MareFrame

A description of the main S & T results/foregrounds

The MareFrame project has a large number of scientific and technological results that will have impact beyond the project lifetime. The overall objective of the project was to contribute to removing barriers that have prevented a more widespread use of an Ecosystem-based Approach to Fisheries Management (EAFM). In that respect, MareFrame has succeeded in developing assessment methods and a Decision Support Framework (DSF) for management of marine resources and has thereby enhanced the capacity to provide integrated assessment, advice, and decision support for an EAFM. Ecosystem models have been extended, and assessment methods to test and compare models across ecosystems have been implemented. New training tools, as well as visualisation tools for different management scenarios, have been created. MareFrame has also developed tools that enable comparisons between relevant "what-if?" scenarios, where stakeholders and decision makers can evaluate likely effects of management decisions on biological-, ecological-, social- and economic indicators. MareFrame has integrated stakeholders throughout the whole project, using a co-creation approach that combines analytical and participatory processes to provide knowledge that can be applied to policy-making, improving management plans and implementation of EAFM. This part has been extremely successful in the project, especially since stakeholder input and acceptance is a key to introducing changes in the marine sector. MareFrame has also cooperated, or connected in one form or another with large number of other national and international research projects, which have been mutually beneficial regarding scientific and technological development.

One of the most important tools created during the MareFrame project was the MareFrame Database (MFDB), an open source toolkit that will outlive the project. The database is a tool to store and retrieve data for analysis of ecosystems, including input to ecosystem models. The MFDB has been used in all case studies and is completely generic, meaning that anyone, anywhere can set up the database for their own system. The database provides output directly to assessment tools in the DSF.

The DSF, as previously mentioned, highlights alternative management actions and their consequences. It therefore allows stakeholders and decision makers to explore “what-if?” scenarios i.e. what are the likely effects of different management decisions. The co-creation process was used to develop the DSF, which involved cooperation with stakeholders to identify, analyse, and explore how to address the management problems. Ecosystem models were then used to understand the likely consequences of the different management options, and a set of computerised Decision Support Tools (DSTs) aided complex planning and decision-making. Finally, the MareFrame project created educational resources to facilitate the use of the DSF.

The co-creation method combines analytical and participatory tools to generate knowledge that has scientific acceptability (credibility), policy relevance (salience), and social robustness (legitimacy). It leads to benefits beyond what could be achieved through traditional research as it is a hybrid approach to participation, combining efficiency, accuracy and legitimacy, and adaptive breadth and depth. Additionally, it is iterative and linked to on-going work programmes such as ICES, GFCM, STECF, and JRC. If successfully implemented, the co-creation process can lead to enhanced and meaningful participatory processes, and transform the culture of science.

Fisheries management is for the most part based on advice derived from **single species models.** These model the population dynamics of a single fish stock as exploited by a single fishing fleet (even if there are multiple fleets) to assess the status, and provide a short term forecast to recommend a total allowable catch (TAC). **An ecosystem model** on the other hand, considers multiple species caught in several fisheries, either by taking multiple fleets into account and/or the predator-prey interactions between the various species. An ecosystem model also considers other components of the ecosystem; essentially the food-web related to the fish species and ultimately the entire ecosystem, including the hydrodynamics. Ecosystem models should also include the human element: ideally the socio-economic components of the fishery. The MareFrame partners recognise that different models can have different outputs, and thus developed at least two models for each ecosystem (in some cases three), to look at model sensitivity. Tools were developed to ensure consistent data going into the various models, consistent coding for each model, and protocols for model comparison.

It is important to remember that ecosystem-based management means different things to different people; fishermen do for example often have a different perspective to scientists. The challenge is in combining ecology, energy and food production: going beyond the ecology. It is vitally important to engage stakeholders. This happens from both sides: from science to industry and industry to science.

In order to help implement an EAFM in the European Union, the MareFrame partners have created a roadmap to function as a guide. The core of the roadmap deals with policy harmonisation (CFP and MSFD), platforms for meaningful participation, capacity building for the generation and uptake of advice, and frameworks for balancing objectives. Furthermore, the roadmap contains advice on how best to integrate structured dialogue in existing work programs, suggests the best practice for cooperation (ACs and MSRGs), contains advice on the use of regionalisation processes to support scoping exercises, suggests encouraging interdisciplinary collaboration to model three ecosystem components, contains advice on how to facilitate the use of DSTs in decision making at local levels, suggests scoping processes involving all authority levels, suggests the conduction of practical experimentation to identify benefits of EAFM to ACs, emphasises the importance of adequate resources and platforms for transdisciplinary cooperation, suggests the enhancement of the capacity of advisory systems to support cross-policy cooperation, and contains advice on how resources may be strategically allocated to broaden the scope of science processes.

A particular challenge within MareFrame was to develop a methodology for comparing different models in different CSs, and how to deal with the lack of social data (the economic data was more obtainable). The outcome of this work was a Socio-economic Impact Assessment (SEIA) where stakeholders were involved in weighting and scoring. This is a methodology that will outlive the MareFrame project.

An important product of MareFrame is the H2020 Marie Skłodowska-Curie MSCA-ETN project SAF21 (Grant Agreement no. 642080, www.saf21.eu). SAF21 is in essence a “daughter project” to MareFrame where 10 PhD students are being educated in topics related to social-science and fisheries management. Early on in MareFrame, some key partners decided to apply for ITN to fill in gaps that MareFrame was not addressing, related to social-science and fisheries. These two projects have consequently supplemented each other and SAF21 can therefore be considered as a product of MareFrame.

This summary of the scientific and technological results/foregrounds of the MareFrame project was derived from work carried out in eight scientific Work Packages (WPs). Following is a more detailed discussion on each WP and their S/T results.

