EU Project MareFrame - Co-creating Ecosystem-based Fisheries Management Solutions: A summary of the MareFrame products and how they could be adapted for Australian use

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Abbreviations

AFMA – Australian Fisheries Management Authority

CFP – Common Fisheries Policy

CSM – Charmingly Simple Model

DSF – Decision Support Framework

EAFM – ecosystem approach to fisheries management

EBFM – ecosystem-based fisheries management

EwE – Ecopath with Ecosim (ecosystem modelling platform)

EU – European Union

GADGET – Globally applicable Area-Disaggregated General Ecosystem Toolbox

GES – Good Environmental Status

GFCM – General Fisheries Commission for the Mediterranean

HD – Habitat Directive

ICES – International Council for the Exploration of the Sea

JRC – European Commission Joint Research Centre

MCDA – multi-criteria decision analysis

MFDB – MareFrame DataBase

MSDF – Marine Strategy Framework Directive

MSPM – Multispecies Stock Production Model

NSAC – North Sea Advisory Council

PELAC – EU Pelagic Advisory Council.

SEIA – Socio-economic Impact Assessment

SMS – stochastic age structure multispecies model

STECF – EU Scientific, Technical and Economic Committee for Fisheries

T-ONS – multispecies model emulator

VMS – Vessel monitoring system

WP – Work package

Executive Summary

Between 2014 and 2018, a large European Union project – MareFrame (http://www.mareframe-fp7.org/) – was run with the intent of identifying and reducing impediments to the implementation of ecosystem approach to fisheries management. Australian researchers engaged with this effort, both to share our experience, but also to benefit from the lessons learnt in this far more data rich context. The MareFrame framework was as much process as technology and consists of:

1. Co-creation process
2. Ecosystem models
3. Decision support tools (a dashboard and infographics for exploring and communicating management options)
4. Educational resources

A significant number of decision support tools were developed over a set of 8 case studies (7 form the EU and one from New Zealand). Learning from those applications there are a number of processes and technologies that would be of direct benefit to ecosystem-based fisheries management (EBFM) in Australia if implemented here, including:

- Ongoing harmonization of environmental and fisheries policy
- Further work on EBFM indicators and tactical management tools (e.g. multispecies harvest control rules)
- Renewal of information on ecosystem status and connections (some data is now many decades old) and development of a pragmatic monitoring scheme (beginning with a review of the potential provided by new sensor technologies)
- Looking into ways to broaden engagement and co-creation (including general information dissemination to the broader community)
- Trialing a combined Simulation-Multi-Criterion Decision Analysis approach to exploring EBFM solutions; potentially employing the “N dimensional potato” process
- Expanding the number of multispecies and emulator models available for doing tactical fisheries assessments
- Major collaboration between members of the Research Providers Network around delivery of a database and reporting framework that can be used to query all available information on Australian ecosystems and fisheries (this would be a natural outgrowth of IMOS and the AODN with significant value-add potential)
- Development of new interactive visualization and decision support tools – these can be linked to the database and/or simulation results to allow for exploration of all available knowledge on the fisheries and EBFM implementation.
- Master classes on fisheries science, ecosystems, new observing technologies, the effective use of information platforms, EBFM and risk assessment protocols
- Development of informative social indices and data streams
- Application of the Socio-Economic Impact Assessment procedures to provide a complete understanding of the socio-economic dependence and vulnerabilities of Australian fishing communities (for planning and future proofing purposes).

Keywords

ecosystem based management, ecosystem approach to fisheries, modelling, decision support, co-design

Introduction

Significant investments (mounting to millions of dollars) have been made in steps toward ecosystem based management in Australia fisheries and in tools to support those efforts. However, many gaps remain and much can be learnt from applications in other jurisdictions – especially one as data rich as the European Union (EU). Australian researchers were invited to be advisers on (and participants in) the European MareFrame project – which aimed to significantly progress EAFM in the EU under KBE funding. Constraints on the access of non-EU members to the funding prevented full Australian participation (i.e. Australians could not support work on a full case study, as New Zealand did), but Australian researchers (co-funded by CSIRO & FRDC) provided software and experience support to the project and were able to access and learn from its inner working. This report highlights the key outcomes of MareFrame in the following sections and summarises the outcome of MareFrame and provides recommendations on how lessons and tools from MareFrame can be adapted to the Australian context and implemented.

MareFrame

The MareFrame project was aimed to facilitate implementation of an ecosystem-based approach to fisheries management (EAFM) in Europe, as there has been numerous papers pointing out the benefits of such a move (e.g. Pikitch et al 2004, Fogarty 2014, Link 2018, Fulton et al 2018a). The overall objective of MareFrame was to remove any barriers preventing more widespread use of EAFM in Europe. This was done through (i) development of new tools and technologies, (ii) development and extension of ecosystem models and assessment methods, and (iii) development of a decision support framework that can highlight fisheries management and development alternatives and consequences. The project took a co-creation approach, embedding all stakeholder groups (e.g. commercial, recreational, indigenous, eNGO and management & researchers) in all development phases. This was done with the aim of ensuring ownership lay with the users, hopefully increasing the likelihood of acceptance and uptake of project outcomes.

The co-creative process and training built into MareFrame proved essential to its success. The co-creation process was iterative and helped adaptively shape the project work to better match needs, broadening the knowledge base, supporting learning, and improving scientific acceptability (credibility), policy relevance (salience), and social robustness (legitimacy) of the final products.

Marframe wanted to move away from simply developing tools and gathering scientific knowledge to translating that information into actual management advice for those managing European fishing stocks. To move away from a simple reliance on single-species management. It wanted to do this within the context of addressing important issues within the relevant EU policies – specifically the Common Fisheries Policy (CFP), Marine Strategy Framework Directive (MSFD) and Habitat Directive (HD); all of which call for the development of EAFM to improve sustainable resource management and ensure preservation of marine biodiversity via assessing the environmental status of marine waters to determine if they are in ‘Good Environmental Status’ (GES).

MareFrame had nine specific objectives aimed at increasing the use of EAFM:

1. Identify paths for implementing EAFM through co-creation with stakeholders
2. Apply novel analytical methods and integrate state-of-the-art data into EAFM
3. Design an integrated and harmonised database containing collated ecosystem data suitable for supporting EAFM development, the MareFrame DataBase (MFDB).
4. Extend existing ecosystem models
5. Develop innovative ecosystem-based assessment methods/tools and conduct performance evaluation
6. Apply and configure the extended ecosystem models and the assessment tools in the respective case studies
7. Develop, test, and adapt a decision support framework (DSF)
8. Compare and evaluate the developed ecosystem-based models and the decision support system, including the socio-economic impact
9. Develop interactive learning tools to facilitate the implementation of EAFM

It was thought (hoped) by the participants and the funding agency that fulfilment of these objectives would align scientific, political, and socio-economic views pertaining to holistic management of marine ecosystems.

As documented in the special addition of Fisheries Research dedicated to *Advancing Ecosystem Based Fisheries Management*, populated largely by MareFrame papers, by the end of the project MareFrame had successfully developed new tools and technologies; extended ecosystem models and assessment methods for the region to address multispecies concerns; and developed a new Decision Support Framework (DSF) for risk management. The later was specifically designed to assist with the selection of preferred scenarios, highlighting alternative management actions and their consequences, understand any underlying preferences among user groups and ultimately to provide an evidence basis for policy makers to assess trade-offs associated with various management options. User friendliness was a key concern of the DSF designers who focused not only on its scientific underpinning (drawn from information coming from the new models and assessment methods), but is 'look and feel' (dashboard & infographics) and the provision of educational resources to facilitate the use of the DSF – entire 'Master Classes' were drawn up to maximise the user skill sets.

Finally, MareFrame provided a roadmap for enhancing the implementation of EAFM in the EU, including guidance on (i) how to implement and improve EAFM in Europe within the CFP and MSFD, and (ii) how to involve stakeholders in decision processes through co-creation (an aspect of Australian style fisheries management that was a glaring omission from EU practices previously – which were very heavily politically influenced).

