



(FP7-KBBE-2011-5)

MYFISH

Maximising yield of fisheries while balancing ecosystem, economic and social concerns

Grant agreement no: 289257

Start date of project: 1st of March 2012

Duration: 4 years



D1.3 - Final operational framework for the attainment of MSY while respecting constraints (Month 24).

Due date of deliverable: 30 March 2014

Actual submission date: 30 June 2014

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Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
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CO	Confidential, only for members of the consortium (including the Commission Services)	

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1. Summary

The **MYFISH** work on identifying and adapting the indicators and models required to produce constrained optimization of different yield measures is completed and the significant advancements described in this report. Under **MYFISH**, a common MSY framework was defined and applied to all regions. The framework ensures that the MSY approach is responsive to specific regional requirements in implementation.

MYFISH has made a specific effort not only to identify indicators and associated reference points, but also to get these indicators accepted and used in management through advice given by ICES. Focus areas included the definition of biomass reference points for exploited stocks (MSFD descriptor 3), Indicators and reference points for GES on biodiversity and sensitive species (MSFD descriptor 1), indicators and reference points of GES of food web indicators (MSFD descriptor 4), indicators and reference points of GES of the pelagic ecosystem (MSFD descriptors 1, 3 and 4) and socioeconomic indicators.

A wide range of different models were adapted and these developments and adaptations have been described in a list of scientific manuscripts, significantly lifting the discipline of fisheries, ecosystem and economic modeling by improving topic models focusing on only one aspect as well as the interface zone between topical models. The models together cover both single species and mixed fisheries, fisheries where both prey and predators are targeted by fisheries, small scale and large scale fisheries and fisheries where there are trade-offs between economic and social aspects such as rent and employment. A particular step forward has been in the application of F-arrays, which have been used to provide Maximum Sustainable Yield from models which can otherwise be used to optimize objective functions directly in forecasts.

Decision Support Tables have been produced, reported and initially discussed with stakeholders in all regions (see deliverable report 2.3) and will be used in further consultations of stakeholders in connection with WPs 2 and 3. The models are well suited to support the development of new multiannual management plans under the new CFP in task 2.4 and communication with DGMARE and ICES has been initiated to ensure that the resulting models and indicators are used as widely as possible.



2. Final operational framework for the attainment of MSY while respecting constraints (Task 1.3)

An initial evaluation of the different aspects of MSY, and how to achieve them was carried out at the Vigo workshop with all stakeholders (24-25 April 2012). This was reported as Deliverable D1.1. Global definitions of MSY variants and trade-offs, regionally relevant trade-offs, constraints and management measures in an European and global context and a draft operational framework were developed in the first year with studies of a range of different fisheries and were included in Deliverable D1.2.

Following these first scoping sessions, and setting of broad definitions, the MSY concepts developed above were further elaborated in the case studies through a series of regional workshops and meetings with stakeholders in WP2 and reported in Deliverable D2.1 into a series of regionally relevant and acceptable MSY variants, constraints and management measures in Deliverable D2.2.

Having completed this work, the next step was to bring both existing and new knowledge together in a single coherent framework to allow a consistent approach to the attainment of the MSY variants, while respecting local views and priorities. This work was carried out at the first synthesis and the subsequent Annual meeting held in Nantes, France 17-21 March 2014. Several workshops were held and the framework developed by the team working in WPs 1, 2 & 4. The core purpose of the framework was to provide a guide to good practice in the development of the regional proposals, both within and beyond **MYFISH**. The framework development is described in Deliverable 4.1.

The Framework

The proposed draft framework is comprised of four steps (fig. 1):

- 1) Problem framing (to determine objectives not currently met)
- 2) Options (to agree dimensions for decisions)
- 3) Implementation (to address the resulting trade-offs moving to new variants)
- 4) Evaluation (to check that outcomes meet wider objectives)

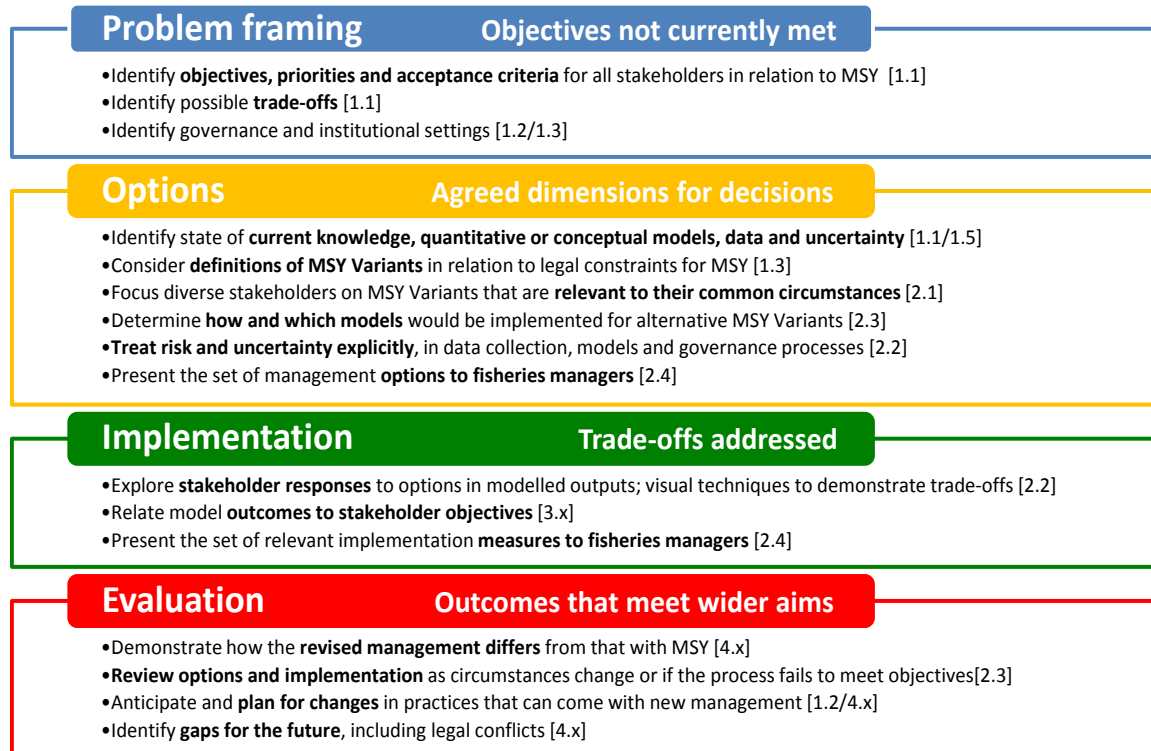


Figure 1. Draft Operational Framework. Linked to “Good Practice Guide” D4.1. Values in brackets denote the task number in **MYFISH** addressing the issue.

Based on this Operational Framework, the project team agreed to evaluate the work of each of the **MYFISH** case studies against these guidelines. This serves both to evaluate how broadly applicable the framework is across a range of different scenarios, but also allow evaluation of progress within the case studies in this context. This evaluation was only possible for the first two steps, as no implementation has yet been carried out (step 3). The following sections present the evaluation by case study against the various components of the framework.

Problem Framing

Identify objectives, priorities and acceptance criteria for a broad range of stakeholders in relation to MSY

Objectives and acceptance criteria were identified at the stakeholder workshop was held in Vigo and followed by further smaller scale consultations (see details in deliverable reports 1.1 and 1.2). Briefly, an extensive list of MSY variants, indicators for conservation, economic and social constraints were collected. Each option was evaluated in terms of availability (data etc.), descriptiveness (was it telling you something useful), and performance (how well was it likely to work), and this resulted in a prioritized list. Possible management measures were also assembled and evaluated in the same procedure. Trade-offs related to biological and technical interactions were intensively discussed as well as economic and social trade-offs arising from aiming at different MSY and MEY variants.

Identify possible trade-offs

Baltic Sea

Expected trade-offs were identified as the conflict between obtaining MSY of predator and prey, conflicts relating to retaining the income balance between countries.

Mediterranean

Expected trade-offs were identified as the conflict between employment and profit in the fishing fleets, between small and large scale fisheries and between rent in the fisheries and the preservation of sensitive species.

North Sea and Western waters

Trade-offs related to biological and technical interactions were intensively discussed as well as economic and social trade-offs arising from aiming at different MSY and MEY variants. Given that the Western Waters is a complex ecosystem including a large number of mixed fisheries, trade-offs are expected on numerous levels.



Widely Ranging Fish

Expected trade-offs in the widely ranging fish were mainly between catch amount and catch stability and between economic performance indicators.

Identify governance and institutional settings

The main broad governance and institutional settings were considered to be common across the case studies, although specific approaches to, for example, quota management will differ between member states. The current legal framework was not ready at the time of the Vigo workshop (the new CFP was still under development), but at further workshops and meetings it became obvious that the new basic regulation (1340/2013), and particularly the landings obligation, will become an important driver and has to be taken into account when exploring options. Plans for regionalization are also important in terms of the regional character of the **MYFISH** case studies. For GES regulation MSFD is the main legal framework. However, the implementation of GES by member states and regional organizations (e.g., OSPAR) and is still not finished. Other major drivers include the habitats and species directives, which will have relevance to constraints in terms of vulnerable habitats and PET species.

Although not governmental, MSC accreditation is a major driver for choices in the context of MSY, and MSC accreditation has been given or is being sought for many fisheries across European waters.

Options

Identify state of current knowledge, quantitative or conceptual models, data and uncertainty and determine how and which models would be implemented for alternative MSY Variants (Criteria 1 and 4 together)

Baltic Sea

To be able to address the MSY variants identified, a combined three-species, age-structured ecological-economic optimization model, including the predatory cod and the two forage fish



species herring and sprat was constructed. The model is an extension of a single-species age-structured fishery model. For the forage fish species (sprat and herring) the age-specific survival rates depend on the predator and prey's spawning stock biomass, capturing the effect of cod predation. Data and estimation of model parameters are mainly based on ICES stock assessment data (ecological data) and the STECF economic data. The objective for model optimization can be varied between pure profit maximization to include conservation and/or equity considerations. The desire for a more constant income stream over time (relative constancy) as reflected in several management plans for European fish stocks, is also reflected the model framework. Finally, fishing mortality matrixes, including variability derived from probability distributions, were used as input (external forcing) in a Baltic Ecopath food-web model to test the influence of fishing strategies on non-fish food-web components.

Potential indicators for each constraint were identified and explored where reference levels are available. Special attention was given to model-based indicators on commercially exploited fish stocks, (e.g. stock size, age-structure, fishing mortality), economic performance (e.g. total profits, fishery-specific changes in profits), as well as social indicators (i.e. equity). Environmental (physical environment), environment-dependent recruitment (for cod) and food-web related (biomass of key species such as the copepods *Pseudocalanus acuspes* and *Acartia* spp.) indicators including reference and target levels or decision making have been constructed.