WP1 – Co-creation & pathways for implementation

MareFrame aimed to generate innovative insights and tools to integrate an ecosystem-based approach into fisheries advice. The co-creation approach was embedded in the research design and implementation through the project lifetime. The co-creation approach combines analytical and participatory tools to generate knowledge that has scientific acceptability (credibility), policy relevance (salience) and social robustness (legitimacy). In practice, this has meant a total of 30 stakeholders meetings, 10 remote meetings, 4 EU level meetings and 166 participants involved in an iterative process. The main conclusion from the WP1 development is that a co-creation approach leads to benefits beyond what could be achieved through traditional research. If successfully implemented, the approach ensures an enhanced and meaningful participatory process, which is particularly relevant due to the complexities of the EAFM and of the EU institutional setting. The pathways to integrate EBFM in the advisory system – considering the ecological, biological, economic and social dimensions- have been jointly identified with the main players (ICES, STECF, DG-MARE, ADVISORY COUNCILS). The results have been widely disseminated to the scientific, policy, industry, NGOs, and other social communities. Furthermore, a recommendation regarding participatory approaches in research and policy processes linked to EAFM has been presented. The researcher-stakeholder teams involved in MareFrame have experienced an in-depth collaborative process with streams that go beyond the project lifetime, contributing to the transformation of the culture of science in the EU.

WP2 - Select & apply analytical methods

The main objective of WP2 was to integrate novel critical processes and supporting state-of-the-art data into the EAFM process. This objective was broken down into four steps:

1. Collect and identify new information to be incorporated into ecosystem models.
2. Evaluate importance of this information
3. Define the functions needed to implement this information into assessment models
4. Identify and recommend areas of future data collection for optimum implementation of the models.

The main challenge was the multitude of tools and techniques that required consideration. To make the best use of new tools and technologies such as genetics, microchemistry, and isotope analyses to develop new knowledge on population distribution, spatial patterns of spawning components, stocks structure and definition, habitat preferences, species interactions (including food-web and predator-prey interactions), migration patterns, and biological parameters such as growth and fecundity. The WP faced the challenge of having to design an experimental approach for novel data, considering both technological and non-technological data.

The most significant results of WP2 can be sorted into two categories. Firstly: internal results, such as the contributions to the model developments in the CSs. Secondly: external results. The protocol for novel data implementation described in D2.4 and the report with conclusions of the evaluation of the novel information used (D2.5) are examples of such external result. D2.5 considers the usefulness of each information type in improving the ecosystem models, and contains recommendations to improve future data collection. This report represents important results that will be relevant for future work where novel data is introduced into Ecosystem models and EAFM.

Many different types of data were generated within WP2, including biological data (age, sex, abundance), fisheries dependent data (effort knowledge, VMS), environmental data (microchemist, climate, oceanography), diet-related data (isotopes and stomach), and genetic data (close-kin, connectivity). WP2 also contributed to five different model types: GADGET, EwE, Atlantis, CSM, and MSPM. Fourteen different protocols were written to describe the final implementation of the novel data into models within each case study. These protocols can be useful to the scientific community to implement similar data in ecosystem models beyond the lifetime of MareFrame.

WP3 - Data management

The main objectives of WP3 were to establish the data that would be generated by case studies and model runs, and make available data that case studies would demand in the appropriate format, to define and set up a database system to serve the needs of other WPs, specifically WP5, and write data extraction routines for models and other existing systems to populate the database. In order to reach these objectives, the MareFrame DataBase toolkit was created.

The MareFrame DataBase (MFDB) is now up to version 6.0. It is designed to be a generic tool for the future, rather than being irrevocably wedded to MareFrame. Enhancements to discard support developed as part of MINOUW twinning have been made, and the MFDB has been used for most of the case studies. In particular, the MFDB was used for the Icelandic CS: all likelihood components in Gadget model, for the SWW CS: Anchovy Gadget model, for the Baltic CS: Cod/Herring/Sprat Gadget models for all the likelihood components, for the Strait of Sicily CS: Hake, White Shrimp and Horse Mackerel model, for the North Sea CS: Survey Data in small Gadget models, survey data for Orange/Red models, and for the Black Sea CS: Turbot Gadget model.

To allow Atlantis to be used as an operating model for GADGET, tools to ingest Atlantis data into MFDB were made. Additionally, a server was set up by UI for sharing model data. MFDB can import and export data, or query this sever directly. WP3 also contributed to RGadget by creating a code to manipulate GADGET configurations and formulae.

The legacy of WP3 is clear. The code written is open source and will continue to be available from the github website, https://github.com/mareframe/mfdb. Additionally, RGadget and MFDB can, together, handle all stages of model development within R, allowing for models that are quick to reconfigure, reproducible, and easily updated with future data. It will continue to be a useful tool for MareFrame partners as evidenced by the following quotes:

- MRI: "We used gadget + RGadget + MFDB to develop two harvest control rules (for tusk and ling in Icelandic waters) and MFDB was fundamental for rapid model development and uncertainty estimation."

- SLU: "MFDB will continue to be the companion of further developments of the Baltic gadget model after MareFrame."
- CISC: "I'm using it every time I need to include new information in the anchovy model“.
- NRC: "I suspect that in the future I will use it for Scientific interrogation of the North Sea Survey data."

WP4 - Ecosystem models & assessment models

The main objectives of WP4 were to develop ecosystem model processes which allow for inclusion of the indicators for Good Environmental Status (GES descriptors 3, 4 and 6), develop common economic and social model processes which allow for derivation of the Ecosystem Approach to Fisheries (EAF) indicators, develop common reporting procedures for model output comparison (model-, case study- and scenario specific), set up the models for forecasting scenarios to conduct virtual experiments (as input to DSF), and develop a virtual ecosystem in Atlantis for generation of indicator data in data-poor cases.

The main challenges in WP4 were uncertainty, model ensemble variability, stationarity – meaning the assumption of status quo ecosystems with no regime shifts and no major unforeseen events - error propagation, the large number of GES indicators, and the complexity of social indicators. Each GES indicator came with its own set of challenges. Biological diversity incurred the need for spatial models, non-indigenous species were data deficient, eutrophication demanded localised hydrography, contaminants in the environment and the fish species required contaminant modelling, and the matter of litter, energy and noise required models as a function of activity. The question of how to define social indicators - e.g. is employment social or economic? – and how to define human well-being in general is a challenging one.