These advances were built on the back of the implementation of 10 ecosystem model platforms (bespoke multispecies and trophic models, GADGET, EwE, Atlantis, a Multispecies Stock Production Model (MSPM), T-ONS, Green-, amber- and red models). These modelling frameworks were configured, tested and compared within and across eight ecosystems (7 in the EU as well as the Chatham Rise in New Zealand). The MareFrame case studies were chosen based on pressing stakeholder identified management challenges that would likely require EAFM management solutions. The final list of EU case study locations was:

- Baltic Sea
- North Sea
- Northern & Western Waters (Icelandic Waters)
- Northern Waters (West Scotland)
- South-Western Waters (Iberian Waters)
- Mediterranean Waters (Strait of Sicily)
- Black Sea

To facilitate intercomparison and use within the DSF, model outputs were standardised.

It was fairly rapidly appreciated that decision-making relating to EAFM is highly complex. This is because of:

- the multiple policies that are involved (not all of which are immediately or obviously aligned);
- differences in objectives and priorities between stakeholders; and
- the need to integrate information from multiple sources which have their own formats, frequency, focus and reliability.

This is why significant effort was put into:

- indicators (physical/chemical, biological, ecological, social and economic) for tracking performance;
- a MareFrame Database (MFDB) for storing and easily retrieving data for analyses of ecosystems; and
- the DSF, which allows for interactive analysis of focal problems and testing of alternative scenarios through simulation.

The database proved instrumental, as it could be used across all EU case study locations due to its open source and generic design (available from https://github.com/mareframe/mfdb). This allowed anyone, anywhere to implement it for their own system and for automation of workflows (e.g. formatting of data for the creation of input files for ecosystem models or statistical analyses and reporting). The data drawn from the database provided input data to assessment tools used in the DSF – these included the ecosystem models, but also Multi-Criteria Analysis (MCA) and Bayesian Belief Networks (BBN) of socio-economic impacts. A working version of the DSF and its visualisation tools (dashboard, online training and infographics) is available at http://mareframe-fp7.org/.

Educational resources were another important MareFrame product. These resources included Webinars and interactive learning tools, which were compiled into an online learning module in an enhanced learning content management system (tutor-web) – available at https://mareframe.github.io/dsf/.

CSIRO's role

FRDC and the CSIRO supported CSIRO personnel's involvement in MareFrame (as EU funding could not be used outside the EU). Dr's Dichmont, Plagányi and Fulton all advised on various parts of the MareFrame work.

CSIRO had an advisory role for MareFrame WP 1 'Co-creation & pathways for implementation' and WP 6 'Develop a decision support framework'. CSIRO also provided information on experience in Australia and elsewhere, regarding what has been needed to successfully deliver on EBFM and decision support, with the majority of CSIRO's participation going into WP 4 'Ecosystem models & assessment models' and WP 7 'Synthesis & training development'.

The major contribution of the CSIRO Atlantis modelling team was support for the development of the Icelandic and Sicily Atlantis models. This involved hosting Erla Sturludóttir (who implemented the Icelandic Atlantis model) and instructing Christopher Desjardins and Matteo Sinerchia on how to use Atlantis. In particular, CSIRO staff provided instruction and support (via Skype and email and one-on-one support during visits to Hobart) around implementing the model, defining the model maps, calculating oceanographic/hydrodynamic forcing of the model and parameterisation of the ecological and fisheries sub-models.

CSIRO provided support around software updates, calibration advice, time series fitting to improve model and forecast skill. This involved adjusting Atlantis software code to allow for reproduction of the form of management used/trialled in the Icelandic and Sicily ecosystems. In addition, we provided instructions on demand (via Skype and email) on how to calculate the ecological, economic and social indicators from the existing model output (adjusting the format where possible to make this easier). All of this also supported performance comparison across model frameworks (e.g. with EwE and GADGET models developed for the same area).

Dr Fulton also contributed to the drafting of the document D7.2 MAREFRAME Analysed case studies which laid out model intercomparison protocols, useful indicators to use for EBFM and model comparisons and key considerations for the use and communication of models.

Together this work delivered CSIRO's contributions to MareFrame tasks:

- 4.2: Incorporate GES indicators
- 4.3: Incorporate economic and social indicators
- 4.5: Forecasting
- 4.6: Performance comparison.

Bringing Knowledge Back to Australia

This report summarises the major products and experience around supporting ecosystem based fisheries management coming from the MareFrame project. A discussion of how these findings and products can be adapted for Australian use closes out in the report.

Objectives

The objectives of the project were as follows

1. To contribute to the EU funded MareFrame Project – supplying modelling expertise and software support so as to allow the use of Atlantis in the intermodal comparison (thereby supporting understanding and development of appropriate ecosystem-based management tools)
2. Summarise the findings of MareFrame and describe how these could be how they could be adapted for Australian use.

Discussion of the Outcomes of MareFrame

The following summary of the MareFrame project activities and products draws on materials available publicly on MareFrame, but primarily on the final MareFrame report submitted to CORDIS[1] in September of 2018 (MATIS 2018, available from CORDIS).

MareFrame tools

The MareFrame project was funded by the framework 7 round of EU funding in order to facilitate increased implementation of Ecosystem-based Approach to Fisheries Management (EAFM) in the EU. To reach this goal, MareFrame developed a new **Decision Support Framework** (DSF) in collaboration with stakeholders. This framework was as much process as technology and consists of:

1. Co-creation process
2. Ecosystem models
3. Decision support tools (a dashboard and infographics for exploring and communicating management options)
4. Educational resources

The intent of the DSF design was to assist with the selection of preferred management and development scenarios, providing understanding of the consequences of those management and development actions, any underlying preferences and inherent trade-offs. Knowledge from the use of the DSF has already been used to weave recommendations on how to implement EAFM (within the framework of the Common Fisheries Policy (CFP), Marine Strategy Framework Directive (MSFD) and Habitat Directive (HD)) into the ICES and General Fisheries Commission for the Mediterranean (GFCM) roadmaps (Figure 1). The core of the MareFrame contributions to these roadmaps deals with (i) policy harmonisation between the CFP and MSFD; (ii) advice on how best to integrate meaningful participation and capacity building (e.g. via structured dialogue) into existing EU work programs; (iii) provision of frameworks for balancing objectives; (iv) suggests active adaptive management (i.e. practical

Figure 1: Mareframe contribution to GFCM roadmap.

[1] https://cordis.europa.eu/project/rcn/111485/reporting/en

experimentation) to identify benefits and pitfalls associated with methods of implementing EAFM, emphasising the essential importance of providing adequate resources to allow for successful transdisciplinary and cross-policy cooperation.

MareFrame integrated stakeholders throughout the project steps, using a **co-creation approach** that combined analytical and participatory processes to provide knowledge directly applicable to policy-making, improving management plans and implementation of EAFM. This approach was extremely successful, generating and synthesising knowledge. This co-creation process allowed for adaptive responses to stakeholder needs, maximising the project's capacity to address changes mid-project, broadening the knowledge bases input and resulting from the project, which in turn improved the credibility, policy relevance and social legitimacy of the tools developed and the recommendations given. This is especially important for implementing EAFM, as stakeholder input and acceptance is a key to introducing changes in the marine sector. The co-creation process was intentionally iterative and linked to on-going international programmes (e.g. ICES, GFCM, the EU Scientific, Technical and Economic Committee for Fisheries (STECF) and the European Commission Joint Research Centre (JRC)). These means of delivering science was a revelation to many EU scientists and required a transformation in the culture of science in a number of institutes in the region. The co-creation process also saw the project take particular care to present materials in eye catching ways (e.g. see the portfolio document cover in Figure 2).

Figure 2: Cover page of the Mareframe portfolio document.

Ten **ecosystem models** of various forms and complexity were developed, extended and compared in this project. With at least two (if not three) modelling frameworks applied per case study ecosystem/location. Multiple models were developed as project partners recognised they produce different outputs and have their individual strengths and weaknesses (meaning an ensemble approach is best as it allows for a more robust consideration of uncertainty). Model protocols and data handling tools were developed to ensure consistent data inputs into the various models and to provide structured protocols for model comparison. The resulting models allowed scientists and regional stakeholders to investigate effects of fishing and climate change on their ecosystem. Moreover, model outputs were used to help test and calculate indicators of 'Good Environmental Status' (GES), required under the MSFD. While the project fell short of management strategy evaluation testing the implementation of multispecies models (e.g. GADGET) using ecosystem model data, the idea remains a good one that should be followed up in future. The project does, whoever, leave a strong legacy in the form of these fully operational ecosystem models ready for use in implementing EAFM.