Mediterranean

West Mediterranean

Bio-economic modelling of the bottom trawl fishery of the Balearic Islands was performed using the available software MEFISTO (Mediterranean Fisheries Simulation Tools, <http://www.mefisto.info>), specifically designed to address management issues under the Mediterranean regulation system (Leonart et al. 2003). In our case, the software was implemented on the R-framework and specifically adapted to reproduce the GFCM assessments of the four main target species of the demersal fisheries. The main results of this modelling showed that: 1) fishing effort reductions of 48-71% would improve the health of fish stocks while increasing the economic profits of the bottom trawl fishery to M€ 1.9 (146% higher than current profits); 2) if all fish stocks were exploited at their MSY (or below) level, the reduction in fishing effort would have to be of 71% from current values; and 3) if equilibrium profits from the fishery were to be maximized, fishing effort would need to be reduced by 48% (Merino et al. 2014). During the last 35 years, for instance, the number of vessels and number of fishermen



have decreased 50% and 60%, respectively. Obviously, the actual decrease in fishing effort has not been parallel to such values owing to the technological improvements (Quetglas et al. 2013); according to our estimates, the effective fishing effort reduction in the bottom trawl fleet during the last 20 years has been of 13.5%.

A similar modelling using MEFISTO will be performed for the small-scale fleet to assess the bio-economic state of this fishery and results will be incorporated in the framework for the attainment of MSY variants in the area. Although there already exists a MEFISTO application to the small-scale fishery (Merino et al. 2008), we will improve the model with new, updated data, new target species and the model adaptations done under **MYFISH** framework. Recreational fishing will be incorporated in our framework because it is a very important component of the fishing sector. According to estimates from the Directorate of Fisheries, about 9% of the habitants are recreational fishers and take a total of 900-1500 tons annually (25% of total landings).

East Mediterranean

Given the available data and the mixed type of the eastern Mediterranean demersal fisheries, models that were able to evaluate technical interactions among fisheries were considered as the most appropriate for the Mediterranean case study. The models considered included MEFISTO and FLR, and the FLR framework was preferred due to the lower sensitivity to limited economic data. The necessary modules of the FLR framework were parameterized based on the data available. Indicators of constraints and their reference levels were identified following the MSFD approach to GES. The selected indicators were related to the fishing activities and were focusing on the sustainability of the populations of target and non-target species. To this end indicators considered were the fishing mortality and stock size levels for various key species. Based on existing studies special attention has been given to constraints related with the state of over-exploited stocks. Additional economic and social indicators were identified in collaboration with stakeholders. Economic indicators of constraints included profit levels, while the social ones were referring to employment.

North Sea

Based on the list of preferred MSY variants, constraints and management measures a mapping exercise was undertaken to compile a list of models available for the North Sea case studies in **MYFISH**. For each of the models it was evaluated whether MSY variants, constraints and management measures top ranked at the Vigo workshop for the North Sea can be modelled.



The selected models included the stochastic multispecies assessment model SMS, the economic model FISHRENT and the ecosystem model Ecopath with Ecosim. Models were adapted to be able to deal with top ranked variants and constraints to the extent possible. Potential indicators for each constraint were identified and explored where reference levels were available. Especially for elasmobranchs and marine mammals work has been undertaken to come up with new effort and F constraints and food web indicators have been identified and used.

Western Waters

One of the challenges in *Irish Sea case study* is the estimation of MSY variants for data poor vulnerable stocks. A specific assessment model that estimates the exploitation level of the stocks based on a scientific survey and discard data has been developed in **MYFISH**. This model is further developed in order to obtain a proxy for MSY.

In the *Celtic sea* a Population-Dynamical Matching Model (PDMM) is used as a model of “reality”. The model can represent entire aquatic food webs, spanning several trophic levels. The model communities contained about 1500 species of primary producers and about 500 consumers, of which about 10 - 20 were targeted fish species. The fishing mortalities giving the theoretical maximum long-term yield summed over all species (MSY) were computed directly from the PDMM using a genetic optimization algorithm.

In the *Bay of Biscay* case study the ISIS-Fish spatially explicit model was used. The MSY reference points (F_{msy} or B_{msy}) were taken from the management plan in place for Sole and from ICES advice for Hake. At present, there are not defined reference points for *Nephrops* and B_{MSY} will be calculated using the current parameterized ISIS-Fish model changing the input global fishing effort. Using ISIS-Fish, it will be explored how the spatial distribution of fishing effort influences the computation of F_{MSY} and a design to reach MSY objectives provided.

In the *Iberian Sea* case study two different models are being used, an optimization algorithm developed by University of Vigo and a simulation model, FLBEIA. The optimization algorithm is used to calculate reference points using a simplified description of the reality and FLBEIA is used to assess the robustness of these reference points using a more detailed description of the system. The optimization algorithm has been used to calculate Multiple Stock Discounted Maximum Sustainable or Economic Yield (MSMSY or MSMEY), MSMSY or MSMEY constrained to generate 70% of current yield each year and a non-stationary pulse fishing strategy. In the case of MSMSY and MSMEY the model will be further developed to calculate the optimum paths to reach the targets in WP3.



Widely Ranging Fish

Different multi-species and single-species models were designed to evaluate the ranked MSY variants and constraints in the widely ranging regional study. A technical interpretation of the ranked MSY variants and constraints was prepared and each of these interpretations treated as 'scenarios' with indicators defined to test their performance. For each of the available models, the scenarios were screened to test whether they could be evaluated with the model and how important the scenario was with respect to the ranked variants and constraints. In addition to the ranked variants and constraints from the Vigo meeting, additional variants and constraints were proposed that had increased in importance after the Vigo meeting. The models included single-species management strategy evaluations, multi-species models and game-theory models. The game-theory models are aimed at evaluating fleet behaviour in relation to achieving MSY variants while the single/multi-species models were aimed at evaluating long-term trends in the biology of pelagic species.

In relation to the highly ranked Good Environmental Status MSY constraint, two workshops were organized to define what is important with respect to GES and the pelagic ecosystem. From these workshops, a framework to test the GES status of a pelagic ecosystem was developed. The framework contains higher level and lower level objectives, where the latter are associated with indicators that can be tested on the basis of existing data.

Consider definitions of MSY Variants in relation to legal constraints for MSY

Legal constraints were discussed at the Vigo workshop, and are treated as generally applicable across all case studies here. In particular, relative stability was considered as an important legal constraint as well as technical measures. Also policy decisions in other sectors can have an influence on the implementation of MSY (e.g. NATURA 2000 sites, closed areas for windparks, shipping/bridges). In general, it was agreed to offer the range of different interpretations of MSY that are compatible with the CFP, instead of suggesting new legal interpretations. Legal constraints were discussed at the Vigo workshop as well as on a local workshop with Greek stakeholders. GES, technical measures and the landing obligation under the new CFP were identified as the main constraints.



Focus diverse stakeholders on MSY Variants that are relevant to their common circumstances

The second part of the Vigo workshop focused on MSY variants, constraints and management measures specifically relevant for the different regions. Stakeholders and scientists together ranked the variants according to their importance in the region but also taking into account data availability as well as the level of uncertainty.

Baltic Sea

The Baltic Sea group in Vigo covered a broad range of interests and initial statements on most important management goals included from “collection of resource rents”, “stability and productivity”, “conservation of protected species”, long-term sustainability”, “stable fisheries” and the use of an “ecosystem approach to management”. The discussions were very lively and fruitful. In some cases, the meaning and definition of single phrases had to be discussed and agreed upon by the group. For a (surprisingly) high number of points a good agreement existed (e.g. the importance of stability).

The Baltic Sea group made extensive comments in their questionnaire, providing clear definitions of most of the MSY variants. There was a clear sense of stakeholders working together and discussing issues. Overall the comments were insightful and in places raised concerns over some definitions (particularly social indicators) and distinctions between them (particularly economic indicators). Group participants felt that the definitions, understanding and rating of indicators would and did vary between stakeholders and sectors. The availability of historical (not just recent) data was considered and uncertainty/data quality was highlighted as an issue; quality changes with time with historical data being more uncertain and yet it is still used to assess situations and make decisions. Ecological indicators (stability and resilience) generated a lot of discussion and that they were important in conjunction with other indicators but did not stand out on their own. Group participants felt that the top rated indicator, from any group, would depend on the nature of constraint and its certainty and so could be replaced by another. Finally, the workshop prioritized 5 MSY variants: two versions of “maximum economic yield”, two “maximize social yield” versions as well as one “maximize sustainability” variant (see workshop report for details).



An ICES-MYFISH stakeholder workshop on Baltic Sea and North Sea Multispecies Trade-offs was held in Copenhagen coming to the conclusions that science should delimit the space for sustainable exploitation providing close-to-MSY (WKMTRADE 2012).

Mediterranean

West Mediterranean

The outlining of the framework for the attainment of MSY variants in the Balearic Islands case was done in close collaboration with the two main stakeholders directly related with the fishing sector, the Fishing Association and the Directorate of Fisheries from the local government of the Balearic Islands. In the further work in the project, the participation of NGOs (e.g. OCEANA, WWF) and recreational fishers, which are very important in the area, will be in focus.

According to the different meetings with stakeholders, the viability of the fishing sector in the Balearic Islands will be governed by economic factors. Together with the increase in fuel price, fishermen have had to cope with a constant decrease of the fish/fuel price ratio during the last years. All of them agree that the main problem is the fuel price and thus there is a need of reducing substantially the fuel consumption to reduce the exploitation costs. These reductions could be achieved by different measures such as lower engine power and/or less time at sea (reducing working hours per day or days per week). All those measures will positively affect the state of the stocks if we assume that reducing fuel consumption implies reducing fishing effort and that stocks are currently overexploited. Together with reducing costs, there is a need of improvements in the commercialization of the fishery products by means of marketing strategies.

Although there is a general agreement that the framework for the attainment of MSY variants in our area should be based on MEY rather than on MSY variants, the socio-economic (MSOY) and ecosystem (MESY, MSUS) variants will also be investigated. Regarding the socio-economic variants, the procedure being developed in the framework of MYFISH will be applied.

Eastern Mediterranean

In addition to the Vigo workshop, a workshop with the main stakeholder in the eastern Mediterranean, the Pan-Hellenic Union of Middle-Range Ship Owners (PEPMA), was dedicated to discussing the various MSY variants, constraints and management measures particularly



important for the Aegean Sea case study. The MSY variants that were prioritized were those referring to the production and income from key-species that compose the main bulk of catches. Concerning management, input control schemes were considered as the most appropriate, and preference was given to effort controls and temporal fishery closures. Two types of constraints were identified as being more important: (a) biological constraints that included the state of key stocks, and (b) socio-economic constraints that were focusing on the sustainability of the jobs in the fisheries sector and in the maintenance of small fishing communities.

North Sea

The second part of the Vigo workshop focused on MSY variants, constraints and management measures specifically relevant for the North Sea. Stakeholders ranked the variants, constraints and management measures according to their importance in the area but also taking into account data and models available as well as the level of uncertainty in data and models. The highest ranked MSY variants were Maximise inclusive governance, Maximise yield in value of key commercial species, Maximise consumer welfare/happiness, Maximise yield in value, Maximise yield in tonnes of key commercial species, Maximise stability and Maximise Net Present Value. Due to modelling constraints, the project focused on the variants Maximise inclusive governance, Maximise yield in value of key commercial species, Maximise yield in tonnes of key commercial species and Maximise Net Present Value.