The most significant results of WP4 were the new ecosystem models created, and the understanding that was reached regarding the models and their data requirements. Knowledge gaps were identified, and steps were taken toward multispecies management strategy evaluation. WP4 leaves behind fully operational ecosystem models ready to implement an EAFM. These ecosystem modelling tools and the associated indicators used in all case studies were all documented in the deliverable reports. In addition, most of these are currently being prepared for peer-reviewed publication, ensuring that the results will be available and used by scientists beyond the lifetime of the project.

WP5 - Apply new methods in case studies

The overall objectives of WP5 were to use ecosystem models in different areas to explore the direct and ecosystem-mediated implications of alternative management strategies, and to couple the implementation of an Integrated Ecosystem Assessment to ad-hoc DSTs in connection with WP6. Additionally, the goal of WP5 was to explore alternative management scenarios in all case studies, and using the online DSTs in the CS areas. Furthermore, each CS area had its own set of objectives, described in the following sections.

Baltic Sea case study

Three ecosystem models (Gadget, EwE and MSPM) were implemented to simulate the effects of different management scenarios in the Baltic Sea on target stocks (cod, herring, sprat) and fisheries taking into account environmental variability and a growing seal population. The models showed considerable differences in the year-to-year variation, but they generally agree in reconstructing the historical long-term trends of catch and fish biomass. The models and their outputs supported the DSTs, and allowed for testing the robustness of alternative fishing management strategies. The models were applied to investigate 1) how consistent the estimation of fishing mortalities which optimise alternative management strategies are and 2) the inference on the state of the ecosystem in relation to those strategies using performance indicators.

Despite the fact that the models presented relatively large differences in the forecasted F-yield curves, they gave consistent answers, both in terms of how to adjust fishing mortality rate to achieve certain objectives, and in terms of which strategies perform best according to selected indicators.

The Baltic DSF is now sufficiently general to host new models and further developments. The CS provided an immensely constructive experience for both stakeholders and scientists to grow into an EAFM. Additionally, it promotes and offers the DSF for testing and exploration of alternative fishing strategies beyond the MareFrame project.

North Sea Caste Study

The objectives of the North Sea CS were to describe MSY in a Multispecies-Multifleet context, and if possible, to consider compliance in context of the landing obligation. The main challenges within this CS were that the North Sea has many species and many different types of fishing gear, many different country interactions with different mixes of species, and different economic and social aims. The North Sea Stakeholders asked for a multispecies model to answer their concerns. This request fitted well with the aim of MareFrame, and the Green model (now known as the T-ONS model) was developed to meet this need. It is a front-end model that emulates the results of more complex biological models using simple approximations, and also builds on to these the required social, economic and GES outputs. This results in a model that is extremely transportable and stakeholder friendly, and is very adaptable to new requirements dictated by the co-creation process. A great strength of the T-ONS model is that it can take fisheries results from a number of pre-existing and developing models for the North Sea, and add the social, economic and GES elements to a consistent standard. This was a successful strategy for the North Sea where previous work of ICES makes several well-established Multispecies models available. Models used include the pre-existing and well-reviewed SMS, EwE, and Ensemble models together with various developments of the Charmingly Simple Model (CSM) and the Multispecies Schaefer model. Collectively this wide range of models meet the several needs of MareFrame and provided strength through diversity and complementarity.

Having achieved a viable long-term model, considerable effort was put into developing the DSF for the North Sea. First, by the use of the MCA approach. Suitable decision trees were readily agreed upon with stakeholders. However, despite considerable work by the North Sea team, including variable stakeholders such as the North Sea Advisory Council (NSAC) and the Pelagic Advisory Council (PELAC), they could not agree sufficiently on the weightings of criteria to use in a MCA. Hence an alternative approach was developed from the ground up following a suggestion of one of the stakeholders (co-creation in action!). This approach, called the N dimensional Potato, was built into the final overview T-ONS model. It has a user-friendly Control Panel that can be used by stakeholders and decision makers on their own computers. The PELAC are already very enthusiastic users of this model. The model also achieved the highest scores from the independent panel judging the MareFrame DSFs.

The Stakeholders had additional concerns regarding area and fish behaviour explicit models, for which the Amber and Red models have been planned to address. However, since these models fall outside the MareFrame DoW they had a lower priority and have so far only been developed to the proof of concept stage, illustrated with a poster at the concluding symposium. This work will be continued within the SAF21 project (which is a daughter project of MareFrame i.e. ITN where 10 PhD students are being educated in social-science and fisheries).

The North Sea Case study took a major role in collaborating with other MareFrame WPs; notably providing the methodological backbone of the Brussels senior managers meeting in June 2018. Presentations of the work to scientific audiences such as ICES ASC‘s (a MareFrame based Theme session was organised and co-chaired there by the North Sea Case study leader) and the Bena conference. Awards were given to North Sea CS work at both venues for the quality and innovation of presentations. In addition to presentations to industry and scientific stakeholders, presentations were also made to DG MARE (2016) and to the European Parliament (2017).

The North Sea CS team is committed to securing the Legacy of the CS both by publication, by the curation of models and by presentations of the work to suitable ICES WGs to encourage them to take ownership. Inputs are also planned to other ongoing EU projects to pass on the MareFrame legacy. The inputs from the stakeholder meetings, twenty meetings in total, have proven the legitimacy of the co-creation approach. A major legacy of this CS is the T-ONS model, which will be curated and made easy for ICES to adopt, as well as DSF approaches that have been clarified and partially adopted by the stakeholders.

North-Western Waters case study (Iceland)

The objectives of the North-Western Waters CS were to build three substantially different ecosystem models for Icelandic waters, investigate the performance of Gadget and EwE based on simulated data from Atlantis, and investigate variations in the current management scheme for cod and related species. The three different ecosystem models were built successfully, and are up and running. Development will continue well into the future. The simulated data from Atlantis was used successfully to investigate the performance of Gadget and EwE, and the data has been fed into MFDB and used as the basis for comparison. To investigate variations in the current management scheme for cod and related species, five scenarios were developed using a Gadget model. Two have already been presented to stakeholders as viable improvements upon the current management schemes.