A particular challenge for MareFrame was how to deal with the lack of social data (the economic data was more obtainable) needed for EAFM. The outcome of this work was a Socio-economic Impact Assessment (SEIA), based on expert and stakeholders scoring and weighting of the factors. This approach will have significant value far beyond the end of the MareFrame project.

The **decision support tools** developed in the project drew on new technologies - including visualisation tools, dashboards and infographics – to feed the ecosystem model and observation data into a **decision support framework** (platform) that could be used to explore the implications of management and development scenarios. The value of the DSF was maximised via the release of the SeafoodSim online training game and the MareFrame DataBase (a generic open source means of storing ecosystem relevant data in an accessible and readily useable way).

The **educational resources** developed in the project include Webinars, advanced training schools, interactive learning tools, online courses and in person Master Classes (workshops) all aimed at the education and training of the users of the decision support tools and the DSF. MareFrame has stored many of these educational materials on Tutor-Web to make sure they are available long term. Project materials were also assembled in a MareFrame Portfolio published at the project website (http://mareframe-fp7.org/mareframe-portfolio-a-fun-way-to-review-our-four-years/); and a special Issue of the *Fisheries Research* journal has been dedicated to peer-reviewed publications on MareFrame results (the special issue is titled "Advancing Ecosystem Based Fisheries Management" – available at https://www.sciencedirect.com/journal/fisheries-research/special-issue/103CX9S3P53).

The following is a summary of the specific scientific and technological work undertaken within each of the eight scientific Work Packages (WPs) in MareFrame (the interconnection of which is shown in

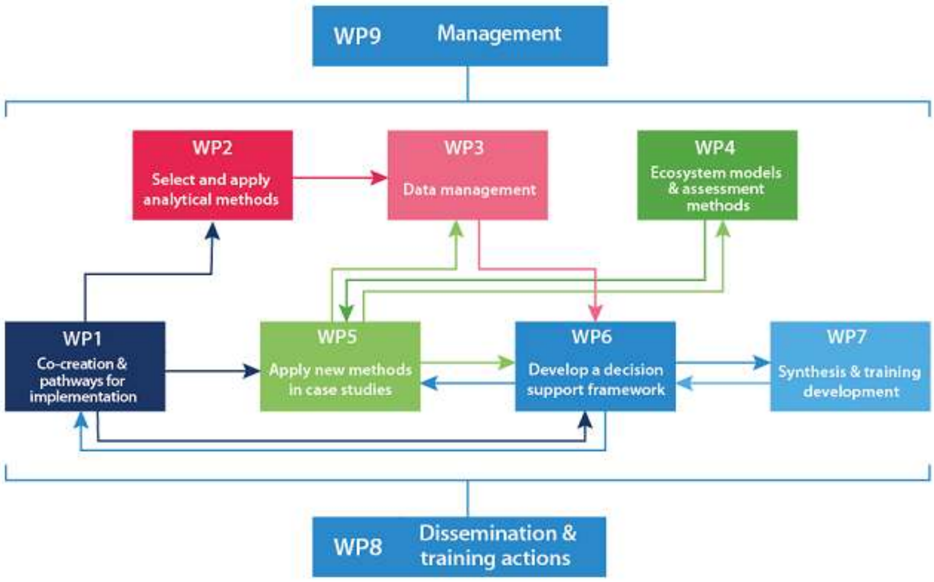

Figure 3).

Figure 3: Work package structure for EU MareFrame project (from MareFrame webpage).

WP1 – Co-creation & pathways for implementation

In practice, the MareFrame co-creation process involved 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 work was that the co-creation approach had benefits beyond what is achievable through traditional research, which is particularly important given the complexities of both EAFM and the EU institutional setting.

This approach saw the pathways to integrate EAFM into the advisory system (across ecological, biological, economic and social considerations) were jointly identified with the main players - including advisory councils, ICES, STECF and DG-MARE. There was also significant effort put into dissemination of results to a broad number of audiences, not just the scientific – including industry, NGOs, policy and local social communities.

WP2 - Select & apply analytical methods

WP2 focused on data provision via:

- Identification of data gaps and collection of new information to be incorporated into ecosystem models;
- Evaluation of importance of the information types and sources
- Define functions needed to implement the information into appropriate assessment models

The main challenge was the multitude of data sources that now exist and had to be integrated, such as genetics (close-kin, connectivity), microchemistry, isotope analyses, acoustics and classical sources such as climatology, oceanography, stomach contents, catch, discards, effort (including logbooks and VMS) and survey biomasses. The intent was to collect information on population distributions and stock structure, spawning spatiotemporal patterns, habitat preferences, trophic interactions, habitat dependence, migration patterns, and biological parameters such as abundance, sex ratios, length-at-age, growth, mortality rates and fecundity. Protocols for handling model data was drawn up as was a guide on the usefulness of different information types, with recommendations on how to improve future data collection in support of EAFM.

WP3 - Data management

WP3 developed a database – the MareFrame DataBase (MFDB) – that could deal with the data from WP2 and other data generated by case studies and model runs. The intent is to make data available in appropriate formats, providing data in a form that serves the needs of the other MareFrame WPs and EBFM long term. This involved writing data extraction routines and a data toolkit to populate the database. The tool is of a generic structure (Figure 4) and open source – remaining available at https://github.com/mareframe/mfdb.

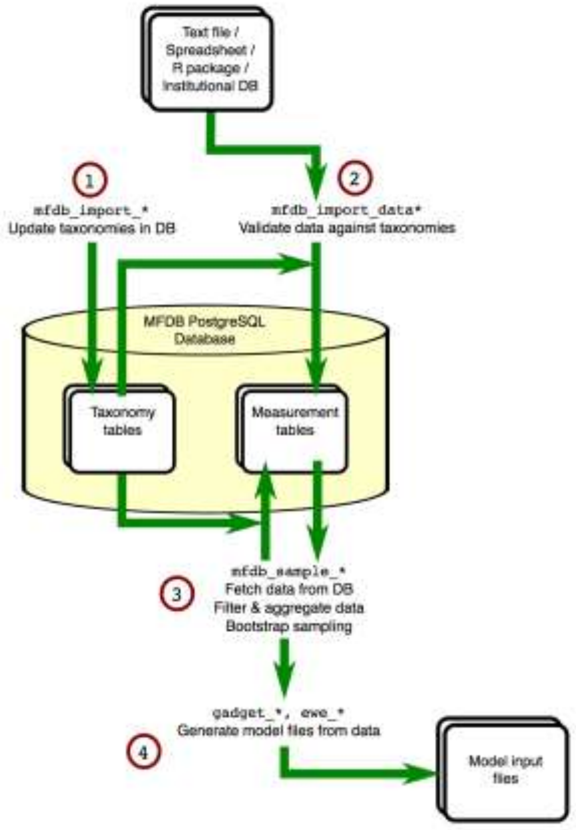

Figure 4: Mareframe database structure (from Mareframe webpage)

The MareFrame Database moves away from the concept of a central database to a common structure that links to an R package (toolbox) to help manage a local database. The MFDB includes automatic set-up and configuration of a PostgreSQL database, functions to ingest data automatically from files or other database APIs, functions to transform and aggregate the data, functions to create input files for ecosystem modelling tools. It facilitates modelling by removing the need for specialist database knowledge benefiting from database features such as structured tables and queries. It also sees researchers and users move beyond the use of spreadsheets and flat files, which are often bespoke researcher to researcher even when using the same model frameworks. In addition, the MFDB automatically error checks data and ensures it matches required formats. This minimises human error-based mistakes within models and analyses undertaken in support of EBFM. By leveraging off R-based toolboxes it also significantly speeds up model development time and eases model updating and ensuring repeatability.

RGadget was also developed to work with MFDB to handle all stages of GADGET model development within R. This allows for rapid model reconfiguration and transparent modelling that is reproducible and easily updated with future data.

WP4 - Ecosystem models & assessment models

MareFrame WP4 focused on developing ecosystem models which allow for inclusion of indicators that can inform EBFM and inform on Good Environmental Status (required under the MSFD). There was also the realisation that it was necessary to develop common economic and social model processes, as they are equally important for EAFM. Atlantis was also used a data generation tool for supplementing indicator data in data-poor cases.