The ICES-MYFISH stakeholder workshop on North Sea and Baltic Sea Multispecies Trade-offs came to the conclusions that science should delimit the space for sustainable exploitation and (WKMTRADE 2012).

Western Waters

The workshop identified the five most relevant MSY variants in the western waters region as Maximise yield in value of key commercial species, Maximise yield in value, Maximise inclusive governance, Maximise willingness to invest in the future fisheries and Optimize number of fishing units. These were considered representatives by all case studies except the Irish Sea and Iberian Sea where further consultations were performed.



The main stakeholders in the *Irish Sea* skate and ray fishery are very few in number and the study to date has focussed on the two operators who work exclusively in this fishery. At the time of interview, this fishery was considered by ICES as Data Poor, and the stocks were either considered as category 3, where surveys could be used to indicate trends, or category 5, where no advice was possible. We have since been able to start developing proxies for the stock biomass based on survey data, and these are detailed in the Decision Support Tables presented in Deliverable D 2.3. The interviews therefore focused on the possible management approaches rather than specific MSY variants, as none were available at that time. The main feedback from the interviewees was that the favoured approach for management would be the use of closed areas. Several of these have been proposed by Irish fishermen to the NWWRAC, including areas in the Irish Sea, and in immediately adjacent areas of the Celtic Sea. NWWRAC could not agree to take these proposals forward, and currently, the legal basis remains uncertain. Respondents also favoured an effort rather than TAC based scheme for this fishery. This has been discussed further with a wider range of fishermen and control and enforcement officials. Willingness was expressed to explore the possibility of some form of effort control in the Irish Sea, and this will be followed up.

Nine different fishermen cooperatives and ship-owners associations (including industrial and artisanal fishing sector) were interviewed in Galicia and Asturias for use in the *Iberian Sea* case study. Six of these stakeholders refused to collaborate with the study and stopped the consultation process after the first interview. However, two more interviews were conducted with the association "Fundación Rendemento Económico Mínimo Sostible e Social" (in English: Foundation Minimum Economic Yield: Sustainable and Social). Its representatives and partners successfully defined the objectives and constraints to potential management measures for the fisheries. In addition, the work in the Iberian Sea Case Study was presented in a GEPETO project meeting, a project lead by the RAC. In this meeting we highlighted the continuity and integration of both projects GEPETO and **MYFISH**, FLBEIA conditioning in **MYFISH** is based on the data base generated in GEPETO project to feed FCUBE method, and this fact was very well accepted by the SWWRAC. Hence, the initial reticence to collaborate with the project has disappeared.

Widely Ranging Fish

The Widely ranging workshop identified the MSY variants Maximize catch in tonnes, inclusive Governance, stability, yield in tonnes and useful knowledge as the five highest ranked variants. It should be noted here that only the top two items are shared between the small and large pelagics and that further variants vary in appreciation between stakeholder areas. As the



exercise of scoring variants, constraints and management objectives wasn't completed at the Vigo workshop, afterwards stakeholders were contacted to complete the exercise leading to the score listed above.

A series of workshops were held to identify GES indicators in the context of MSY targets. The broad conclusions can be summarised as follows (Shephard et al 2014, Trenkel et al 2014). Pelagic fish are key elements in marine foodwebs and thus comprise an important part of overall ecosystem health. A suite of ecological indicators that track pelagic fish community state and evaluate state of specific objectives against Good Environmental Status (GES) criteria were developed based on stakeholder defined objectives for the pelagic ecosystem. Indicator time-series were calculated for the EU Marine Strategy Framework Directive "Celtic Seas" (CS) and "Greater North Sea" subregions. Precautionary reference points are proposed for each indicator and a simple decision process is then used to aggregate indicators into a GES assessment for each subregion. The pelagic fish communities of both subregions currently appear to be close to GES, but each remains vulnerable. In the CS subregion, fishing mortality is close to the precautionary reference point, although the unknown dynamics of sandeel, sprat, and sardine in the subregion may reduce the robustness of this evaluation. In the North Sea, sandeel stocks have been in poor state until very recently. Pelagic fish community biomass is slightly below the precautionary reference point in both subregions.

Treat risk and uncertainty explicitly, in data collection, models and governance processes

Baltic Sea

Risk and uncertainty is directly taken into account in all models of the Baltic Sea. Error bars for optimization results were obtained from a Monte-Carlo sensitivity analysis based on standard errors of estimated parameter values. Uncertainties were explicitly communicated to stakeholders.

Mediterranean

Western Mediterranean



MEFISTO explicitly simulates fish recruitment as a stochastic process, with variability based on fits of Stock Recruitment observations to three different models. In addition, the analyses highlights the uncertainty of the price formation process in Mediterranean fisheries.

Eastern Mediterranean

Risk and uncertainty was considered during the modelling approach. The modelling framework was been adapted to be able to incorporate variation and stochasticity in important biological processes, such as recruitment, through Monte-Carlo simulations.

North Sea

Risk and uncertainty is taken into account in the stochastic multi species model SMS directly. For the deterministic models Fishrent and Ecosim, B_{pa} was chosen as biomass reference point instead of B_{lim} . B_{pa} can be seen as proxy for a 95% probability to stay above B_{lim} . In addition, model outcomes are compared to each other to get an idea on structural uncertainties. Uncertainties will be explicitly communicated to stakeholders using a pedigree approach. This approach allows the documentation of uncertainties not only for model outcomes but also for input data used.

Western Waters

In the *Iberian Sea* case study, risk analysis will be carried out explicitly using FLBEIA. The robustness of the reference points calculated using the optimization algorithm and of the related management strategies will be assessed taking into account key sources of uncertainty in the system such as stock recruitment dynamics, fleet and stock specific catchabilities, fleet dynamics, advice implementation... The uncertainty on these processes will be modelled using Monte Carlo simulation, conditioned, as far as possible, using existing data. The performance of the management strategies will be quantified using indicators that take this uncertainty into account.

Estimates of Total Stock Biomass for data poor *Irish Sea* case are based on swept area conversions from survey CPUE. Uncertainty is captured here using repeated runs of the conversion model for each year (N repeats = total number of hauls per year - 1) with a randomly selected 10% of hauls deleted in each repeat. This produced a population of overall annual biomass estimates for each species, from which a mean and SD were calculated. For the harvest ratios (proportion of fish removed/ total population), discard data were mainly used, as the



main pressure on these stocks is as bycatch component. No explicit uncertainty was calculated here and a general value of 20% variability taken from estimates of uncertainty calculated for discard observers working with the French demersal fleet in the same area was used.

Widely Ranging Fish

Risk and uncertainty are an important part of both the single and multispecies Management Strategy Evaluation models used in **MYFISH**. These models take data uncertainty, model uncertainty and implementation uncertainty directly into account and associate results to risk of population overexploitation, such as B_{lim} and B_{pa} . The game-theory approach to a lesser extent includes uncertainty in data collection but evaluates the uncertainty related to human behaviour in detail.

Present the set of management options to fisheries managers

Baltic Sea

Work from the Baltic Sea case study was also discussed at a workshop from the Nordic council of ministers on a general outline of multi species advice. A full day workshop to discuss results with the Baltic Sea AC was held in June 2014.

Mediterranean

Western Mediterranean

Local fisheries managers (Directorate of Fisheries from the Government of the Balearic Islands) collaborate with the project and participate actively in the design of the different scenarios considered for our Western Mediterranean Case Study. Once the final scenario outlining the framework for the attainment of MSY variants in our area is agreed with all stakeholders, it will be presented to local fisheries managers.

Eastern Mediterranean

The work in the Aegean Sea case study was discussed with various local management authorities and the Fisheries Directorate of the Greek Ministry of Agricultural Development and Food.



North Sea

SMS results from **MYFISH** were presented at WKMTRADE (WKMTRADE 2012) and the main result was that according to stakeholder opinions ICES/**MYFISH** should delimit the space for sustainable exploitation within acceptable good environmental status. Afterwards the policy decisions and trade-offs can be carried out by managers and stakeholders informed by the ICES/**MYFISH** analysis of the consequences of these trade-offs. WKMTRADE came to the conclusion that GES related constraints are most important. Work from the North Sea case study was also discussed at a workshop from the Nordic council of ministers on a general outline of multi species advice and at a DGMARE scoping workshop on mixed-fisheries management for the North Sea in Brussels on 27.02.2014. A full day workshop to discuss results with the North Sea AC demersal Working Group was held in July 2014.

Western Waters

DSTs were constructed highlighting trade-offs in the *Iberian Sea* fisheries including constraints for hake, megrims, anglerfish and southern mackerel. North East Atlantic Mackerel, blue whiting and western horse mackerel are also included in the modelling framework as these species are important stocks for the fleets considered. As these stocks are widely distributed and the impact of the Iberian Sea fleets on these stocks is limited, at least for the moment, it is considered that the TAC and biomass of these stocks is maintained constant over time. The performance was compared of multi species reference points with the single stock reference points defined by ICES working groups in the framework of MSY. The results were presented at stock and fleet level using weak and strong sustainability indicators. A joint meeting was held with the SWWAC in June 2014.

In the *Irish Sea*, and adjacent areas in the Celtic Sea, the initial proposal for closed areas was presented through the NWWRAC, and included areas proposed by the **MYFISH** scientists and by industry. Although generally accepted, a closed area approach was not agreed by the RAC, and has not been forwarded to the EC. **MYFISH** has entered discussions with managers on the potential for an effort based approach possibly combined with closed areas.

Widely Ranging Fish

The results of the model evaluations of MSY scenarios related to MSY variants, constraints or management objectives, in the small pelagic case study, were presented at a workshop in The



Hague in January 2014. Managers and also stakeholders were asked to rank the scenarios evaluated according to their preference.

Implementation

Explore stakeholder responses to options with modelled outputs, using visual techniques such as DSTs to demonstrate trade-offs and relate model outcomes to stakeholder objectives

Baltic Sea

Considering trade-offs in multi-species fisheries in a transparent way requires analytical tools for assessing conflicts among fisheries such as our coupled ecological-economic model system. The models suggest that cod recovery strategies based on profit maximization may cause the risk of stock collapse for forage species with low market value, such as Baltic sprat. Economically efficient conservation efforts to protect sprat would be borne exclusively by the forage fishery, challenging resource use equity between fishing sectors. Optimizing equity instead of sprat biomass would reduce potential profits of the overall Baltic fishery, but may offer an acceptable balance between overall profits, species conservation and social equity. Approaches like ours, adding equity considerations to the traditional trade-off between economy and ecology, might enhance credibility and hence compliance to management decisions. With the models available DSTs were constructed highlighting trade-offs for 3-5 MSY options (economic optimization, including conservational and/or equity considerations at two levels). In collaboration with Imperial College innovative visualization techniques were explored, and added to number-based DSTs. Data have been collected at the joint BSAC-MYFISH workshop in June 2014 and await further analyses. The feedback from stakeholders will be taken into account and an iterative and adaptive approach will ensure that updated DSTs are useful for stakeholders and will aid in the construction of multiannual management plans.

