other models. For instance, a Shannon index derived from outputs from EwE will be comparable to the same index derived from other models if it is calculated using the proportion of species in the landings, and not the proportion of functional groups (i.e. group of species) in the landings. It is therefore crucial to investigate whether the indicators can be 'fairly' compared across ecosystem models before interpreting the results.

When comparing the common indicators across case studies, it is essential to consider the specificities of each case study before drawing conclusions. The targets for indicators usually differ between case studies (ICES, 2014). Therefore, the target level of each indicator needed to reach GES in each case study should be defined prior to analyzing the model results. The indicator values obtained in each case study should then be compared with the corresponding target values in order to assess whether GES has been reached or not.

In order to compare all these common indicators across ecosystems and case studies it is useful to report them in a summary table, such as the example shown in Table 1. Such table would include, for each model, one value per indicator. This value will most likely be the value reached at the end of the simulation period when all models should reach towards equilibrium. However, in order to compare the outputs from all models across time, it is useful to report the values of all common indicators as traffic plots. Traffic light plots are a useful way of identifying concomitant changes in different ecosystem indicators over time. Traffic light plots are created by color-coding the value of indicator each year:

- Dark red: indicator well below average (0-20%)
- Light red: below average (20-40%)
- Yellow: average (40-60%)
- Light green: above average (60-80%)
- Dark green: well above average (80-100%)

When plotting a traffic light plot, indicators are sorted by their loading factor on the first principal component so that indicators showing similar trends across time are grouped together. This results in a graphic which sums up a lot of information while being easy to read, such as in the example given in Figure 1 taken from Tomczak *et al.* (2013).

	Model type	Number of trophic levels	Goodness of parameterisation (rank 1 to 10)	% of species reaching stability at end of simulation	Economic sustainability (trend in landings)	Total fisheries revenue	Average catch/biomass ratio	Number of overfished stocks	% in weight of large species (LFI)	Number of species with significant landings	Shannon's diversity index	Mean maximum length of all species of fish	Mean trophic level	Mean trophic index	Pelagic/demersal ratio
EwE	Food web														
FishSUMS	Length-based														
Gadget	Length-based														
Simple Size Based Model	Length-based														
Simplified Summary Model	Age-based														
Atlantis	Food web														

Table 1: Example of a reporting table listing indicators common to all ecosystem models