The indicator and model intercomparison work involved developing common reporting procedures for model output and virtual experimental design (scenarios for input to the DSF). This involved having clear rules around model uncertainty, model ensemble variability, stationarity (the assumption of status quo ecosystems with no regime shifts and extreme events), error propagation, and the calculation/generation of indicators (where possible minimising complexity as much as possible). This was not a trivial exercise as each indicator has its own associated challenges. For example, good local hydrography is needed for eutrophication indicators, while biodiversity indicators benefit from having spatial contexts (and thus spatial models), and simply defining human well-being is a significant challenge. There are also a number of indicators of interest to EBFM (and ecosystem based management more generally across all industries active in the oceans, which fall under the MSFD) that are not easily handled in most existing ecosystem models. For example, entry of non-indigenous species, contaminant/pollutant movement through the environment and species living within the area (where pollutants include chemicals, litter and noise). Consequently, a number of model extensions were undertaken to allow for at least rudimentary (and where possible a sophisticated) representation of these processes.

WP5 - Apply new methods in case studies

The models developed in WP4 were applied in WP5 to explore the implications of alternative management strategies for ecosystem components and the human dimensions of the systems. Effort was put in to coupling the implementations with Integrated Ecosystem Assessment processes, feeding the results into the DSF. Each case study area (see Figure 5) had its own set of objectives, which are summarised in the following sections. Information on these case studies is summarised below but also available at: http://mareframe-fp7.org/work-packages/

Figure 5: Location of the MareFrame case studies. 1. Iceland, 2. Western Scotland, 3. North Sea, 4. Baltic, 5. Gulf of Cadiz and Iberian Peninsula, 6. Sicily Strait, 7. Black Sea and 8. Chatham Rise of New Zealand (from MareFrame webpage).

1. Iceland

The Iceland (EU North-Western Waters region) case study had a number of objectives:

- build three ecosystem models using different ecosystem modelling frameworks
- investigate the performance of GADGET and EwE based on simulated data from Atlantis
- investigate variations in the current management scheme for Atlantic Cod (*Gadus morhua*) and related species

All these objectives were successfully met and the resulting model data has been fed into the MFDB – which facilitated model comparisons.
A range of tools for easing model construction were developed during the course of the work and these are available at:
• 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

Five scenarios were developed with stakeholders using the GADGET model and trialled in the other two models. Two of these proved viable improvements upon the current management schemes. This work has already contributed to the development of new stock assessment and harvest control rules for Icelandic stocks of Tusk (*Brosme brosme*) and Common Ling (*Molva molva*), which have been accepted by ICES.

2. West of Scotland

The Scottish case study (EU Northern Waters region) saw:

- the development of an EAFM framework for the areas
- development of two ecosystem models
- development and implementation of decisions support tools
- scenario testing
- drafting of a proposed management plan
- identifications issues with the co-creation method.

While the scientific objectives were successfully met, the case study work found the short-term interests of the stakeholders (e.g. the discard ban) quite challenging, as was settling long-term issues with the EAFM framework (e.g. GES).

The results of the scenario work showed that in multispecies fisheries that consideration of trophic interactions is critical when assessing different fishing scenarios is crucial. For example, applying the ICES defined single species FMSY values recovers Atlantic Cod, but does not recover Whiting (*Merlangius merlangus*) above the limit reference point within the 20-year simulation period. To achieve the objectives for Whiting requires a reduction in juvenile mortality – which likely requires a reduction in bycatch of these fish in the *Nephrops* fishery. While considerable reduction in effort across all fisheries was required for best ecological indicator performance, all the alternative scenarios tested (regardless of effort levels) converged on similar long term total profit levels.

A significant issue encountered within the case study was a mis-match of the available scientific tools (which did not initially include a discards model, one of the stakeholders specific interests), which made it difficult to engage many stakeholders. Of those stakeholders that did engage, there was a sense of frustration as they often desired (expected) results much more rapidly than could be delivered, ultimately resulting in significant stakeholder fatigue.

3. *North Sea*

The North Sea case study aimed to:

- describe MSY in a Multispecies-Multifleet context; and
- consider compliance in context of the landing obligations.

The complexity of North Sea fisheries (which are multi-fleet, multi-gear and multi-species, not unlike Australia's Southern and Eastern Scalefish and Shark Fishery) is exacerbated by the fact it is a multi-country arena, with each country favouring different mixes of species and having different economic and social aims. This complicates the co-creation process significantly.

Work on the multispecies questions was facilitated by ICES's previous focus on developing multiple multispecies (MICE-like) and ecosystem models for the region. These include Ecopath with Ecosim (Mackinson et al 2018), T-ONS (an emulator that approximates the outputs of more complex biological models; MATIS 2018), SMS (stochastic age structure multispecies model; Lewy and Vinther 2004), the Charmingly Simple Model (CSM; Pope et al 2006) and the Multispecies Schaefer model (ICES 2007). Collectively this wide range of models were well suited to an ensemble approach and provided strength through diversity and complementarity.

Consideration of the alternative scenarios was done in a number of ways, including an attempt at using multi-criteria decision analysis (MCDA). This ultimately proved to be a dead-end as no consensus could be reached on appropriate weights for the decision trees despite significant input and effort by the research team and various stakeholders such as the North Sea Advisory Council (NSAC) and the Pelagic Advisory Council (PELAC). At this point instead of settling on a single weighting a different approach was taken in concert with stakeholder groups – called the N dimensional Potato (Pope et al 2019), which aims not to optimise but to avoid the most undesirable outcomes (like cutting out rotten parts of an old potato and using what remains). Each group of stakeholders cuts away those parts of the decision space they find unacceptable. What remains is the joint decision space that all find somewhat acceptable (i.e. the compromise solutions); if nothing remains post the cuts then this shows that any solution will leave some disaffected. The models and co-creation approaches are a major legacy of the work, with wide uptake and adoption into ICES.

4. *Baltic Sea*

The Baltic Sea case study focused on:

- the development of three ecosystem models – suggest listing them
- scenario evaluation

GADGET, EwE and a Multispecies Stock Production Model (MSPM) were all implemented to simulate the effects of different management scenarios on target stocks in the Baltic – Atlantic Cod, Atlantic Herring (*Clupea harengus*), European Sprat (*Sprattus sprattus*). These models were also parameterised taking into account environmental variability and a growing seal population. The models were used to investigate fishing-mortality focused management strategies and(?) based the implications for ecosystem state for those strategies using performance indicators. There were relatively large differences between the forecasted F-yield curves from the different models, but the various trajectories still provided consistent answers in terms of how to adjust fishing mortalities to achieve objectives and which strategies perform most effectively based on selected indicators.

5. *Gulf of Cadiz and Iberian Peninsula*

The Gulf of Cadiz (EU South-Western Waters region) case study had the primary objective of exploring management options leading to greater biological and economic sustainability under environment drivers. This involved developing both a GADGET and bioeconomic model for European Anchovy (*Engraulis encrasicolus*) implemented the region, which was done in a probabilistic framework that was able to account for uncertainty. The model was then delivered for a web-based interface so could accessed by any stakeholder in a fully transparent manner. This has seen the main stakeholders become aware of and accept management strategies that outperform the present fixed TAC harvest strategy. This has led to demand for further work to see management reform and modification.

Models of the broader Iberian Peninsula were also developed using GADGET (which included the southern stock of the European Hake (*Merluccius merluccius*) and two cetacean species) and EwE. These models were used to consider interactions between target species and the cetaceans – looking at the effects of fisheries management measures and trade-offs between two maximizing fisheries yield and maintaining healthy dolphin populations. The model results suggest that the recovery of the European Hake stock slows when considering the cetaceans interactions, since a reduction in fishing effort also releases the cetacean populations, which subsequently increase and consume more hake (increasing its rates of natural mortality).

6. *Strait of Sicily*

The objective of the Strait of Sicily (Mediterranean Sea region) case study aimed develop a tools to support EAFM in the area. This involved developing GADGET and Atlantis models for the area – with the GADGET model focused on tactical short-term and Atlantis on medium term strategic advice. These are the first structured tools for the implementation of EAFM in the Mediterranean, and will provide support to the General Fisheries Commission for the Mediterranean (GFCM) management plan for trawl fisheries exploiting the Deep-Water Rose Shrimp (*Parapenaeus longirostris*) and European Hake. The GADGET model has already been adopted as an alternative assessment model by the GFCM.

As with many of the other case studies it was found that trying to apply/achieve single species F_{MSY} targets in the area may not be feasible for harvested populations that are linked via trophic and technical (fleet-based) interactions. This is because the European Hake and Deep-Water Rose Shrimp are predator-prey populations that are simultaneously(?) targeted by multi-national fleets; thus, achieving F_{MSY} for hake would result in foregone catch for shrimp, while reaching F_{MSY} for the shrimp would see the hake stock overfished.