Mediterranean

Western Mediterranean

From the beginning of the MYFISH project, two different stakeholders directly involved in the fishing industry have collaborated with us: 1) The Fishery Association of the Balearic Islands; and



2) The General Directorate of Fisheries of the Autonomous Government of the Balearic Islands. There have been constant contacts and meetings with representatives of both stakeholders to outline a framework for the attainment of MSY variants and the design of the DST. Finally, a workshop was organized with the participation of an important sample of fishermen and representatives of the fishing sector to discuss the main management scenarios and their corresponding constraints. Feedback from stakeholders will be taken into account and an iterative and adaptive approach will ensure that final DSTs are useful for stakeholders.

Eastern Mediterranean

Based on the model results, DSTs were constructed highlighting trade-offs for 4 management options. DSTs focused on economic MSY variants illustrating the economic implications of effort reductions necessary to bring the stock biomass of over-exploited species on sustainable levels. Further consultation with stakeholders is planned. DSTs and graphical model outputs will be presented and discussed with the main stakeholder (PEPMA). Feedback from stakeholders will be taken into account and an iterative and adaptive approach will ensure that final DSTs are useful for negotiating management scenarios.

North Sea

DSTs are available highlighting consequences of aiming for different MEY variants including constraints for cod, CO₂ and catch of elasmobranchs, for multi species F_{MSY} using different optimization approaches and harvest control rules and for the flatfish and brown shrimp fisheries case study the consequences of implementing different MSY/MEY variants utilizing the bioeconomic model Fishrent and the ecosystem model Ecopath/Ecosim. Reactions have been recorded from the joint NSAC-MYFISH workshop in July 2014 and are awaiting further analyses. Feedback from stakeholders will be taken into account and an iterative and adaptive approach will ensure that final DSTs are useful for stakeholders.

Western Waters

DSTs were constructed highlighting trade-offs in the *Iberian Sea* fisheries. DSTs are available highlighting consequences of aiming for different MSY variants including constraints for hake, megrims, anglerfish and southern mackerel. The results were presented at stock and fleet level



using weak and strong sustainability indicators and reactions have been recorded from the joint SWWAC-MYFISH workshop in June 2014 and are awaiting further analyses. Feedback from stakeholders will be taken into account and an iterative and adaptive approach will ensure that final DSTs are useful for stakeholders.

DSTs have been developed for several options for the *Irish Sea* fishery and these are planned to be explored in detail with stakeholders in the coming year. Initial discussions with stakeholders on model predictions have been conducted and a preliminary perception from respondents was that the models may be overestimating the stock. MYFISH will follow up on this in future meetings.

Widely Ranging Fish

The Widely ranging case was the first of all cases to have their joint meeting with the stakeholders. Hence, reactions were recorded and used to modify subsequent workshops in other regions.

The format of the DST's was difficult to follow for many of the stakeholders. Although some (industry especially) were used to formats such as the presented DST's they indicated that the lack of detail in the presentations made it difficult to value the scenarios presented. It required a thorough introduction to each of the models used to evaluate scenarios to get all stakeholders well enough informed to make a ranking of the scenarios presented.

There was a general interest to be informed on further progress and participate as stakeholders in upcoming exercises to work towards the design of long-term management plans.

The scoring of the preferences for each model and scenario by all workshop participants were stored and is available for further analyses. An analysis will be carried out to relate the ranking exercise at the DST workshop to stakeholder objectives. On this basis, model scenarios might be adjusted and verified with stakeholders in a later stage.

Present the set of relevant implementation measures to fisheries managers

The dialogue with managers has been initiated through a series of meetings involving MS manager representatives as well as DGMARE representatives during the first half of 2014. The dialogue is planned to continue throughout the rest of the project.

3. Determine indicators of constraints and their reference points (Task 1.4)

Under this task, each case study has identified appropriate indicators of their relevant constraints. In most cases, such indicators were readily available but in a few cases, further development of indicators and reference points were required. Economic and social indicators were typically difficult to derive reference points for and instead different scenarios were measured against the indicators directly rather than performing constrained optimisation directly. **MYFISH** made a dedicated effort to fill knowledge and indicator gaps in five areas: Definition of biomass reference points for exploited stocks (MSFD descriptor 3), Indicators and reference points for GES on biodiversity and sensitive species (MSFD descriptor 1), indicators and reference points of GES of food web indicators (MSFD descriptor 4), indicators and reference points of GES of the pelagic ecosystem (MSFD descriptors 1, 3 and 4) and socioeconomic indicators.

Definition of biomass reference points for exploited stocks

MYFISH has made a dedicated effort to ensure that precautionary biomass limits are available for the stocks modelled. In the *Baltic Sea*, **MYFISH** participants were key contributors to the setting of biomass reference points of cod, herring and sprat and these biomass limits were subsequently implemented as constraints. In the *Iberian Sea*, Three indicators have been defined for commercially exploited stocks the Stock Spawning Biomass (SSB) level, for some of them the age structured in the population and the fishing mortality as a proxy for stock abundance, length distribution and exploitation respectively. The initial guess for reference points for SSB and fishing mortality are those defined by the assessment working groups in the ICES F_{MSY} framework. In the case that SSB reference points, B_{LIM}^1 and $B_{trigger}^2$, are missing for any of the stocks the initial guess for B_{LIM} is B_{LOSS} (the lowest observed SSB) and for $B_{trigger}$ B_{PA}^3 =

¹ B_{LIM} corresponds with the limit reference point in the ICES precautionary approach framework. It is also used in the ICES MSY framework as a point below which there is high probability of stock collapse and additional more drastic measures must be taken.

² The breakpoint in the ICES MSY framework HCR. Above this points the TAC advice corresponds with the fishing mortality at F_{MSY} and below the corresponding F is decreased linearly.

³ B_{PA} is the precautionary approach SSB in the ICES precautionary approach framework.



1.4* B_{LIM} a common approach used in ICES in the framework of precautionary approach (Hauge et al., 2007). The length and age distribution of the *Southern Hake stock* is known through the assessment model. However, little or nothing is known about the ideal length distribution of the stock. Therefore, **MYFISH** analyse its value a posteriori and evaluate how it changes depending on the management measures used. The evaluation of the obtained age distributions is compared with the distribution in the virgin biomass using the Euclidean distance between the two.

Indicators and reference points for GES on biodiversity and sensitive species

Three groups of sensitive species were identified as lacking indicators: elasmobranchs (skates and rays), seabirds and cetaceans. Indicators for these were addressed for the regions Western waters and North Sea.

North Sea

The aim with defining indicators for North Sea elasmobranchs, seabirds and marine mammals was to allow these to be inserted as constraints in the fleet based models FISHRENT and Ecopath with Ecosim to ensure that populations will not be endangered due to fishing.

The approach for *marine mammals and seabirds* is based on the use of PBR to set limits to allowed removals, and on observations of the rate at which bycatch occurs in different fishing gears (Smout and Northridge 2014). These allowed removals were transformed to maximum weighted efforts across fleets.

Skates and rays are caught as bycatch in the mixed demersal round- and flatfish fishery in the North Sea (WGEF 2011). There are no defined reference points for these stocks and therefore assessment of the state of the stocks is based on a qualitative summary based on surveys and landings. Especially Common skate (*D. batis*) and Thornback ray (*R. clavata*) are threatened. Common skate that was formerly widely distributed over most of the North Sea is at present depleted and only found in the northern part of the North Sea. For Thornback ray the area of distribution and the abundance has decreased over the past century, and at present the stock is concentrated in the south-western North Sea. In the present context Maximum Economic Yield (MEY) for the demersal mixed fishery fleet in the North Sea has been estimated, with TAC constraints on North Sea cod, and without this constraint for comparison. This is further compared to the degree of overfishing of skates and rays in the scenarios where the fishery is

run with 2011 efforts, and the minimum and maximum scenarios outlined in connection with a DST (Northridge and Smout 2014).

Western waters

A population model for common dolphin has been constructed to estimate the maximum total mortality that would permit the *Iberian Sea* population to remain stable at or above current levels (i.e. achieve GES for this population as defined by Spain following the requirements set by the MSFD). The model uses the ages obtained from stranded animals and assumes a sex ratio of 1:1 and a maximum lifespan of 30 years. It uses a range of published pregnancy rates for the species. Using life table methodology, we fitted a 3-component mortality curve (after Siler, 1979) to the age distribution data. Separating the total mortality experienced by the population into by-catch and “natural mortality” allowed the exploration of population trajectories under different scenarios of natural mortality (i.e. in the absence of bycatch) and a combination of both natural and bycatch mortality. Using a bycatch mortality estimate derived from the stranded animals in the study area (Galicia, NW Spain), current bycatch levels are shown to be unsustainable. This model will allow the establishment of a maximum level of removal the population can withstand. It should be taken into account that use of stranded data is subject to several biases and that life table methodology assumes a stable age structure.

The available data for the abundance of cetaceans in the *Iberian Sea* is the number of individuals caught by trip for a range of years which does not allow modelling the abundance of the stock. Hence, only the number of individuals caught by metier was considered as a proxy for the level of exploitation of the population. In model scenarios, metiers that catch cetaceans incidentally will be allowed to catch only a certain level of individuals. Once this limit has been overpassed the metier will be closed and the effort of the fleet will need to be reallocated among the rest of the metiers, to assure that no more cetacean individuals are caught. As the biomass of cetacean populations and its dynamic is unknown, the definition of a reference point for the number of individuals that can be caught without jeopardizing the survival of the population is highly arbitrary. In this subcase study several ‘acceptable’ reference levels, which are within the historical observations, are tested and their impact in the economic performance of the fleet will be evaluated.



Estimates of Total Stock Biomass for data poor *Irish Sea* case were developed based on swept area conversions from survey CPUE. Uncertainty is captured here using repeated runs of the conversion model for each year (N repeats = total number of hauls per year - 1) with a randomly selected 10% of hauls deleted in each repeat. This produced a population of overall annual biomass estimates for each species, from which a mean and SD were calculated. For the harvest ratios (proportion of fish removed/ total population), discard data were mainly used, as the main pressure on these stocks is as bycatch component. No explicit uncertainty was calculated here and a general value of 20% variability taken from estimates of uncertainty calculated for discard observers working with the French demersal fleet in the same area was used.

Mediterranean

In the western Mediterranean, **MYFISH** is using detailed spatiotemporal information of vulnerable species (elasmobranchs) to evaluate their spatiotemporal trends and the potential influence of fishing impact (i.e. using the Vessel Monitoring System-VMS as fishing activity indicators). Further, spatiotemporal information derived from size-spectra of the bottom communities is extracted to identify the most sensitive areas to the fishing impact (i.e. VMS). By combining the information obtained from these two techniques with that of MSY and MEY, the relative importance and contribution of different MSY variants for the Balearic Islands system as well as the potential trade-offs can be assessed.