The legacy of this CS included knowledge transfer, software development, and new management plans. The software developments include:

- RGadget http://www.github.com/hafro/rgadget;
- GadgetLite http://www.github.com/bthe/gadgetLite;
- Gadget-models http://www.github.com/bthe/gadget-models
- Visualising Atlantis Toolbox (VAT) http://www.github.com/mareframe/vat

The work performed within the CS has already contributed to the development of new stock assessment and harvest control rules for tusk and ling using MareFrame tools; these have been accepted by ICES.

Northern waters case study: west of Scotland

The objective of the northern waters case study was to develop an EAFM framework, two ecosystem models, identify issues with the co-creation method as well as the best scenario, implement DSTs, and draft a management plan proposal.

The main challenges involved in this case study were the short-term interests of the stakeholders (e.g. the discard ban), the long-term issues with the EAFM framework (e.g. GES). The fact that no discard models were used was also challenging, and sometimes it was difficult to engage stakeholders. The stakeholders that the partners did manage to engage often expected quicker results than projects like MareFrame can deliver, leading to stakeholder fatigue.

The CS produced two up-to-date ecosystem models and a visualisation tool. The Decision Support Framework method and its tools are applicable beyond the MareFrame project, making them a lasting legacy.

The west of Scotland faces several management issues: the stocks of cod and whiting in ICES area 6a are currently depleted and the population of grey seals, and consequently the predation mortality on gadoids, has been increasing for the past two decades. In addition, bycatches of juvenile gadoids by the Nephrops fishery is resulting in discarding and higher fishing mortality, particularly for juvenile whiting. Case study leaders met with stakeholders and agreed on a set of alternative management strategies to address these issues. Two models were adapted for that purpose, Gadget and EwE.

Gadget has been parameterised for both single and multispecies models, and EwE is now fully parameterised and has successfully been used to perform simulations of alternative management strategies. The EwE model includes both GES indicators and socio-economic indicators. Case study leaders met with stakeholders and agreed on a set of alternative management strategies to address these issues. These alternatives were modelled with EwE using the latest assessment and survey outputs. In addition, Good Environmental Status and socio-economic indicators were computed from the model outputs to assess the performance of the alternatives regarding ecosystem health and fisheries economy.

The results showed that the importance of considering trophic interactions when assessing different fishing scenarios is crucial. Applying the single species F_{MSY} values defined by ICES recovers cod, but is insufficient to bring whiting within safe limits by the end of the 20-year simulation period. Results revealed that a decrease in the fishing mortality applied to juvenile whiting is essential for the whiting stock to recover, suggesting that the reduction of bycatches by the Nephrops fishery is necessary. Unsurprisingly, the alternative with the lowest fishing mortalities across species returned the highest ecosystem indicators overall, but resulted in the lowest biodiversity. Increasing fishing mortality on crustaceans and pelagic species increased profit in the short term but not on the medium and long term. All alternatives tested, including the ones with the lowest and highest fishing mortalities, converged towards similar long term total profit at the end of the simulation period.

South-Western Waters Case Study

The main objective of the SWW case study was to explore management options leading to greater sustainability in the biological and economic realms for a fishery of societal importance but highly fluctuating under environmentally driven and nonhuman controlled drivers.

The main challenge was to implement the socioeconomic components demanded by the stakeholders in a model that includes not only the biology but also the environment that impacts the biology. To do so in a frame scientifically rigorous, but also transparent beyond the scientific realm, so that real impact is feasible.

In order to reach the objectives of the CS, a bioeconomic model based on real data of the stock and the fleet was created. The model was implemented in a probabilistic frame able to account for uncertainty. Additionally, the model was implemented in a DST available on the web and that can be used by any stakeholder in a fully transparent manner.

Due to this CS, the main stakeholders are now fully aware, accept and look for better management strategies than the present fixed TAC. They are requesting further work and actions along this line.

The South-Western Waters (SWW) case study was comprised of two different subcases: (1) in the Gulf of Cadiz the aim was to model the anchovy dynamics including fishing and environmental factors (2) in the whole Atlantic Iberian Peninsula the aim was to model fisheries-cetaceans interactions. The main objective in both sub-cases was to evaluate management trade-offs and conflicting objectives such as single species, ecological, social and economic targets. In the Gulf of Cadiz two models were developed: A bioeconomic model and a Gadget model. The bioeconomic model developed for anchovy stock provides the framework for simulating alternative policy options to manage European anchovy in the Gulf of Cádiz together with an assessment of its performance that combines anthropogenic, environmental and biological factors. The Gadget model estimates the recruitment time series from 1989 to 2016 and this output is used to prove a “causal” relationship that can be used for forecasting. This Gadget model was presented in the ICES WKPELA 2018 workshop, where it was decided that it will be used to provide assessment and scientific advice for ICES. In the Atlantic coast of the Iberian Peninsula two different ecosystem models were developed: (1) A GADGET model for the southern stock of the European hake and two cetacean species: common dolphin and bottlenose dolphin. The model included the predation and the mortality caused by their interaction of these species with the fishery. The effects of fisheries management measures were explored and trade-offs between two different targets: maximize the fisheries yield and keep dolphin populations healthy. The results suggest that hake recovery slows down when considering the cetaceans interactions, since fishing effort reduction increases cetacean population that increases the hake natural mortality. (2) An EwE trophodynamic model was also developed in the Cantabrian Sea Shelf ecosystem. It includes bottom-up and top- down controls to provide the model with trophic flexibility. This CS has therefore provided four models that are parameterised and operational, it has co-created with stakeholders to evaluate trade-offs and developed DSTs that have been used to evaluate “what if?” scenarios. These are all outputs that will live beyond the MareFrame project; and the Gadget model for Gulf of Cadiz is already being used by ICES.

Mediterranean Case Study – Strait of Sicily

The objective of the Mediterranean CS was to develop a tool for the application of EAFM in the Strait of Sicily (SoS). This objective was successfully reached with the development of two new models, Gadget and Atlantis, and two DSTs were also developed and applied. These are now ready to be used for tactical short-term advice (Gadget based) and medium term strategic advice (Atlantis based). These are the first structured tools for the implementation of EAFM in the Mediterranean and will provide support to the GFCM management plan. The Gadget model has in fact already been adopted as an alternative assessment model to VPA/XSA by GFCM.