A multi-criteria decision analysis (MCDA) was also undertaken for the region to help balance biological, social and economic objectives. The MCDA and the models were then used to understand trade-offs associated with management strategies identified with stakeholders in meetings held in Sicily in 2014 to 2017. This exercise established an atmosphere of cooperation between researchers and stakeholders with FAO, Italian DG Pesca, Medac and GFCM. This has seen the models developed for the case study picked up for use by important stakeholders (including the GFCM).

7. *Black Sea Case Study*

The Black Sea case study focused on Turbot (*Psetta maxima maeotica)* and involved stakeholders from fishing organisations from Romania and all six countries bordering the Black Sea, national agencies for fisheries and aquaculture, as well as regional commissions and working groups. The work hinged on two ecosystem models - GADGET and EwE – with Bayesian belief networks applied as additional decision support tools. The models were built for the Romanian coastline and helped define a common roadmap for the area with GFCM. The work was made particularly challenging by the gaps in the fishery dependent data sets and the unknown rates of discards and IUU catch.

8. *Chatham Rise Case Study*

Two Chatham Rise case study was delivered by NIWA (New Zealand) researchers and used as a comparison with the EBFM process in Europe. An Ecopath and Atlantis model were developed for the case study area – which is to the east of New Zealand and is an important region for fisheries and biodiversity, and the site of proposed seabed mining activity. The Ecopath model was used to estimate trophic importance of each group and the food web. That information was used in combination with an expert opinion-based assessment of anticipated direct impacts of mining on these trophic groups to inform the New Zealand Environmental Protection Agency's decision committee regarding potential impacts of mining. Impacts were likely to be low or negligible, except perhaps for small demersal fish, hard-bodied macrozooplankton (krill), cephalopods and rattails & ghost sharks (Chimaeriformes).

The Atlantis ecosystem model was used to explore technical details pertaining to representation of stock recruitment relationships and to explore alternative future fishing scenarios and the implications of those for key target species (e.g. Hoki *Macruronus novaezelandiae*) and prey species that may also become fisheries targets (e.g. myctophids).

WP6 - Develop a decision support framework

The Decision Support Framework (DSF) iteratively developed within this work package was used during the case study stakeholder workshops to support communication of scenario outcomes and assist in the development of generic management plan proposals. The focus of the DSF was the presentation, comparison, and structured evaluation of a set of scenarios developed to represent candidate strategies to address identified management problems and concerns. Development occurred with the express intent of supporting evaluation of trade-offs between and within the scenarios across a range of relevant dimensions, taking stakeholder preferences and priorities explicitly into account. The results of these scenario analyses then comprised the starting point for development of management proposals. While the DSF cannot ensure stakeholders consensus, the structured approach does facilitate stakeholders/users to transparently document their positions regarding the identified strategies.

The DSF is based around interactive access to (i) summarises of the context and scenarios for the region of interest (e.g. Figure 6), visualisation dashboards that serve up model runs for comparison (e.g. Figure 7), interactive axis to Bayesian Belief Networks (Figure 8) and the Multicriteria Decision Criteria Analysis decision trees (Figure 9).

The tools making up the DSF are generic and are readily applied to new cases. Nevertheless, the MareFrame developers stressed it is not an ending point, but a beginning and they actively encourage further expansion of the toolbox to include a suite of instruments to advance EAFM. To date two on-going EU Horizon 2020 projects (REEEM[2] and FarFish[3]) are utilising the DSF and MATIS (an Icelandic Food and Biotech R&D institute who had a leadership role in MareFrame) has committed to hosting the DSF into the future.

WP7 - Synthesis & training development

This work package focused on:

- evaluation and comparison of the different ecosystem models with respect to: (i) their suitability for predicting ecosystem changes; (ii) their capability to assess socio-economic impacts; and (iii) their potential role in improving marine policies;
- proposing a roadmap for implementing integrated EAFM in Europe; and
- developing interactive learning tools to facilitate EAFM implementation.

Model comparison protocols were drawn up in conjunction with model developers. This has contributed to standardisation of protocols across international efforts (e.g. within IPCC and IPBES advisory projects such as the ISI-MIP/FISH-MIP process) and led to a seminal paper summarising the socioeconomic modelling capacity of different modelling packages and approaches (Nielsen et al 2018). The clear lack of social data (which is a lot less obtainable than economic data) saw the MareFrame researchers resort to an expert-based approach involving stakeholders weighting and scoring factors within a socio-economic impact assessment (SEIA).

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[2] REEEM: Role of technologies in an energy efficient economy – a model based analysis policy measures and transformation pathways to a sustainable energy system.

[3] FarFish aims to provide knowledge, tools and methods to support responsible, sustainable and profitable EU fisheries outside European waters, compatible with Maximum Sustainable Yield

The developers working in this work package also created a MareFrame training tool – SeafoodSim – which is a fisheries management simulation game that allows a single player to run one or more scenarios for a simulated fishery. The intent of the game is to help stakeholders understand how to propose 'good' management scenarios for testing in the models and to how to get the most out of interacting with simulation models. This can often be a significant impediment to maximizing the effectiveness of management strategy evaluation projects. The tool is still largely a scientific tool (available to developers at https://github.com/tokni) rather than a generally accessible piece of software. However, there are early efforts underway to port it to an Australian context and to make it more readily accessible for an Australian context

Case Study: Northern & Western Waters – Iceland Waters

Objective: Maintain the fish stocks in Icelandic waters at a highly sustainable level, thereby ensuring efficient exploitation, stable employment and settlement throughout Iceland.[1]

Management Problem

In general, there is a good consensus within the stakeholder group with both the objectives and the implementation of the *Icelandic Fisheries management act*. The main concerns of the stakeholder group were linked to the effects of increased taxation and apparent uncertainty which frequent regulatory changes have for the fishing industry and the Icelandic community, at both local and national level. Other issues raised by the stakeholder group include removal of the quota consolidation barriers (currently 12% of TAC), effects of municipality controlled quota, aggregation of quotas in both the small (jig and line) and large type ITQ, and whether the industry should in general take socio-economic factors into account.

Management Setting

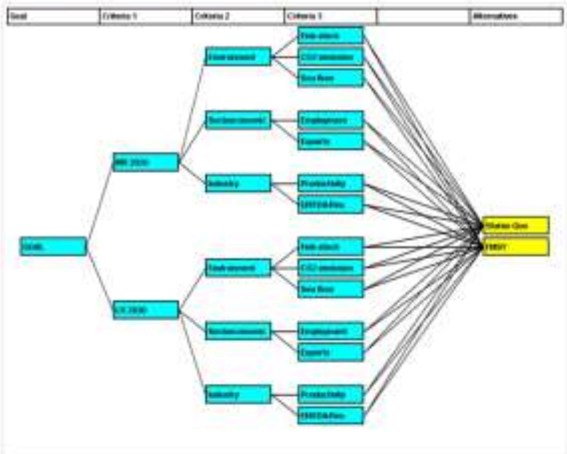
In Iceland, almost all fisheries are subject to a management system based on the concept of individually transferable quotas (ITQs). The Ministry of Industries and Innovation (formerly the Ministry of Fisheries) is responsible for management of the Icelandic fisheries and implementation of the legislation. Each fishing year (September-August), the Ministry issues regulations for each commercial fishery, including the total allowable catch (TAC) of each stock. The TAC for each species is set on the recommendations of the Marine Research Institute (MRI) which also advices the government on other regulatory issues, such as spatial and seasonal closures, gear restrictions and where applicable days-at-sea. Additional, non-biological regulations, are set by the government without consultation with the MRI.

Main objectives and criteria

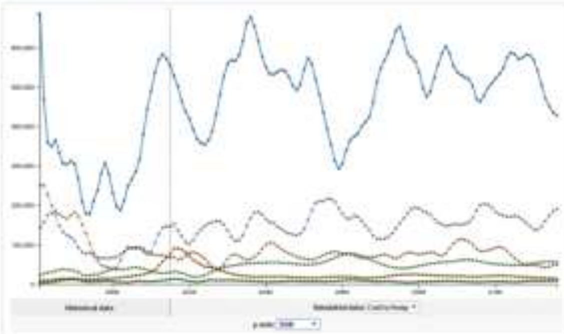
A management proposal for the case study will be evaluated in relation to a set of objectives and criteria (see the list below). These criteria were determined in co-creation with stakeholders.