Indicators and reference points of GES of food web indicators

To ensure that it is practically possible to take account of ecosystem constraints in management, **MYFISH** has been the driving force in shaping a format for multispecies advice in ICES. The format is the result of a series of stakeholder consultations incorporating representatives from the industry, NGOs and management both at the MS and EU level (WKMTRADE 2012, WGSAM 2012, <http://www.ices.dk/publications/Documents/Miscellaneous%20pubs/A%20framework%20for%20multispecies%20assessment%20and%20management.pdf>). The format has since been implemented for both the Baltic Sea and the North Sea, resulting in the first integrated multispecies advice given by ICES for the two regions in spring 2013 (WGNSSK 2013, WGBFAS 2013).



MYFISH work on food web indicators has centred on the suggestion, screening, evaluation and implementation of indicators. Food web indicators were suggested in a joint workshop between the ICES working groups WGFE and WGSAM in 2012, resulting in a list of 26 indicators for MSFD descriptors 1, 3 and 4 which were evaluated using expert judgment in on a scoring system developed by WGECO (2013) at the 2013 meeting in WGSAM (WGSAM 2012 and 2013) and subsequently in WKFOOI and WGECO (WGECO 2013, 2014, WKFOOI 2014). Since then selected indicators from the WGSAM list have been implemented in scenario forecasts. An additional indicator, life expectancy, has also been developed to reflect changes in both fishery and natural mortality. Although the majority of the indicators achieve reasonable scores in total, only a few are considered to have both a strong signal to noise ratio and are responsive to management. However, in many cases, the scores on these two criteria was based on expert opinion alone and it is likely that some of the indicators may exhibit response to pressures or have a higher signal to noise ratio, given more thorough investigation. The work has since then focused on producing forecasts of the status of these indicators under different combinations of fishing pressure to demonstrate the pressure response and signal to noise ratio of the indicators. It is therefore recommended by WGSAM that the proposed indicators are further investigated. Especially the percentage of natural mortality in total mortality can be used to disentangle natural and anthropogenic impacts on fish stocks. However, it can be only applied to assessed stocks what is a major shortcoming. For the North Sea it became evident that natural mortality becomes the dominant source of mortality due to a successful reduction in fishing mortality.

In parallel to the identification of new indicators, work on the Large Fish Indicator (LFI) has continued in the project. An important outcome of this work is better understanding of the dynamics of this indicator in response to pressures, and the recovery of this indicator when pressures are released. The LFI quantifies a particularly vulnerable aspect of the structure of marine food webs and feeding interactions between fish contributed substantially to this vulnerability. Recovery of fish community size-structure took multiple decades in simulations suggesting that management interventions for size-structure recovery may require much longer than previously thought. These results demonstrated the need for community-level modelling to set realistic targets for management of community size-structure (Fung et al. 2013). An application to the Celtic Sea showed that LFI could require decades to recover and a very large reduction (20%) in fishing pressure (Shephard et al. 2013). The work on indicators will also be presented at ICES workshop to develop recommendations for potentially useful food web indicators in 2014 (WKFOOWI 2014).

Indicators and reference points of GES of the pelagic ecosystem

High level ecological, economic and social objectives for pelagic ecosystems were identified following a two-stage stakeholder consultation (Shephard et al 2014, Trenkel et al 2014). Based on reviewing the literature on pressures and impacts for European pelagic ecosystems, operational objectives and suitable indicators were suggested for a selection of these objectives acknowledging that the primary anthropogenic impact is fishing. Given the strong but species-specific links of pelagic species with the environment and the large geographic scale of their life cycles, pelagic indicators are needed at the level of species (or stocks), independent of area, while community indicators may be set for certain (sub-)areas. The chosen examples illustrate the link between organism biology or food web dynamics and particular operational objectives. A species-centred approach was a necessity for pelagic ecosystems, because of the relatively few species (except for plankton) and high spatio-temporal variability.

Further, **MYFISH** evaluated the state of specific objectives against Good Environmental Status (GES) criteria (Shephard et al 2014, table 1) for the EU Marine Strategy Framework Directive subregions “Celtic Seas” (CS) and “Greater North Sea”. Precautionary reference points were proposed for each indicator and a simple decision process was then used to aggregate indicators into a GES assessment for each subregion. The pelagic fish communities of both subregions currently appear to be close to GES, but each remains vulnerable. In the CS subregion, fishing mortality is close to the precautionary reference point, although the unknown dynamics of sandeel, sprat, and sardine in the subregion may reduce the robustness of this evaluation. In the North Sea, sandeel stocks have been in poor state until very recently. Pelagic fish community biomass is slightly below the precautionary reference point in both subregions.

Indicator	Descriptor	North Sea		Celtic Sea	
		Assessment	State	Assessment	State
1.1	D3	100% of stocks above B_{lim} , 80% above B_{pa}	Below GES	80% of stocks above both reference points	Below GES
1.2	D3	Average F/F_{MSY} is < 1	GES	Average F/F_{MSY} is < 1	GES
2.1	D4	Above threshold in 3 of last 5 years	Below GES	Above threshold in 5 of last 5 years	GES
2.2	D4	Below F threshold	GES	Below F threshold	GES
2.3	D4	No strong deviation from trend	GES	No strong deviation from trend	GES
3.1	D1	All stocks above reference points	GES	All stocks above reference points	GES
3.2	D1	All stocks above reference points	GES	All stocks above reference points	GES
4.1	D1	Negative trend, recovery above reference	GES	Negative trend with some recent recovery	Below GES
5.1	D1	Several data-poor stocks	Below GES	Several data-poor stocks	Below GES
5.2	D1	Proportion of pelagic biomass included: 98%	GES	NA	NA

Table 1. Pelagic fish community results for the North Sea and Celtic Sea MSFD subregions. From Shephard et al. 2014.



Socioeconomic indicators

Appropriate indicators of income distribution had not previously been derived on a fleet level, and hence **MYFISH** has introduced a new indicator, the Gini index of income equality across fleets in the *Baltic Sea*. The indicator was used to describe the outcome of different MSY scenarios (Voss et al. 2014a). Economic indicators of constraints in the *eastern Mediterranean* included profit levels, while the social indicators related to employment. In the *Iberian Sea*, Minimum TAC levels were associated with the employment level in order to have a HCR constrained by the maintenance of employment and the presence of positive profits year by year was used. Constraining the management to maintain the employment level will be in detriment of the net profit and/or salaries. These kind of trade-offs will be analysed a posteriori and separately for both fleets. Stability was included in several cases through constraints on annual TAC variability. Although not originally planned, special attention will be paid to the problem with discards derived from the landing obligation. Several cases investigate indicators of the maintenance of the current number of vessels, which is directly related with the number of employees and also to maintain the employment of fishery-dependent economic activities (processors, distributors, wholesalers and hauliers). The establishment of minimum thresholds for TACs was attempted to guarantee the continued economic viability of vessels.

4. Identify and adapt the models necessary to evaluate the effect of interactions on the achievement of MSY variants (Task 1.5) and adapt models to deliver constrained optimisations of yield and assessments of the risk of passing reference levels for constraints (Task 1.6)

Tasks 1.5 and 1.6 focus on adapting the models of the two types of interactions which are of importance to MSY: biological interactions, where fish exert an effect on prey or competitors and *vice versa*, and technical interactions, where several species are caught together during the fishing process. The models are adapted to predict the impact of MSY-based fishing on ecosystem indicators, employment, fish protein production, and other aspects of social 'yield'. Together, the tasks produced the tool necessary to produce the Decision Support Tables delivered in Deliverable 2.3. The models used include a suite of ecosystem and economic models, each of which was chosen as the most appropriate for a given case and subsequently applied in at least one case study.



Single species models

Single species models were primarily used for the stocks in the Widely Ranging regional case as the target species here are generally caught with a low bycatch of other species. Models adapted include single species SMS, production models and MSE models.

Small pelagics such as sprat and sandeel were modelled using the *stochastic single species SMS* which was adapted to evaluate MSY variants related to maximising catches while being constrained by precautionary principles (low risk of overexploitation) or catch guarantees (van Deurs et al 2014). In general, aiming for a management strategy with a slightly lower sustainable use will result in greater stability of catches and fewer years with fishery closures. The model was used to change the current unprecautionary management rule to a precautionary MSY rule.

For tuna, the *production model* of Mueter and Megrey (2006) was adapted and combined with a simulation model to forecast catches for the next 50 years from 2010. The management framework of tropical tunas include periodical assessments of the state of exploitation of the three stocks (bigeye, yellowfin and skipjack) and quota proposals towards achieving single species MSY under the Indian Ocean Tuna Commission (IOTC). The management measures are based on recommended MSY levels as well as other technical measures to limit fishing capacity and decrease negative impacts on non-target species. In the numerical model, the impact of alternative levels of target Biomass Reference Points (BRP) is assessed for each of the three stocks composing the Indian Ocean tropical tuna fisheries. The biomass relative to MSY will be considered as a limit reference point. The constraint to the numerical model is for quotas never to exceed or fall below 70-120% of the estimated MSY. The numerical framework is composed by an Operating Model that will be driven by a surplus production function and by the impact of SOI. In contrast, the Management Procedure model will be composed by the same surplus production model without any environmental driver but with alternative target Biomass Reference Points for management. The aim of this investigation is finding robust target BRP to ensure that biomass is below MSY levels with high probability. The model includes a Management Procedure model and an Operational Model. According to the management procedure model (Eq.1), quotas are imposed in a periodical basis so that biomass will achieve a target reference point with a deterministic model.

$$\text{Quota}_t = \text{Assessed biomass}_t - \text{BRP} + \text{ASP}_t \sim f(\text{Assessed Biomass}) \quad (\text{Eq.1})$$



where ASP= Annual Surplus Production and BRP is the biological reference point. The probability of maintaining stocks above MSY level is estimated through the Operating Model (Eq.2):

$$\text{Biomass}_{t+1} = \text{Assess biomass}_t - \text{Quota}_t + \text{ASP}_t \sim f(\text{GAM} \{ \text{Assessed Biomass, SOI} \}) \quad (\text{Eq. 2})$$

The framework will be used to include the impact of the most influential environmental driver on tropical tuna fisheries in the Indian Ocean (Southern Oscillation Index, task 2.3) on fisheries dynamics and management. A variant of this scenario is the management according the multispecies MSY. The influence of the SOI in the productivity of these species is investigated through GAM models.

The modelling of Norwegian spring spawning and North Sea herring included adjusting an existing *single species age based simulation model* to explore novel harvest strategies for this stock such as a harvest control rule allowing higher harvest rates when a strong year class is entering the fishery. Such a strategy should stabilize the population fluctuations and, consequently, increase stability in catches. Evaluation of the different harvest control rule options was performed using a stochastic simulation model. The model simulates the biological stock, i.e., the true stock, and the observed stock, i.e., the perceived stock. The model was run for 98 years, whereof short term (first 5 years), medium term (first 10 years and years 6 to 15), long term (first 50 years) and stationary equilibrium (last 50 years) averages over 1000 replicate runs were calculated. The results from all except the last 50 years are influenced by the initial conditions.