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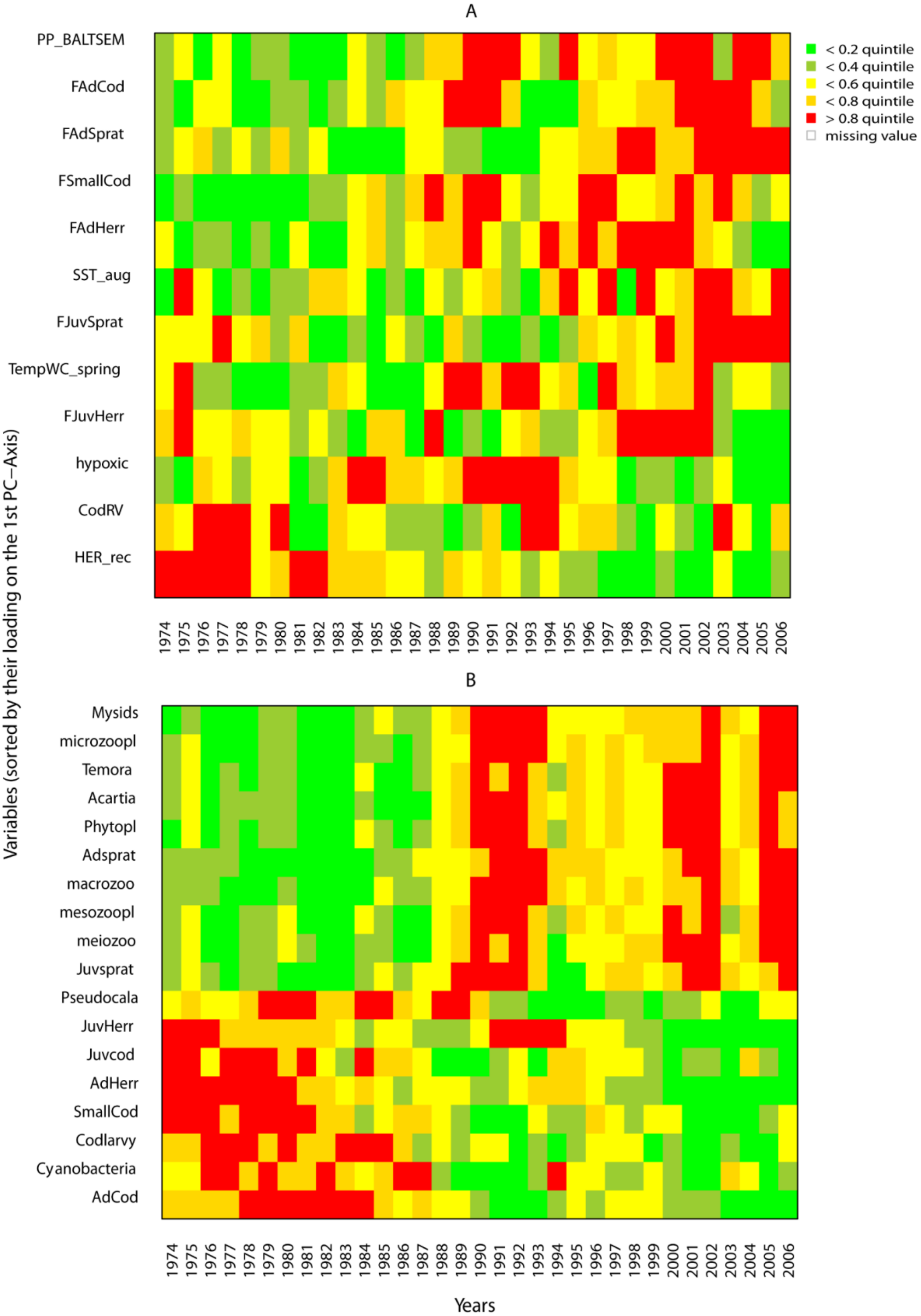

Figure 1: Example of a traffic light plot used to present numerous results in a reader-friendly format, taken from Tomczak *et al.* (2013)

Quantifying uncertainty

Many of the ecosystem models mentioned above are deterministic and do not provide confidence intervals for the estimations of outputs. However, it is possible to quantify uncertainty and assess the robustness of management strategies by performing Monte Carlo stochastic simulations. Monte Carlo simulations are performed by inducing variability on one or several parameters of the model, for instance by sampling a value randomly from a normal distribution, and performing multiple (usually a thousand) simulations. Confidence intervals can then be calculated for each output based on these multiple results.

Common reporting: a common structure to present results

Much of the information stated above focused on developing common indicators that could be obtained from the various ecosystem models employed in MareFrame. Such indicators would be an efficient and straightforward way of comparing the performance of a management strategy performance across case studies. However, in order to provide accurate information on the modelling tools employed and facilitate the comparison of results between models and case study, it would be desirable to use a common structure when reporting findings from each model in each case study. Following such common structure, the reports could for example include:

- Short introduction: brief description of the key elements of the case study (1 paragraph) and a brief description of the model employed (1 paragraph)
- A food-web diagram of the model employed to explain how the model functions and to the showcase the dynamics involved
- Comparative plots of model outputs and 'real' data: indicates how well a model replicates the real world
- Plots of residuals plots and goodness of fit: indicates how well the model fits the data
- Run time: provides information on the computation efficiency of the model
- Outputs specific to the model: graphic and tables with results by functional group, or length/age class, depending on the model considered
- Common reporting: indicators comparable across models given in (i) a table such as the Table 1 example, containing values achieved at the end of the simulation, and (ii) a traffic light plots displaying variations in those indicators over the simulated period

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