The MareFrame management proposal for the SoS that was developed in co-creation with stakeholders can substantially contribute to the development of the GFCM management plan for trawl fisheries exploiting the deep-water rose shrimp (*Parapenaeus longirostris*) and hake (*Merluccius merluccius*) facilitating the inclusion in the plan of a more holistic approach and the provision of a strategic advice for ecosystem based management.

F_{MSY} target may be beyond reach for harvested populations which are linked through trophic interaction and are fished in a mixture. Hake and deep sea rose shrimp are predator-prey populations which are shared among multi-national fleets in the Strait of Sicily. Reaching F_{MSY} for hake would result in lost fishing opportunities for the fleet while reaching shrimp F_{MSY} would imply overfishing of the hake stock. An additional major complication is the normative requirement of applying transparent environmental, social and economic criteria to guide management decisions. The problem is two-fold: how to develop estimates for these quantities, and how to integrate all these criteria into a meaningful framework. The first challenge was tackled by applying an end-to-end ecosystem model, Atlantis, and a multi-species model, Gadget, to produce quantitative forecasts for the many aspects of the fishery and the environment. The second challenge was approached with a multi-criteria decision analysis (MCDA) process heavily resorting to participatory modelling developed in WP6. Atlantis was implemented as a strategic tool for investigating the medium-terms effects of management control rules on the ecosystem functioning (energy path), fisheries and socio-economic compartments. The model includes 58 biological groups and 8 fleets. Business as usual (BAU), aims to shift fishing pressure to sustainable levels (Fmsy) by 2020, by investigating selectivity changes and fisheries restricted areas, and considering the biological and socio- economic implications. Output of the model includes GES indicators (biomass, proportion of groups with F<Fmsy) and socio-economic indicators (catch, revenue, cost profit, profit to fishers). Gadget was designed to provide advice on the effects of prey-predator relationships on hake and rose shrimp. Biological, socio-economic and ecosystem indicators were used to explore the trade-offs associated to a set of different management strategies identified with stakeholders during case study meetings held in Sicily from 2014 to 2017.

A key legacy of the SoS CS is the roadmap that was created to deliver CS outputs to GFCM. Another important legacy is the cooperation that was established with FAO, Italian DG Pesca, Medac and GFCM.

The models developed for this CS are already being used by important stakeholders, such as GFCM and will be developed further in the future.

Black Sea Case Study

The focus of this CS was the Black Sea turbot (*Psetta maxima maeotica)* and the stakeholders involved in this CS were the fishermen and fishing organisations from Romania and from all six countries bordering the Black Sea; National Agencies for Fisheries and Aquaculture; Regional Commissions and Working groups. Two ecosystem models, Gadget and EwE, were developed and Bayesian belief networks were applied as DSTs. Based on this work, the partners were able to adapt measures to the regional situation, build a common roadmap with GFCM, and increase the collective expertise in ecosystem modelling. Restoration of turbot fisheries to more productive levels, considering both the effect of fisheries and the ecosystem change occurred in the last 30 years, was the main objective of the Black Sea case study. The main challenges of this data poor case study were the gaps in the fishery dependent data sets, related to official landings and effort data, the unknown rates of discards and IUU catch. Both Gadget and EwE were implemented in the western sector of the Black Sea (Romanian coasts). Results from the first Gadget model were however not satisfactory, and following the guidance from Icelandic model experts, a second version of the Black Sea model was therefore developed for a single species only. The data used for turbot were biomass, catch, length distribution, mean length data, CPUE, age-length distribution (all for commercial data), covering the period 2007-2013.

The EwE model proved more successful in this CS, as it was able to consider 10 species or a pool of species (turbot, anchovy, sprat, whiting, gobies, mussel, cetaceans, zoobenthos, zooplankton, and phytoplankton). Other data included were biomass, commercial landings, IUU catches, P/B = Z (total mortality), Q/B (consumption rate). Bayesian belief networks were used as DST when co-creating Harvest Control Rules and considering measures to take IUU. The stakeholders involved in the participatory processes were fishermen and fishing organisations from Romania and from all six countries bordering the Black Sea, national agencies for fisheries and aquaculture, regional commissions (BSC) and working groups (GFCM), during 4 face-to-face meetings.

Chatham Rise Case Study

Two ecosystem models were developed for the Chatham Rise area, an important region for fisheries and biodiversity, and the site of proposed seabed mining activity, to the east of New Zealand. A balanced (EcoPath like) food-web model of the Chatham Rise ecosystem was developed, and used to explore the potential effects of a seabed mining proposal for phosphorite nodules on the top of the rise. The model was used to estimate trophic importance (the impact of changes in biomass of a particular group on other groups in the food-web), and then qualitative (expert opinion) assessment of anticipated direct impacts of mining on the groups with the highest trophic importance was undertaken. Results were presented to the New Zealand Environmental Protection Agency’s decision committee, and were considered when making their consenting decision. The anticipated direct impacts of mining on most of the groups with the highest trophic importance’s are likely to be low or negligible, because these groups are widely spread over the Chatham Rise or planktonic so the scale of impact is likely to be small. This analysis suggests that the four groups with trophic importance’s that are higher than average and are at the highest direct/habitat-mediated risk from mining are likely to be small demersal fish, hard-bodied macrozooplankton (krill), cephalopods and rattails & ghost sharks.

An Atlantis ecosystem model was developed, and used to explore specific fisheries stock recruitment aspects of ecosystem modelling, along with alternative future fishing scenarios. Preliminary results explored the implications for hoki (key target) and mictophids (key prey, and potential target for lanternfish fishery) of changing fishing practices.

WP6 - Develop a decision support framework

A Decision Support Framework (DSF) was developed and used in case study specific workshops with stakeholders to support the development of generic management plan proposals. The DSF was improved based on constructive feedback received in workshops. The DST software that represents a key element in the DSF is operational. The DSF supported the presentation, comparison, and structured evaluation of a set of scenarios developed to represent candidate strategies to address identified management problems and concerns. The approach allows users to evaluate trade-offs between the scenarios across a range of relevant dimensions, while taking their preferences and priorities explicitly into account. The scenario comprises a starting point for the development of a management proposal. The DSF can support the scoping for problems and potential solutions in the context of EAFM. The DSF cannot ensure that stakeholders end up with an agreed compromise on how to proceed. However, the structured approach to evaluation facilitated by the DSF allows users to document their positions on identified strategies in a more transparent way than is normally possible in a complex decision-making situation, characterised by multiple indicators, objectives and trade-offs.