Seven Harvest Control Rule (HCR) options were examined for Norwegian spring spawning herring. The different harvest control rule options in general yielded rather similar results. None of the tested strategies was precautionary within the time scales affected by the initial, current conditions of the stock. However, in four management options, the risk of SSB falling below B_{LIM} is > 5% only in one year (2017): current management plan, F depending on recent recruitment, current management plan modified with zero-F at zero-SSB and F depends on recent recruitment with zero-F at zero-SSB. However, because the risk is estimated as the maximum probability that SSB falls below B_{LIM} within a time period, the HCRs are not precautionary on short (first five years), medium (first 10 years), nor long term (first 50 years). Five of the strategies are precautionary on the medium term excluding the first years (years 6 to 15). In the stationary equilibrium situation where the current conditions no longer influence stock dynamics (the last 50 years of the 98 year simulation period), all strategies are precautionary. This might be due to the fact that even though several noise components are included in the

model, it is possible that strong enough stochasticity fully echoing that observed in nature and real fisheries systems has not been achieved. The stationary equilibrium scenario should thus be interpreted cautiously. Because none of the HCRs evaluated are precautionary within the next 5 years, the effects of using lower target F than in the current management plan in the next 5 years was also considered. In this analysis the same F was used for the whole five-year period regardless of the stock size (not in accordance with the current management plan). To be precautionary in the short term, the target F for the first five years should be 0.086 (Table 2).

Table 2. Average catch, F , SSB, TAC IAV (%), maximum probability that the true SSB is below B_{LIM} over the set of years (B_{LIM} max prob), probability of the true SSB falling below B_{LIM} at least once during the set of years (B_{LIM} once prob), and probability of the perceived SSB falling below $B_{trigger}$ with altering $B_{trigger}$ for current management plan (HCR 1). The averages over the first five years, first ten years, years 6–15, first 50 years, and the last 50 years of the 98 years simulation period are shown.

$B_{trigger}$	Catch	F	SSB	TAC IAV %	B_{lim} max prob	B_{lim} once prob	Prob $B_{trigger}$
First 5 years							
4000	444	0.108	3800	28	9.2	12.1	83
5000	412	0.098	3847	30	6.1	8.0	97
6000	384	0.090	3901	30	4.1	5.6	100
First 10 years							
4000	447	0.107	4164	26	9.2	14.0	83
5000	422	0.098	4260	27	6.1	9.4	97
6000	400	0.090	4348	26	4.1	6.5	100
Years 6-15							
4000	526	0.111	4974	21	3.2	5.5	81
5000	514	0.104	5141	22	2.2	3.6	95
6000	501	0.097	5291	21	1.7	2.4	98
First 50 years							
4000	692	0.120	6062	17	9.2	15.0	83
5000	688	0.115	6197	18	6.1	9.6	97
6000	682	0.110	6350	19	4.1	6.7	100
Last 50 years							
4000	821	0.125	7070	14	0.2	0.7	9
5000	820	0.122	7157	15	0.1	0.3	22
6000	817	0.119	7290	16	0.1	0.1	38



SMS

The *stochastic multispecies model SMS* has been adapted to investigate the sensitivity of the estimated multispecies F_{MSY} to the applied stock recruitment relation and assumed noise distributions for the North Sea and Baltic Sea case studies (Vinther and Rindorf 2014). Correlations between species in recruitment success were quantified and the estimated correlation implemented in the SMS forecast. In addition to these changes, a separate SMS forecast module was developed to predict in a deterministic or stochastic multispecies framework the distribution of yields at different combinations of fishing mortality while accounting for predation effects between species. A visualization tool has been developed to present the main output from the high number of F combinations in a way that can be understood by stakeholders in order for trade-offs to be discussed by managers and stakeholders. The method should be seen as a qualitative approach for decision support rather than a quantitative one. In addition, a stringent quantitative method has been developed to automate the process of excluding the less likely F_{MSY} candidates from the total set of F . This method mimics the process of confining the number of F combinations as done by decision makers on the basis of the overview plots developed. Based on this approach point estimates or ranges of F_{MSY} can easily be estimated given clearly stated objectives. The tool has been refined after consultations with two different groups of stakeholders, one dominated by stakeholders and the other dominated by managers, in a series of workshops. Both groups found the format useful as a starting point for discussing trade-offs. This is the first time a stochastic multispecies model with internal estimation of parameters from data has been used to produce information on the necessary trade-offs caused by species interactions. It is hence also the first time this type of information has been presented to larger groups of both stakeholders and managers with a subsequent discussion of the effect of these trade-offs on management in a European context. ICES WKMSYREF2, primo 2014, made guidelines for estimation of MSY single species reference points. Their approach differs from the approach previously implemented in SMS. Therefore, the SMS model was subsequently modified to accommodate the suggested ICES approach. Further work with the development of guidelines is planned for the autumn of 2014 (WKMSYREF3).

Ecopath with Ecosim

An Ecopath with Ecosim (EwE) model was parameterized for the southern part of the North Sea (Staebler et al. 2014). The model is based on the Mackinson and Daskalov North Sea EwE model (Mackinson and Daskalov 2007) but is re-parameterised to model ICES areas IVb&c to separate the shallow southern North Sea ecosystem with its specific fisheries from the northern part of

the North Sea inhabiting a different species assemblage and fisheries. The focus in the model is on flatfish and brown shrimp, but the model represents all parts of the ecosystem including cod, whiting, rays and sharks, marine mammals and seabirds. The fishery is represented by the main fleets fishing in the southern and central part of the North Sea (demersal trawls and seines, beam trawls, shrimpers, gill nets etc...). Therefore, the model parameterized for **MYFISH** allows for the evaluation of mixed-fisheries problems specifically relevant for the flatfish and brown shrimp fisheries. The model enables a closer look at the food web in the shallow part of the North Sea and to evaluate the influence of multi species interactions on the MSY/MEY of flatfish and brown shrimp (figure 2). The model will be used in WP2 to test effort levels that give the maximum yield/profit according to different MSY/MEY variants as estimated in the bioeconomic model FISHRENT. It will be tested whether the effort levels lead to problems with reference points for by-catch and PET species to reach GES. Ecosim itself will be used to give information on maximum yields from the whole ecosystem under different levels of primary production influenced by assumed levels of eutrophication.

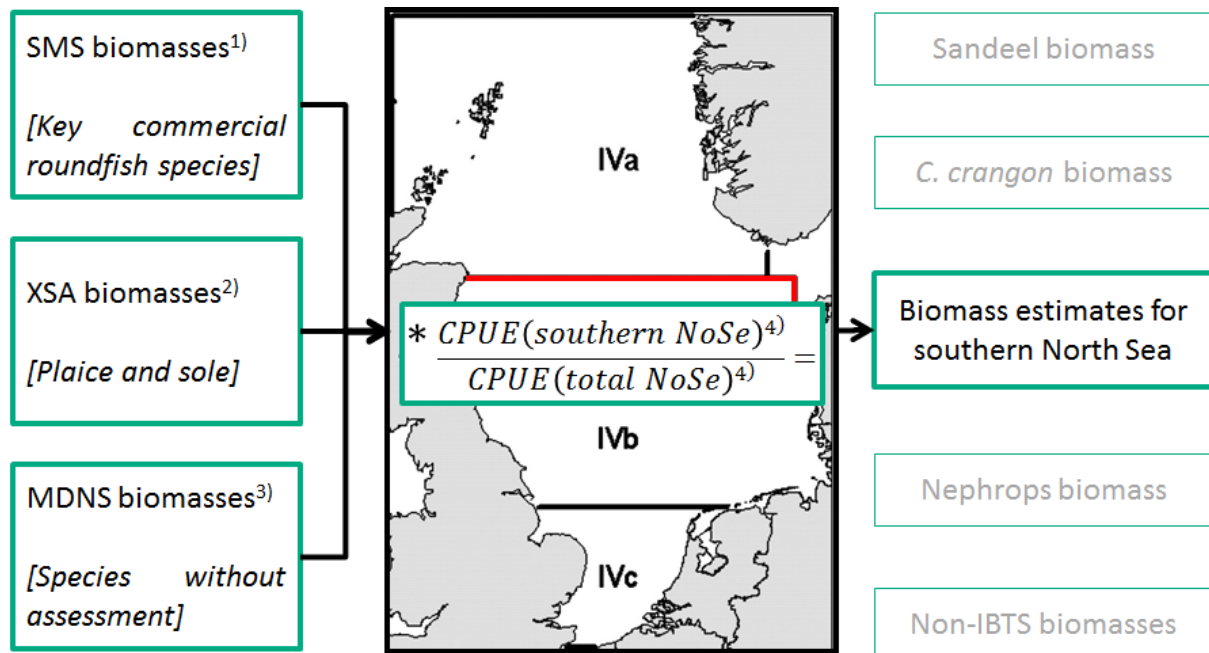


Figure 2: Schematic representation of the way biomass densities for the EcoPath Basic Input were calculated. 1) & 2) (WGNSSK 2012); 3) (Mackinson and Daskalov 2007); 4) Datras.ices.dk, download date 23 July 2012.



Fitting an Ecopath with Ecosim (EwE) model of the Celtic Sea to time series data in preparation for use in evaluating the ecosystem impacts of management strategies designed to achieve MSY was also attempted. Fitting the model proved to be a complex task due to issues with initial model parameterisation and poor contrast in the time series data. The work has progressed slower than hoped due to challenges in the time taken to systematically explore many different parameterisations. The time series is currently updated to include 2005-2012 data and results may be included later in **MYFISH** if they become available in time. Such difficulties of fitting complex food-web models to data are not specific to the Ecopath with Ecosim or the Celtic Sea, though they may be exuberated by the complexity of this ecosystem combined with data limitations.

Fleet based models without economic considerations

In cooperation with the FP7 project SOCIOEC, the *FCUBE* model of the mixed demersal fisheries in the North Sea has been adapted to investigate the potential effect on short and long term yield of operating with F target ranges rather than points. This work has become extremely relevant as the new CFP revealed the need to implement a landing obligation. The adaption of *FCUBE* is based on the same principle as is used in the adaption of *SMS* (effects of an F array for each species). This work will be extended under tasks 2.4, 3.3 and 3.4.