Objectives for the management plan (interest variable)	Candidate operational objectives and indicators
Increasing cod stock	B_{4+} = 1,106,000 $B_{trigger}$ = 220,000t B_{lim} = 125,000t TAC = 218,000t by the end of planning period.
Stable haddock stock	B_{3+} = 104,000 $B_{trigger}$ = 45,000t B_{lim} = 45,000t TAC = 30,400t by the end of planning period.
Stable saithe stock	B_{4+} = 296,000 $B_{trigger}$ = 65,000t TAC = 58,000t by the end of planning period.
Lower CO2 emissions	10% less CO_2 emission by the end of the planning period.
Maintain sea floor integrity	5% less damage to the sea floor by the end of the planning period.
Ensure social stability	Employment in fishing and aquaculture around 2-3% of LF throughout the planning period Export earnings nearly 50% of all operating revenues of fishing by the end of planning period.
Maintain strong economic performance of industry	Increase labour productivity by 10% by the end of the planning period Mean EBITDA/Revenue level ≥ value in starting year by the end of the planning period.

Multi-Criteria Analysis



Scenario Model output



Management Scenarios

1. **Business as usual:** This scenario serves as baseline to other potential management scenarios. In the scenario the current status of management is maintained and the effects on the status of the ecosystem explored going forward. In terms of control variables this entails that the current fleet composition and harvest rate maintained.
2. **Cod to F_{msy}:** This scenario offers a slight modification of scenario 1 as here the harvest rate is adjusted in such a way that the yield of the cod fishery reaches its maximum while fleet composition remains fixed.
3. **Changes in fleet composition:** The effects of specific changes in fleet composition in terms of management restrictions are explored. Currently the small scale fishery is allotted a proportion of the quota that cannot be transferred to larger fishing vessels. This scenario analyses of the effects of removing this restriction on quota transfer from the small scale fishery.
4. **Multi-species maximum sustainable/economic yield:** The fishing rate and fleet composition is altered such that either of the following yield levels is attained:
    a. Maximum sustainable yield from the resource
    b. Maximum economic yield
5. **Environmental concerns:** This scenario investigates the effects of adjusting the harvest rate and fleet composition is such a way that overfishing and over depletion is prevented and the effects on the environment such as CO2 emissions and damage to the sea floor is reduced.

Figure 6: Screen shot of the information summary for the Icelandic case study and the modelled scenarios for that region

(a)

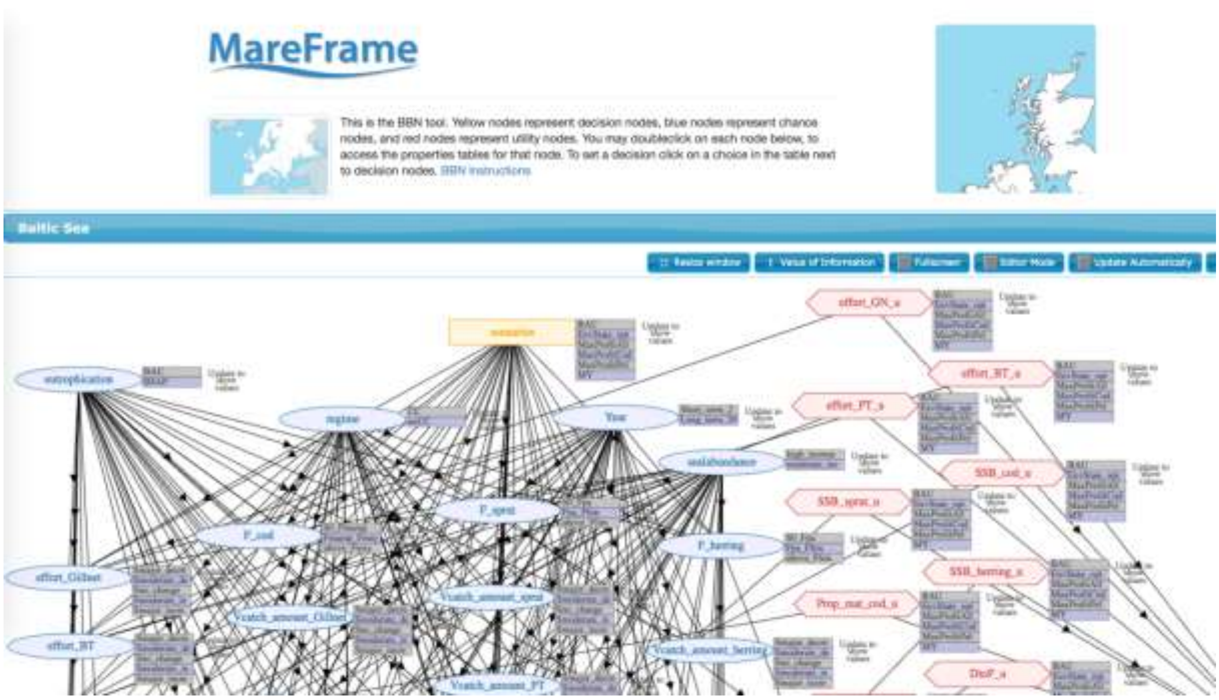

To compare scenarios click here
Timeline
Scatterplot (Biomass v Landings)
Traffic Light
Historical data
Model: EwE
Simulated data: BAU-HSE-EnvState_optimization
y-axis: Catch
Model: EwE, Env scenario: BAU, Seal scenario: HSE, Mgmt scenario: EnvState optimization
Fish
Select All
Deselect All
Fleet
Select All
Deselect All
Species
herring
sprat
Name
bottrawl
gillnet

(b)

Species	Red-Yellow	Yellow-Green	BAU	EnvState_optimization	MaxProfitAll	MaxProfitCod	MaxProfitPel	MaxYieldCod
herring	0.56	0.579	740.730	733.020	632.187	632.187	335.414	262.599
sprat	0.216	0.299	1334.053	507.613	2246.731	2246.731	571.159	1937.102
cod	0.072	0.086	148.039	225.124	41.627	41.627	13.204	153.338

Figure 7: Example dashboard plots – (a) time series and (b) traffic light results from the Baltic case study models.

(a)



(b)

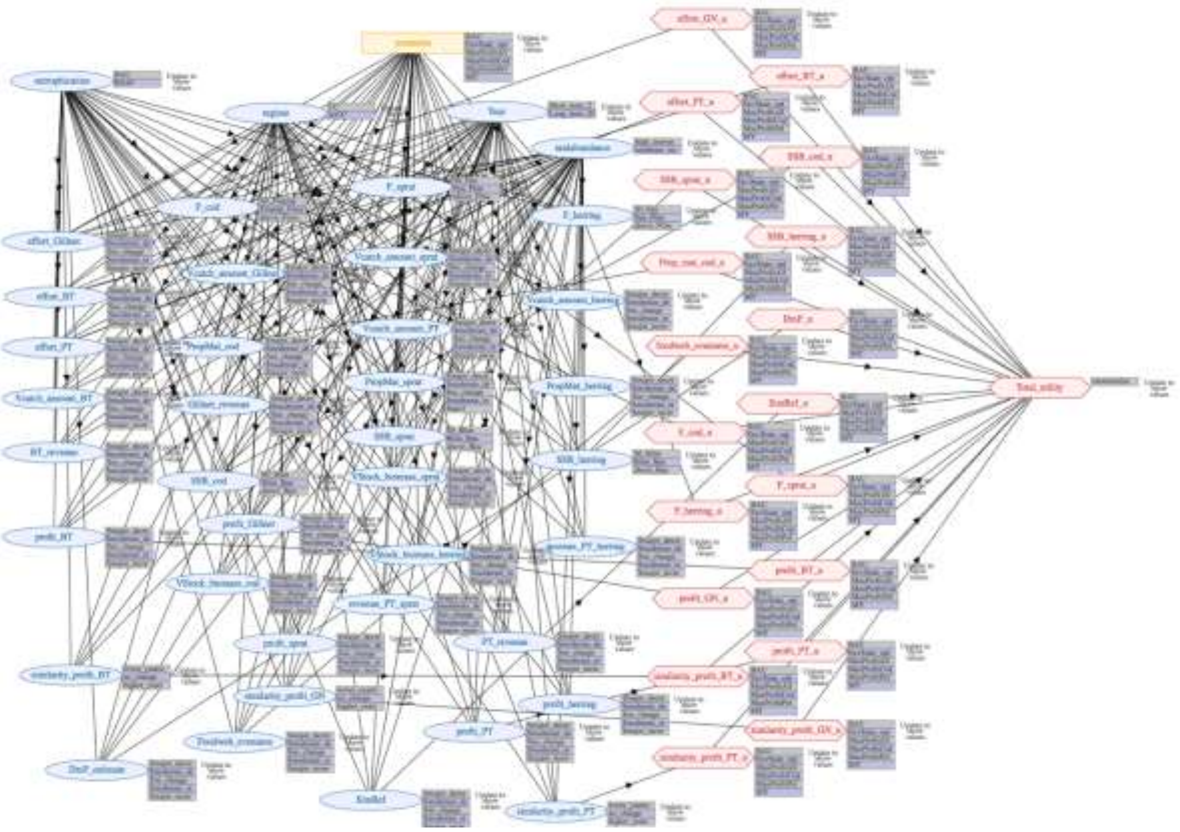


Figure 8: Example of the MareFrame Bayesian Belief Network (a) interactive interface and (b) entire model structure for the Baltic case study.