Most of the tools are generic and can be readily applied to new cases, and this is supported by available guidelines. It is important to encourage the further use and development of the DSTs, and some are currently being used and extended in new projects. A number of planned publications will help to facilitate awareness and foster critical discussion about the development and use of the DST as instruments to advance EAFM.

MATIS has committed to hosting the DSF beyond the lifetime of MareFrame and there are at least two on-going H2020 projects that will be utilising the DSTs i.e. REEEM and FarFish.

WP7 - Synthesis & training development

The objectives of WP7 were to compare and evaluate the developed ecosystem based models and the decision support system with respect to their suitability to predict ecosystem changes in the regional case studies investigated in the project, and their capability to improve marine policies, assess socio-economic impacts and propose how a new integrated EAFM can be implemented in Europe, and develop an interactive learning tool to facilitate the implementation of EAFM.

The main challenges of the WP were starting from scratch to develop a methodology for comparing different models in different CSs, a lack of social data (the economic data is more obtainable), involving stakeholders in weighting & scoring the socio-economic impact assessment (SEIA) for the CS. This was particularly difficult due to timing, and due to how careful the partners had to be to avoid stakeholder fatigue. It was also a challenge to make sure the communication between modellers and socio-economists was good in order to improve the data collection, and finally it was a challenge to make certain that visualisation was adequate for the training tools (budget and time did not allow for optimal DSS training tool solutions).

The most significant results of the project were the methodology for comparing models and assessing DSF, the methodology for SEIA, the DSF roadmap, the MareFrame training tool v1.0 (SeafoodSim: a fisheries management simulation game, http://tokni.com/dev/main.html, the web based training material, and FARMAR – the Green Model applied in the Faroe Islands in combination with SEIA (a side project to MareFrame). The SeafoodSim training tool is a single player fisheries management simulation game, where the "player" can run one or more Scenarios. Each scenario is a simulation of a fishery. The purpose of each scenario, is to choose the best management strategy.

WP8 - Dissemination & training actions

The objectives of WP8 were to make the project's results well-known in Europe and to disseminate the results to SMEs, consumers, retailers, consumer organisations, solution providers and control authorities etc. Additionally, the objective was to disseminate the results to other on-going projects and initiatives relevant for the project in order to create synergies and to increase the visibility of the project worldwide.

The expected results of WP8 according to the DOW were to generate MareFrame presentations for the general public, create and maintain a MareFrame webpage, publish MareFrame presentation in a portable document format (*.pdf) for conferences, "Fish-in corner", weigh in on the final evaluation of the EAFM, and publish articles in selected magazines and newspapers. Additionally, WP8 was to compile training material in collaboration with WP7.

The main challenges of WP8 were due to the size and the diversity of the consortium (28 partners from different regions). The complexity of the scientific concepts and approaches made it challenging to disseminate them accurately to stakeholders and wider audiences. It was also a challenge to involve stakeholders in the MareFrame co-creation process.

At the end of the project, the partners increased online and Social Media activity.

Dissemination during public, scientific & stakeholder events 2017:

- @MareFrame at the International Conference Environmental Engineering and Sustainable Development, Alba Iulia, Romania,
- 25-26 May 2017 #EAFM#sustainable_development
- @MareFrame #BlackSea CS at the International Conference #MaritimeSpatialPlanning in the Black Sea - #Constanta, #Romania, 3-4 May 2017 Magda Nenciu Mariana Golumbeanu
- @MareFrame @UN_FAO_GFCM Roadmap in action! #Workshop on the assessment of #management measures on #BlackSea #turbot fisheries
- 12-13 June 2017, Constanta, Romania
- New Era of Blue Enlightenment, 12-14 July 2017, Lisbon, Portugal

- ICES ASC 2017, 18–21 September 2017, Greater Fort Lauderdale, Florida, US
- INternational CongRess on Engineering and Sustainability in the XXI cEntury - INCREaSE 2017, Faro, Algarve, Portugal, 11-13 October 2017

The legacy of WP8 and the exploitation of the MareFrame Foreground are closely entwined. The following deliverable outputs mostly serve the objective of producing and disseminating innovative knowledge:

- D5.3. Report on model outputs in each CS
- Video interviews with the MareFrame Coordinator and Scientific Manager (both attached to Final Report in EC portal)
- Video describing Co-creating Ecosystem-based Fisheries Management Solutions (attached to Final Report in EC portal)
- DSF tools
- WP1 Case Study Fact Sheets
- Teaching material
- Papers: 20 published, many in preparation
- Fisheries Research Special Issue!
- MareFrame Portfolio

Commercial outputs are as follows:

- Potential customers = fishing industry, NGOs, decision makers
- Commercialisation channels = consultancy services
- Website active until 2020 (domain and hosting covered)

Potential IPR: software codes

- MFDB (MareFrame DataBase) package homepage

https://github.com/mareframe/mfdb

- MareFrame Decision Support Framework - Mapix Foreground:

http://mareframe.mapix.com/

The dissemination and training activities under WP8 were organised in compliance with the Description of Work (DoW) and the tasks and objectives set at the beginning of the project. The aim of the dissemination in the MareFrame project was to make the project results well-known in Europe and to disseminate the results to all potential stakeholders. In addition, MareFrame has been disseminating the results to other on-going projects and initiatives relevant for the project, aiming to create synergies and to increase the visibility of the project worldwide.

The dissemination strategy has been focused on awareness (activities and outcomes), understanding and action (change of practice resulting in the adoption of the MareFrame approaches). Special attention for dissemination activities was paid on the Decision-Support Framework/Tools (DSF/DST) users. Furthermore, decision or policy makers, the fishing associations and other stakeholders directly involved in the Management Plans of fisheries were engaged in specific activities in order to communicate major findings of the MareFrame achievements, e.g. Policy Day in Brussels, 20th June

2017, in the frame of WP1; Final MareFrame Policy Day on 13th December 2017 (More general communication was addressed to stakeholders with the same profile).