Technical interactions for the main demersal species in the trawl fishery operating in the *Iberian Sea* were modelled using *Generalised Additive Mixed Models (GAMMs)* with a modelled fishing effort distribution driven by the main objective to maximise profits. This mixed fishery is characterized by a wide array of exploited species. Between 2002 and 2011, 22% of the landings were composed of demersal fish such as European hake (*Merluccius merluccius*), the white and black-bellied anglerfish (*Lophius piscatorius* and *L. budegassa*), megrim (*Lepidorhombus* spp) and other demersal species. The aim of this study was to investigate the relationship between effort and fishing mortality for hake and white anglerfish in fishing operations target to demersal species. Two métiers were identified within the fleet, one métier target to pelagic species and other métier target to demersal species. A selection process to identify the trips targeting demersal species were carried out based on the catch composition of the trips. The individual vessel is considered as a random effect modelling the variation in landings, conditional on effort (hour trawling) and the space (ICES rectangle) and time variables (seasonality: month and time series: month_year). The model fitted indicated that the vessel effect explained the largest amount of difference in hake catches, followed by time, area, hours



trawled and seasonality. The fishing efficiency varied among individual vessels indicating their ability to catch fish which will depend on the technical characteristics of the vessel, fishermen knowledge and its crew expertise. The temporal variability of species abundance was assessed by the smoother effect of time, showing a progressive increase from the beginning of the series to 2010. The effect of national regulation limiting the hake catches by vessel was observed in the second semester of 2010. A slight seasonal effect was detected with higher catches of hake in April and May. In the case of white anglerfish, the vessel effect is the main driver of the anglerfish catches. The area had also a high effect finding an increase of catches to eastern area. A nearly linear relationship was found between anglerfish catches and hours trawling. Factors having a significant effect in the relationship between effort and landings (fishing mortality) could be taking into account in the elaboration of management rules that use nominal effort to reduce fishing mortality in mixed fisheries

Game theory Model

A game theory model of pelagic fishing of widely dispersed stocks was developed focusing on the North East Atlantic Blue Whiting stock within the Widely Ranging Fish Case Study. The model was constructed to address the following questions:

- How is fishing activity and wealth re-distributed between fleets when individually tradable quotas (ITQs) are introduced?
- How does this affect the trade-off between risk and profit for fishers in terms of the profitability of the fleet?

The model simulates the effect of individual decision making in a shared stock, focusing on overall level of investment, choice of age class, and sale and purchase of quotas between fleets based on the underlying Schaefer production model. The recruitment of blue whiting is subject to regime shifts, so these were modelled as shifts in reproductive rate which last for a number of years. Investment was incorporated by assuming there is a cost efficient level of fishing effort for a given level of investment, and a positive correlation between investment and fishing effort. However, as the effect of depletion increases, the catch per unit marginal effort diminishes, giving an optimum level of investment for the fleet in the short-term (Figure 3). A game was developed where fishers could choose to:

1. Fish – keep fishing at the same level as last year.
2. Invest – spend money in increasing rate of fishing effort.
3. Trade or sell quota.

4. Buy quota.

Five long term strategies with different combinations of above choices were defined and compared under conditions of cheap and expensive quotas. The results show a tendency for a high (possibly excessive) level of investment, and a choice of older age classes where these can be selectively targeted, with ITQs having more effect on the distribution of stock between fleet than the overall level of exploitation.

Genetic algorithms were then used to select optimal strategies over time resulting in different evolutionary stable strategies (ESS). The ESS was dependent on the underlying assumptions, for example a strategy dominated by choosing adult fish, buying quotas and moderate investment was favoured where ITQs were valuable, and a strategy dominated by investment and exploitation of juveniles was favoured where juveniles were valuable and ITQs were not.

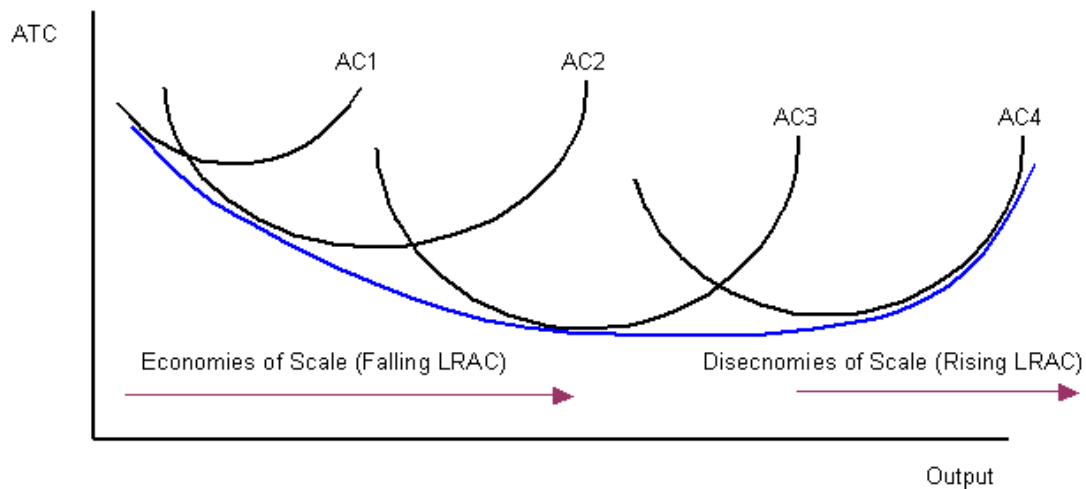


Figure 3: Relating the catch curve to the economic model of investment, with AC1 to AC4 representing different individual investment strategies and the blue line showing the overall investment strategy for the fleet given the individual investment strategies. ATC is the average total cost and LRAC is the long range average cost.

Ecological–economic modelling

A combined three-species, age-structured ecological-economic model, including the predatory *G. morhua* (cod) and the two forage fish species *C. harengus* (herring) and *S. sprattus* (sprat) was constructed for the Baltic Sea. The model is an extension of a single-species age-structured fishery model by Tahvonen et al. (2013) and full details are given in Voss et al. (2014a, b). The age-structured multi-species population dynamics are derived from the most recent assessments. Residual (M1) and predation (M2) mortality estimates for the different age-classes of herring and sprat are based on regression analysis, using the output of a stochastic multi-species model (SMS) on mortality for different stock sizes of cod (WGSAM 2012). Predation mortality is almost linearly dependent on the cod stock biomass for a wide range of stock states. This shortcut in calculation of M2 values was used to reduce model complexity and implies a dependency of predation mortality on both, predator and prey abundance. Data and estimation of model parameters are mainly based on ICES stock assessment data (ecological data) and STECF economic data.

The fisheries management challenge of trading-off the recovery of collapsed cod stocks versus the health of ecologically important forage fish populations was the focus of the model. Using the model framework profit maximizing management solutions were derived for the entire multi-species fishery. Subsequently, two different management approaches for protecting sprat stock for its ecological value, one based on profit maximization only, and an alternative considering equity between demersal and pelagic fishing sectors were considered. Uncertainties in the stock-recruitment relationships as well as in predation rates were used in the scenario work. For the multi-species setting, the objective is to maximize

$$V = \sum_{t=0}^{\infty} \rho^t \frac{1}{1-\eta} \left(\Pi^{1-\eta} + (\lambda x_{s0})^{1-\eta} \right)$$

where ρ is the discount factor and η is the representative fisherman's aversion against intertemporal income fluctuations. The higher η is, the more a constant income stream over time is preferred. Such a desire for relative constancy is reflected in several management plans for European fish stocks (e.g. Baltic cod, EC 2007), which have been agreed upon by a broad range of stakeholders, including fishermen, as well as at the Vigo workshop. It is expressed, for example, as a requirement that total allowable catches (TACs) shall not change by more than a certain percentage between two subsequent years (15% in the case of Baltic cod).



The first part of this objective is the intertemporal utility of fishing income; where fishing income is a generalized mean of fishing incomes from the cod, sprat, and herring fisheries,

$$\Pi = \left(\frac{1}{3} \pi_C^{1-\theta} + \frac{1}{3} \pi_S^{1-\theta} + \frac{1}{3} \pi_H^{1-\theta} \right)^{\frac{1}{1-\theta}}$$

The parameter $\theta \geq 0$ captures the social aversion against inequality of incomes for the three different fisheries. The higher θ is, the more a constant income distribution is preferred. The second part of the objective captures the non-market benefits derived from ecosystem services provided by the sprat spawning stock X_{S0} , with $\lambda \geq 0$ being the price (in Euros per kg of sprat spawning stock) society is willing to pay for these ecosystem services. Precautionary biomass levels for all species are used as constraints when varying the parameters and deriving the variants (i) profit optimization, (ii) profit optimum while respecting sprat B_{PA} , and (iii) optimizing equity between fisheries while respecting sprat B_{PA} (Voss et al. 2014a, b).

FISHRENT

The FISHRENT model (Salz et al., 2011) was further developed to provide multiannual optimisation of the objectives Net present value, Maximum cumulative catch of species and Maximum cumulative revenue of species in the model and to including undersize discarding of a species (e.g. small plaice can be discarded in the shrimp single species fishery). Further, an effort was made to link the methodologies of Ecosim and Ecospace with FISHRENT and accordingly, the FISHRENT model has been adjusted. FISHRENT can now optimise a set of objectives over a period of 20 to 30 years. The model allows for indirect interactions of fisheries through undersize discards of non-landed species. The multi-annual optimisation is now also compatible with the spatially explicit model, although the period of optimisation and the number of areas are limited due to computational issues.

A FISHRENT model was also calibrated for 12 demersal North Sea fleet segments, originating in Denmark, Germany, France and Great Britain, and 10 species, including the demersal species cod, haddock, saithe, and whiting, together with important bycatch species (herring, Norway pout, plaice, sole, sandeel and sprat) to compute Maximum Economic Yield (MEY) variants for the Demersal roundfish fishery. The 12 fleet segments were chosen to cover 60% or more of the EU catch weight of the four demersal species in the North Sea. The FISHRENT model is a



coupled bio-economic model, providing feed back between the biological growth of fish stocks, and economic fleet behaviour (optimal fishing patterns, dynamic capacity change given earnings). The model includes five modules; biological, economic, market, behaviour and a policy module. FISHRENT enables the simulation of both input and output based management measures, from TAC and other quota regimes to those based on fishing effort. Moreover the model allows for constrained optimisation, thus making the model ideal for MSY assessments including economic as well as biological constraints. In the present context the key management options assessed with the model are Maximum Economic Yield (MEY) scenarios, taking into account biological sustainability issues, the landing obligation as well as socioeconomic considerations.

The economic modules of the model were calibrated using STECF data from the period 2008-2011, while the biological part was calibrated using ICES stock data. The start year of the model simulations and optimisations was set to 2011 (Hoff et al. 2014). A list of economic constraints relevant in the present context, and of the indicators used to measure them, was defined, including setting the revenue equal to or greater than the breakeven revenue for all included fleet segments (thus ensuring that they operate at positive profit), keeping average wages above a given level (thus securing a viable livelihood for the people working in the primary fishing sector), and keeping total national employment above a given level (Hoff et al. 2014). The model was used to produce DSTs which have been presented for the North Sea demersal working group in July 2014 and work with optimal paths will continue in task 3.3.