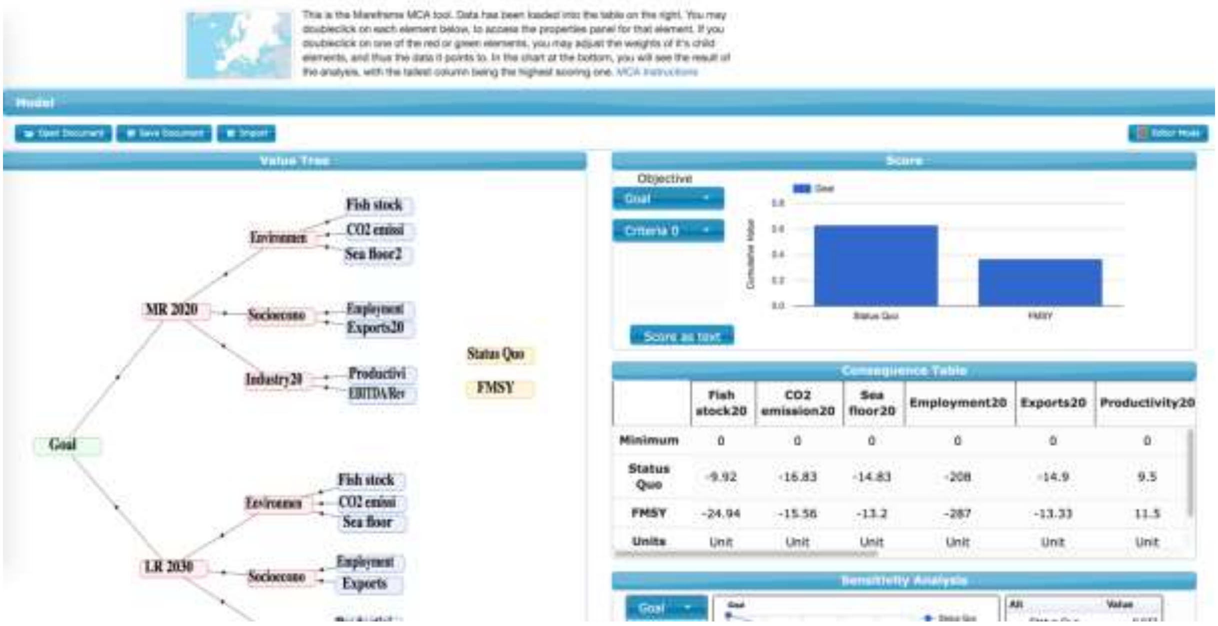


Figure 9: Example of the MareFrame multi-criteria decision analysis interactive tool.

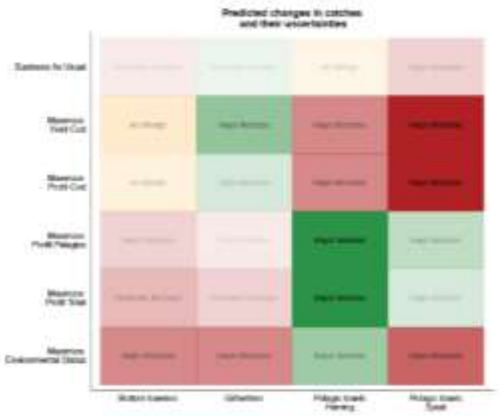
WP8 - Dissemination & training actions

The final work package was tasked with communicating results and to disseminate the results to stakeholders, consumers, consumer organisations, retailers, regulators, decision and policy makers, industry, NGOs, other researchers (EU and globally) etc. The size, complexity and diversity of the MareFrame project (which had 28 partners from within the EU, Australia and New Zealand) meant the task was not a trivial one, especially if the scientific results were to be communicated accurately to audiences of diverse backgrounds. This meant effort was invested in:

- (i) a social media presence (@MareFrame on Twitter);
- (ii) a range of presentation styles – with infographics used to try to summarise the model findings (e.g. Figure 10) – including a YouTube channel (https://www.youtube.com/watch?v=2KKpeMGQI0w&list=PLZGs8XSSa2cIYp6I0Erhl92tp_0Fo14Rn) featuring short videos describing the project, its intent and outcomes;
- (iii) case study fact sheets;
- (iv) ongoing website (hosted and maintained by Matis until at least 2020;
- (v) technical scientific papers (including a special issue);
- (vi) teaching materials hosted online as a Master Class; and
- (vii) the MareFrame Portfolio document (which summarises the entire project).

The dissemination strategy focused on awareness (activities and outcomes), understanding and action – aiming at a change of practice due to the adoption of the MareFrame approaches. This is why special attention was paid to dissemination activities associated with the Decision-Support Framework and associated tools and their potential users. Dedicated effort was also put into communicating directly with decision and policy makers, the fishing associations and other stakeholders directly involved in the fisheries Management Plans. As an example, a Policy Day was held in Brussels on the 20th June 2017, and another on the 13th December 2017.

(a)



(b)

(c)

Figure 10: Example MareFrame summaries and infographics for scenario results

Useful MareFrame Links

A number of useful MareFrame links remain active:

Main MareFrame page - http://mareframe-fp7.org/

Decision Support Framework - https://mareframe.github.io/dsf/

You tube channel content - https://www.youtube.com/watch?v=2KKpeMGQI0w&list=PLZGs8XSSa2cIYp6I0Erhl92tp_0Fo14Rn

Database git hub - https://github.com/mareframe/mfdb

Advancing EBFM in the EU

The MareFrame researchers produced a road-map for integration of the decisions support framework into EU processes in support of EAFM. This document took the form of a policy brief that both identified barriers for the implementation of the framework and EAFM and provided for EU decision and policy makers recommendations on how to overcome these barriers. This document has broad value and has future utility not only to policy makers but also to researchers and stakeholders – instructing on how to ensure ecosystem issues (including socio-economics) are considered effectively in future resource management decisions (Figure 11 and Figure 12).

Future directions were also stressed in the final MareFrame products – pointing out that while ecosystem models are slowly shifting to being socioecological models, much remains to be done on this front. To successfully implement EAFM will require closer collaboration across disciplines. Moreover, while economics has received some attention in EAFM already, the social aspects need much richer consideration, as the socio-economic impacts of implementing EAFM could be extreme (and are highly contingent on how decision makers prioritise trade-offs). The very fact that ICES's goal of achieving single species MSY across all species cannot be achieved means that a rethink is required and in doing that there will need to be transparent discussion around the fact that some stocks, fleets and regions will be prioritised in future actions. One such trade-off already identified within MareFrame was the trade-off between the demersal cod fishery and the pelagic fishery in the Baltic Sea, where there is a clear benefit for the fleet targeting cod to protect the pelagic fish stocks (as prey), but no benefit to the pelagic fleet over avoiding the overfishing of cod (a predator that competes with the fleet).

HOW TO ADVANCE TOWARDS AN ECOSYSTEM-BASED APPROACH TO FISHERIES MANAGEMENT (EAFM) IN THE EUROPEAN UNION

The widespread implementation of an EAFM is a central goal for the EU. Although there have been significant advances, is wider implementation still faces structural and institutional challenges. MareFrame has identified four central challenges: policy harmonization of the CFP and MSFD; inadequate platforms for meaningful participation; insufficient frameworks for balancing objectives; and the need of capacity building for advice and uptake.