After four years of implementation, the MareFrame widely accepted slogan is: “Co-creation is OK!”.

The visibility of MareFrame steadily increased since the beginning of the project in 2014, using both traditional tools (such as scientific conferences, workshops, publications etc.), as well as the new updated social media.

All dissemination activities were counted and documented by uploading on the ECAS Portal. There is a total of 246 dissemination activities documented to date (28th February 2018).

Peer-reviewed publications are also a significant MareFrame outcome. To date, there are 23 uploaded scientific papers, but a special issue of the Journal of Fisheries Research will be published in 2018, containing many of the papers presented during the MareFrame Scientific Conference.

Each work package generated a series of exploitable results and in order to determine which of the expected results have the best exploitation potential, two surveys were designed and circulated within MareFrame, one focusing on the scientific results and the other on the commercial outcomes. Out of the project deliverables, it resulted that D5.3. Report on model outputs in each CS and DSF tools have the highest capitalisation potential, as well as the teaching material resulting from training activities. Concerning the commercial outputs, the potential customers are represented by the fishing industry, NGOs, decision makers, and the commercialisation channels may be represented by consultancy services. As a continuation of the project, the MareFrame homepage will be active at least until 2020 (domain and hosting covered) and the resulting FFDB and DSF will be subsequently taken over by another entity for hosting and granting access (MATIS).

MareFrame Highlights

- Co-creation process that combines analytical and participatory processes to provide knowledge that can be applied to policy-making, improving management plans and implementation of EAFM.
- The Fact Sheets summarising the events and outputs of each case study, which can be used to raise awareness of EAF at stakeholder and public regional sea levels.
- A protocol for the correct implementation of novel data types into assessment models, allowing assessment scientists to put the tools developed by MareFrame to their intended use in future ecosystem models.
- The finalised version of the MareFrame DataBase (MFDB), designed to be a generic tool for the future, rather than being irrevocably wedded to MareFrame. The code written is open source and will continue to be available from the github website, https://github.com/mareframe/mfdb.
- The parameterisation of two or more fully operational ecosystem models for each case study.
- The developed case studies that allowed scientists and regional stakeholders to investigate the effects of fishing and climate change scenarios on key ecosystem processes.
- The N dimensional Potato approach, which was built into the final overview T-ONS model. It has a user-friendly Control Panel that can be used by stakeholders and decision makers on their own computers. The PELAC are already very enthusiastic users of this model. The model also achieved the highest scores from the independent panel judging the MareFrame DSFs.
- The following software developments:
    - RGadget http://www.github.com/hafro/rgadget;
    - GadgetLite http://www.github.com/bthe/gadgetLite;
    - Gadget-models http://www.github.com/bthe/gadget-models
    - Visualising Atlantis Toolbox (VAT) http://www.github.com/mareframe/vat
- The SWW CS provided four models that are parameterised and operational, it has co-created with stakeholders to evaluate trade-offs and developed DSTs that have been used to evaluate “what if?” scenarios. These are all outputs that will live beyond the MareFrame project; and the Gadget model for Gulf of Cadiz is already being used by ICES.
- A key legacy of the Mediterranean - Strait of Sicily CS is the roadmap that was created to deliver CS outputs to GFCM.
- Socio-economic Impact Assessment (SEIA) where stakeholders were involved in weighting and scoring. This is a methodology that will outlive the MareFrame project.
- The “MareFrame Decision Support Framework (DSF) platform for EAFM decision support”. It can be used by stakeholders, policy makers and researchers as an interface and a source of data to explore “what if scenarios” to support EAFM planning.
- The DSF roadmap that was created for the implementation of DSF. It is a comprehensive guideline for the implementation of EAFM based on the project findings, and may be used by researchers, policy makers and stakeholders alike to ensure that ecosystem issues are considered robustly in future resource management decisions.
- The MareFrame “SeafoodSim” DST Training Tool, http://tokni.com/dev/main.html.
- Fisheries Research Special Issue on MareFrame results.
- MareFrame Portfolio
- MareFrame slogan: “Co-creation is OK!”

MareFrame list of publications:

WP1

- Ramirez-Monsalve et al., 2016. Ecosystem Approach to Fisheries Management (EAFM) in the EU-Current science-policy-society interfaces and emerging requirements, Marine Policy 66: 83-92.
- Ballesteros et al. 2017. Do not shoot the messenger: ICES advice for an ecosystem approach to fisheries management in the European Union. Journal of Marine Science, October.
- Ramírez-Monsalve et al., forthcoming. Carrots or sticks: How to improve EAFM advice within CFP
- Ballesteros et al., forthcoming. Who joins the table? A critical overview of the co-creation approach for the implementation of an Ecosystem Approach to Fisheries Management.

WP2

- Elvarsson, B. P. 2015. Evaluating stock structure hypotheses using genetically determined close relatives: a simulation study on North Atlantic fin whales. ICES Journal of Marine Science, 72 (2): 661-669. doi: 10.1093/icesjms/fsu140.
- Perez et al. (in prep.) Questions and answers about the use of genetics for stock assessment and management. European hake as an example.

Contribution to other publications through novel data implementation into models:

- Baltic CS. Diet data in the Baltic Sea especies.
- Pope, J.G., Hegland, T.J. Ballesteros, M., Nolde Nielsen, K. (in prep). The N Dimensional Potato: A simple approach to finding feasible solutions to fisheries systems where different Stakeholder Groups have conflicting objectives.

WP3

- Source code available for all R packages on Github site:
  - https://github.com/mareframe/mfdb
  - https://github.com/mareframe/mfdbatlantis
- Documentation for all R packages published online:
  - https://mareframe.github.io

WP4

- Serpetti et al. (2017). Impact of ocean warming on sustainable fisheries management informs the Ecosystem Approach to Fisheries. Nature Comms.
- Rincon et al (2015). The economic value of environmental data: A notional insurance scheme for the European anchovy. IJMS.