FLBEIA

FLBEIA was adapted to account for the modelling requirements identified in task 1.1 to 1.5 and in task 2.1. The data to condition de model has been mainly taken from the ICES assessment working groups (the biological part) and the GEPETO (<http://gepetoproject.eu/>) project (the fleet part). Economic data were obtained through the Annual Economic Report and the data already available to the institutes involved in the *Iberian Sea* case study. The main difficulty in terms of conditioning of the model has been adapting the available data to the dimensions of the case study. The GEPETO project provides the catch and effort data by stock and metiers aggregated in biomass whereas the data by age was needed for MYFISH. Age data from the assessment working groups missed information on metier. Thus additional data and assumptions were necessary in order to disaggregate GEPETO data by age and working group data by metier. The model was conditioned and initial runs made which represent the base case



of the sub case study. The number of cetaceans caught will be part of the covariables component of FLBEIA. This component includes the variables of interest not represented in the biological and fleet components. In this case, the covariable includes a reference point which indicates the maximum number of individuals that can be caught by a given fleet. The fleet must reallocate the effort among metiers in order to optimize the catch of the commercially exploited stocks while respecting the cetacean maximum catch.

MEFISTO

The numeric model used for the Balearic Islands (Spain) and Aegean (Greece) is an adapted R-version (R foundation 2013) of the MEFISTO 3.0 bio-economic simulation model (Leonart et al. 2003, Maynou et al. 2006). The model used was composed of two main submodels (biological and economic). The first simulated the population dynamics of the main target species of a fishery using an age structured model for each, including stock recruitment relationships, individual growth, length-weight relationships, age specific natural and fishing mortality and maturity. The fishing mortality was composed by a “static” species and age-specific component or catchability coefficient and a “dynamic” component or fishing effort, equal for all species and ages, measured as the number of boats multiplied by their activity days and hours at sea. The economic component accounted for the catch of target and species, the value of both through a market function, a detailed vessel level cost structure and the total balance between value of fish and total costs, named net profits in this document.

The main modification introduced in **MYFISH** is the secondary species equation. In order to avoid high catch of secondary species in the cases where fishing effort reduces and not considering the potential increase of catch when fishing effort increases above the target species MSY, a new equation was used. The original function of the model assigned a linear model linking the amount of catch of target and secondary species. The function was composed by two parameters, the catch of secondary species in the absence of target species catch and a coefficient measuring the weight units of secondary per unit of target species. The new equation adds another multiplier using fishing effort (Eq. 3).

$$catch_{sec} = \frac{2 \cdot Ef / Ef_0}{(1 + Ef / Ef_0)} \cdot (a + b \cdot catch_{target}) \quad (\text{Eq. 3})$$

For fishing effort (Ef) larger than current (Ef_0), the catch of secondary will increase with respect to the estimated by the original model, i.e. for levels of $Ef > Ef_0$, the revenue of secondary will still



increase despite the overexploitation of target species. In contrast, the catch of secondary will decrease with fishing effort as it does with reduced catch of target species. For $Ef=0$, there will be no secondary species catch, in contrast to what happened with the original model where a is the catch of secondary in the absence of catch of target species. For $Ef=Ef_0$ the effort multiplier is 1. Using Eq. 3, even though fishing effort reductions are expected to significantly increase one species landings, they will not produce equivalent increases in secondary species. For fishing effort levels above present, target species landings would decrease if the species is overexploited while catch of secondary will not be reduced to the same degree. This new equation is a better reflection of the contribution of secondary species to the economic yield of Mediterranean fleets. The contribution of the traditional non-target species is particularly relevant for Mediterranean demersal fisheries and thus modifications to the secondary species equation are expected to have a notable impact. MEFISTO was adapted to estimate economic MSY variants of the bottom trawl fishery from the Balearic Islands (Quetglas et al 2014).

FLR

Given that the economic data from the examined fisheries in the eastern Mediterranean are not available to the resolution required by more detailed models (e.g. MEFISTO), more general information will be used as well as expert knowledge. This information is utilized in the FLR framework which has the flexibility to accept modifications that allow dealing with such data-poor situations. The necessary modules of the FLR framework were parameterised based on the data available. The model was adapted to account for the identified biological and ecosystem constraints and will be used to evaluate the biological implications of targeting the reference points of the chosen MSY variants. The constraints refer mainly to the optimal state of key stocks. In the process, the FLR framework was adapted to be able to incorporate variation and stochasticity in important biological processes, such as recruitment.

Other fleet based economic models

The constraining effects of economic behaviour when *more selective gear is introduced* were investigated using a fleet model of the flatfish fisheries in the North Sea. The work is an adaption of the model described by Poos et al. (2010) and investigates the effect of an improvement in selectivity to obtain a higher yield. Although more selective gear in theory could increase MSY, the population level selectivity (resulting from the interaction between the gear and the



adaptive behaviour of the fleet) changes and the sensitivity of MSY reference points values to fisheries management may alter the result. Further work focused on developing a framework to simulate the behaviour of flatfish in the North Sea to estimate F_{MSY} for a highly dynamic system where variability in environmental conditions and food availability give rise to migration patterns.

A new algorithm was designed to simulate the economic effect of different HCR in a stochastic age structured model. The model is able to construct *a set of HCR's* (ranging from constant escapement rules to constant catch) with only varying one parameter. Moreover, the HCR defined by this new algorithm is independent of the natural mortality in our model, which is one of the largest sources of biological uncertainty. After doing several interviews with stakeholders, we identified four scenarios for our analyses: Discounted Mixed fisheries MSY, Minimum sustainable catches, pulse fishing and maintaining the number of vessels.

Under the *discounted Mixed MSY* scenario, the reference point was computed as the steady-state solution of a dynamic optimal management problem. The optimization problem takes into account that: (i) species are caught simultaneously in unselective fishing operations, and (ii) intertemporal discounting equal to 0.95 (i.e. an interest rate equal to 5 per cent) (Da Rocha, Gutierrez and Cerviño, 2012). This addresses the problem through an algorithm that analytically calculates mixed-fishery economic reference points. Hake recruitment was obtained using the Shepherd (1982) S–R relationship using data from 1978–2006. For the rest of the species, the expected recruitment is assumed constant over time. Under the *Minimum sustainable catches* scenario, fishing mortalities are constrained to reach -as minimum- 71 % of the current Yields of each species. A nonstationary policy was designed for *Pulse fishing* reaching on average over five years the current total Yield (Da Rocha et al. 2012 and 2013). In the scenario *Maintaining the number of the vessels*, fishing mortalities are maintained constant at its initial values.

5. Identify and adapt models necessary for data poor situations (Task 1.7)

Task 1.7 elaborates and applies trait-based models founded on established ecological theory and general information on life history traits in order to evaluate MSY variants and approaches, using theoretical-based MSY regimes to provide a first approach in data poor situations.

Ecosystem effects of fishing were analysed using a *size- and trait-based model* of a generic fish community (see <http://130.226.135.24/SSC>). Two analyses were conducted: an analysis of



“balanced harvesting” and calculations of multi-species MSY under “conservation” constraints. The analysis of the “balanced harvesting” pattern recently proposed in high-profile publications concludes that a size-unselective balanced harvesting pattern may have a smaller impact than traditional selective fishing patterns, however the catch is comprised largely of small forage fish and juveniles of larger species (Jacobsen et al. 2013). The calculations of multi-species MSY under the “conservation” were performed under the constraint that no species is allowed to be overexploited. Two measures of MSY were compared: protein output (maximization of biomass) and maximum economic yield (Andersen et al. 2014).

A size-based reformulation of the classic Beverton-Holt single-species theory has been conducted based on size and life-history invariants and is particularly well suited to data-poor stocks. The theoretical foundation of the framework was developed within the FACTS project. Within **MYFISH** the framework has been refined and applied to the assessment of data-poor stocks, in particular with focus on their status relative to F_{MSY} . The size-based life-history theory has been applied for a single stock to:

1. Calculate F_{MSY} for a data-poor stock where only the asymptotic size is known. The predicted reference points were compared to currently used reference points in stock assessments of ICES stocks and found to be in agreement.
2. Develop an interactive simulator where the impact of fishing on a single stock can be simulated in any web-browser. The fishing mortality can be specified with a trawl, gill-net or “balanced” type of selectivity and the biomass and yield is calculated. See: <https://www.stockassessment.org/spectrum>.
3. Simulate assessments of data-poor stocks where the only information is a size-distribution of the catch. The degree to which such an assessment is able to correctly classify the status of the exploitation of the stock as “under-exploited” or “over-exploited” was investigated. A classification of “under-exploited” has a 70% probability of being correct, while classification of “over-exploited” has a 90 % probability of being correct. It was further shown that adding information of length-at-age or maturity ogive will not improve the reliability of the classification noticeably. Only information of the physiological mortality, i.e. the ratio between mortality and specific consumption (similar to the classic “M/K” ratio), will improve the reliability of the classification.

Work is continuing on applying the framework to North-Atlantic cod stocks to test the reliability of the data-poor assessment against current state-of-the-art assessments of data-rich stocks.



To investigate the implications of structural instability of real and modelled marine food webs, management strategy evaluations have been conducted using the *Population-Dynamical Matching Model* (PDMM) as the operating model (the model for “reality”), because this food-web model is known to reproduce the phenomenon of structural instability. The PDMM characterizes each model species in terms of its maturation body mass, its trophic niche as a consumer and as a resource, and its time-dependent population biomass. Consumer functional responses are of type II (saturating), modified to describe prey-switching. The model can represent entire aquatic food webs, spanning several trophic levels. Food webs are generated using a randomized algorithm that mimics the natural process of community assembly. In the parameterization used here, typical model communities contained about 1500 species of primary producers and about 500 consumers, of which about 10 - 20 were targeted fish species. The PDMM is naturally suitable for addressing data-poor situations, as it successfully emulates the phenomenon of structural instability suspected to occur in natural marine fish communities, which amplifies the effects of parameter and model uncertainty in forecast models (Rossberg 2013).

The PDMM has been expanded to simulate and evaluate 10 different management strategies (high-level harvest control rules) in comparison with the theoretical optimum allocation of harvesting rates. The theoretical optima were identified using a genetic optimization algorithm modified to better deal with the rugged structure of the optimization landscape. A variety of different constraints, based on population biomasses and size-spectrum structure can be invoked in the simulations. Even when constraints were imposed, application of some harvest control rules could inadvertently lead to a violation of these constraints, in which case this is recorded by the program code. Implementations of the model on several high-throughput supercomputing platforms have been realized and tested. This code has been used to derive decision support tables for subsequent tasks (see deliverable D2.3).

6. Conclusion

The **MYFISH** work on identifying and adapting the indicators and models required to produce constrained optimization of different yield measures has now been completed. The common MSY framework was described and applied to all regions to show its generality. **MYFISH** made a specific effort to not only identify indicators and associated reference points, but also to get these indicators accepted and used in management through advice given by ICES. A wide range of different models were adapted and these developments and adaptations have been described in a list of scientific manuscripts, significantly lifting the discipline of fisheries, ecosystem and



economic modelling by improving topic models focusing on only one aspect as well as the interface zone between topical models. Though changes and additions to models will still be required, these result from the presentation of results to stakeholders or other developments outside **MYFISH**. Decision Support Tables have been produced from all regions (see deliverable report 2.3) and are currently being used in the consultation of stakeholders in connection with WPs 2 and 3. In addition to this, the models are available to support the development of new multiannual management plans under the new CFP in task 2.4 and communication with DGMARE and ICES has been initiated to ensure that the resulting models and indicators are used as widely as possible.



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