- Pope, J. A swift transportable and User Friendly Multispecies Model of the North Sea that describes the main tradeoffs involved in an Ecosystem Approach to Fisheries Management (EAFM).
- Colloca et al. A Gadget multispecies model to explore the fisheries management implications of prey-predator interactions in the Strait of Sicily trawl fishery.
- Elvarsson et al. Using Gadget in a multi-criteria analysis of the Icelandic cod fishery Gadget.
- McGregor et al. Spawning stock recruitment when natural mortality is dynamic: a proposed solution for ecosystem models.
- Saavedra et al. Cetacean fishery interactions: A multi-species model for ecosystem management in Atlantic waters of the Iberian Peninsula.
- Fernandes et al. The future of European Fisheries under sustainable management.
- Baudron et al. Can the Common Fisheries Policy achieve Good Environmental Status in exploited ecosystems:
- the example of West Scotland fisheries?
- Fallon et al. Towards ecosystem-based fisheries management: Modelling multispecies interactions between grey seals and demersal fish species in the West of Scotland.
- Rincón et al. Granger-causality analysis of integrated-model outputs, a tool to assess external drivers in fishery.
- Corti et al. Benchmarking the ability of different stock-assessment models to capture the highly-fluctuating dynamics of small pelagics.
- Sturludottir et al. Ecosystem model of Icelandic waters using the Atlantis modelling framework.
- Sinerchia et al. Simulating the effect of alternative management solutions in the mixed fisheries of the Strait of Sicily using the Atlantis end-to-end ecosystem model.
- Pope et al. Comparing the Steady State Results of a range of Multispecies Models between and across the geographical areas considered by the MareFrame Project using a Jacobian matrix approach.
- Pope et al. A time varying extension to the Charmingly Simple Model of the North Sea that can fit tropic level data.

WP5

Baltic Sea CS:

- Bauer et al. Effect of the underwater habitat quality on the top predator Baltic cod and its food web interactions
- Kulatska et al. Ontogenetic and temporal variability of Eastern Baltic cod diet
- Bartolino et al. Impact of spatial heterogeneity of survey data on the assessment of Baltic Sea sprat
- Bauer et al. Sources of structural uncertainty and its impacts on simulated fisheries management strategies in the Baltic Sea

- Rahikainen et al. A decision support tool for ecosystem approach of the Baltic fisheries

North Sea CS:

Publications: 5 papers proposed for special edition. Probably 2 follow-on papers through SAF21 and WGSAM.

Iceland CS:

- Elvarsson, Bjarki Þór. "Evaluating stock structure hypotheses using genetically determined close relatives: a simulation study on North Atlantic fin whales." ICES Journal of Marine Science: Journal du Conseil (2014): fsu140.
- Sturludottir et al. Ecosystem model of Icelandic waters using the Atlantis modelling framework
- Sturludottir et al. "Can Ecopath with Ecosim mimic the Atlantis ecosystem?"
- Frater et al. "Evaluating Gadget using an OM" (working title)
- Ribeiro et al. "Ecopath model for Icelandic waters" (working title)
- Elvarsson et al. Using Gadget in a multi-criteria analysis of the Icelandic cod fishery Gadget
- Elvarsson et. al: Taking a data challenged stock further: a case-study on Icelandic ling
- Elvarsson et. al: Gadget

Scotland CS:

- Serpetti et.al. Impact of ocean warming on sustainable fisheries management informs the Ecosystem Approach to Fisheries.
- Baudron et.al. Can the Common Fisheries Policy achieve Good Environmental Status in exploited ecosystems: the west of Scotland fisheries example.
- Baudron et.al. Multispecies Maximum Sustainable Yield in the west of Scotland fisheries
- Fallon et.al. A length- and age-based multispecies model for the west of Scotland fisheries

SWW CS:

- ICES journal of Marine Science on what are the advantages of an insurance to the stock
- Marine Policy on the different management strategies
- Fisheries Oceanography (still in review) on the consequences of climate change under different management strategies.

Mediterranean CS:

- Di Lorenzo, M., Sinerchia, M., & Colloca, F. 2017. The North sector of the Strait of Sicily: a priority area for conservation in the Mediterranean Sea. Hydrobiologia,

- Colloca, F., Scarcella, G., & Libralato, S., 2017. Recent trends and impacts of fisheries exploitation on Mediterranean stocks and ecosystems. Frontiers in Marine Science, 4, 244
- MareFrame Fisheries Research Special issue: three manuscripts in preparation

WP6

- Rahikainen & al.: Mareframe toolbox supporting informed multi-attribute fisheries management decisions
- Nielsen & al.: Participatory planning and decision support for the West coast of Scotland mixed fisheries
- Nielsen & al.: Tools and processes to support scenario based planning in Ecosystem Based Fisheries Management: lessons from seven European case studies
- Rahikainen & al. Decision support disentagles the multiple EAFM goals of the mixed shrimp and hake fishery in the Strait of Sicily
- (Others in cooperation with/led by WP5 persons)

WP7

- Raakjær, J., Ramirez, P., Nielsen, K.,Ballesteros M., Santiago, J.L., Laksá, U., Gregersen O. 2015 Institutional challenges for policy-making and fisheries advise to move to a full EAFM. Journal Manuscript
- Jonsdottir, A. H., Jakobsdottir, A. and Stefansson, G. 2014. Development and use of an adaptive learning environment to research on-line study behavior. Journal of Educational Technology & Society (In press).
- Jonsdottir, A.H., Bjornsdottir, A. & Stefansson, G. (2014). Difference in learning among students doing pen-and-paper homework compared to web-based homework. Submitted to the International Journal of Science and Mathematics Education.
- Desjardins, C. D., Jonsdottir, A. H. and Stefansson, G. 2014. Enhanced Learning Through an Open-Access Content and Drill System (in prep). [CP] Lentin, J., Jonsdottir, A.H., Stern, D., Mokua V. and Stefansson, G. 2014. A mobile web for enhancing statistics and mathematics education. First presented at icots9. See http://arxiv.org/abs/1406.5004 (to be submitted to ISI journal).