MareFrame has designed a ***Decision Support Framework*** (DSF) to address these challenges in cooperation with stakeholders. The DSF includes:

(1) a co-creation process, involving cooperation with stakeholders to identify, analyse, and explore how to address the problem;
(2) ecosystem models, to understand the likely consequences of management options
(3) a set of computerized Decision Support Tools that aid complex planning and decision-making
(4) educational resources to facilitate the use of the DSF

	Component of the MareFrame DSF addressing specific challenge			
Challenge	**Co-creation**	**Ecosystem Model**	**Decision Support Tools**	**Education materials**
Policy harmonization of the CFP and MSFD	✓	✓		
Inadequate platforms for meaningful participation	✓		✓	
Insufficient frameworks for balancing objectives		✓	✓	✓
Capacity building needed for advice and uptake	✓	✓		✓

The findings of MareFrame advocate that managers adopt all four components of the DSF together for best practice, but the components can be implemented piece by piece in the case of scarce resources or context-dependent circumstances.

1. Policy harmonization of the CFP and MSFD

There is room for improving the CFP and the MSFD coherence associated to the interplay of the multilevel governance (Member States and EU level), facilitating how decision makers, science advisors, and stakeholders should analyse trade-offs.

What MareFrame has done	Barrier Remaining	Recommended Action
Identified institutional and legal barriers and challenges	Sector/area based policies may slow down advances towards EAFM (fisheries, environmental)	Enhance regional policy structures and strengthen links with Regional Sea Conventions
Analysed the advisory system for an EAFM	Lack of resources/ resource optimization; fragmentation of the knowledge pool, piecemeal advice	Allocate resources strategically to broaden the scope of science processes
Used scoping exercises to address cross policy issues (e.g. joint consideration of GES Descriptors 3, 4 and 6)	Different users request different advice	Enhance capacity of the advisory system to support cross-policy cooperation (involving ICES, GFCM, STECF, JRC)

Figure 11: Page 1 of the MareFrame roadmap for implementing EAFM

2. Inadequate platforms for meaningful participation

There are many stakeholder forums in the EU, but their activities are in many cases weakly connected to decision-making. Meaningful participation with regard to EAFM requires platforms that foster iterative scoping of problems for adaptive planning and management.

What MareFrame has done	Barrier Remaining	Recommended Action
Enhanced participatory processes with facilitators and scientific support	Lack of funding and awareness (resources and commitment)	Integrate structured dialogue in existing work programs
Analysed the relationship between Advisory Councils and Member States Regional Groups	Underdeveloped links between (some of) the ACs and the MSRGs	Provide guidance on best practice for cooperation
Analysed the science-policy-society gaps and the need for multiple sources of knowledge connected to relevant policy fora	Stakeholder fatigue and "misuse" of consultative processes detached from decision-making; overlapping work and underestimation of requirements and workloads; legitimacy of constituencies; differences in capacity to influence the dialogue	Use the regionalization process to support scoping exercises. Regionalization should include management at regional, sub-regional and supra-regional levels

3. Insufficient frameworks for balancing objectives

EAFM requires the capacity to address and balance a number of conflicting ecological, economic, and social objectives in a fair, transparent, and legitimate manner where costs and benefits of specific options on the various dimensions of sustainability are described systematically.

What MareFrame has done	Barrier Remaining	Recommended Action
Developed methodology supporting joint consideration and evaluation of ecological, economic, and social objectives/ trade-offs	Lack of social and economic indicators and defined thresholds; limitations with regards to incorporate such indicators in ecosystem model frameworks; difficulties of reconciling multiple objectives with multiple decision makers at multiple levels	Support the collection of relevant data. Interdisciplinary collaboration to model full ecosystem by considering social, economic and environmental aspect. Define reference levels for ecosystem indicators; establish scoping processes involving all authority levels
Developed DSTs for informed decision-making	DSTs have not been tested in real planning decision-making	Facilitate the actual use of DSTs at local level to test suitability and usefulness

4. Capacity building needed for advice generation and uptake

There is a need to strengthen the supply of EA advice from scientists and stakeholders. In addition, capacity building is necessary for decision makers to better know how to handle EA advice.

What MareFrame has done	Barrier Remaining	Recommended Action
Cooperation between natural social sciences, transdisciplinary research to address uncertainty and complexity of social-ecological systems	Lack of skills for enhancing multi-disciplinary research approaches	Promote "a sustainability sciences approach," providing adequate resources and platforms for transdisciplinary cooperation in research
Assessed the role of the ACs in the EAFM and relevant fora for the exploration of trade-offs	Lack of availability of stakeholders to provide knowledge into a compatible and connected format within an EAFM	Conduct practical experimentation connected to ongoing activities with ICES and STECF to identify the benefits of an EAFM for the ACs

Figure 12: Page 2 of the MareFrame EAFM roadmap.

Potential for Australia

Australia is arguably further down the ecosystem-based fisheries management (EBFM) road than the EU. However, it is far from having a complete or comfortable implementation – especially at tactical levels. This led to intense interest around the development of the national harvest strategy policy (FRDC project 2010-061), finalised in 2018, and has seen recent interest in the definition of multispecies harvest strategies (FRDC project 2018-021) and a review of the ecological risk assessment of the effects of fishing (ERAEF) framework (as part of FRDC project 2018-020). Consequently, there are still lessons from MareFrame that can be useful on the Australia fisheries management front. The following paragraphs outline what aspects of the MareFrame work can be transported to Australia – addressing each of MareFrame's 4 core principles in turn.

Co-creation processes

There has been growing appreciation that **co-creation processes** are important iterative processes that can utilise stakeholders' local knowledge to improve transparency, the reliability of outcomes and increase uptake. Co-creation and participation are already at the heart of the Australian Fisheries Management Authority's management and scientific committees. Co-creation is less clear at the state level, but at the federal level it is well established. The community level response as part of the 'supertrawler experience' (where there was a public backlash to the application to bring in a factor freezer trawler for the small pelagic fishery; Tracey et al 2013) indicates there is likely a need to interact with an even broader audience if Australian fisheries are to remain an evidence-based undertaking. Such broad engagement by the research and management community would likely need to involve online and other media avenues and would require the authentic building of trust around the content. It will not be an easy or necessarily rapid process (Mercer-Mapstone et al 2018), but the level of connection and cross validation of options across all parties will be required for Australian fisheries and coastal communities to navigate the issues of sustainability and adaptation necessary in the currently rapidly changing conditions (Fulton et al 2018b).

It is certainly the case that where there is a mis-match of the available scientific tools and stakeholder interests it is hard to engage many stakeholders, and those that do participate can become fatigued if they do not see progress at their expected/needed timeframe (as seen in the Scottish case study of MareFrame). Also, as identified by Ramírez-Monsalve et al (2016a), it can be difficult for some stakeholders to make the mental shift from short-term/tactical to long-term/strategic thinking. Although, experience from climate change research and negotiations around appropriate responses would indicate that this failing goes far beyond fisheries and is a cognitive barrier that needs to be addressed with specific re-framing exercises (Richert et al 2017).

Nielsen et al (2019) indicated that one means of anchoring stakeholder expectations in practical (feasible) and evidence-based bounds is to firmly ground co-design activities in the context of governance and policy – something the current management arrangements endeavour to do. Though it must be noted that it can take careful facilitation to avoid group dynamics that either see certain short-term interests dominate (seeing the co-design process dominated by specific interests) on the one hand (Nielsen et al 2019), or fragmentation and hostility on the other (Colvin et al 2015).

Ecosystem models

Arguably Australia remains amongst the world leaders in the development and implementation of ecosystem models. For instance, in 2017-2018 Australian researchers produced the world's first ensemble consideration of the impacts of climate change on regional fisheries (Fulton et al 2018b); with the output now being used in a risk and vulnerability assessment process that aims to increase the robustness of AFMA fisheries to climate effects (FRDC project 2016-059).

Australia still has areas of improvement, however. There are few implementations of multi-species assessment models – such as GADGET – in Australia, with the Northern Prawn Fishery models being a notable exception (Dichmont et al 2008). This is likely to be important going forward, especially in the context of multi-species harvest strategies. Models of intermediate complexity (MICE; Plagányi et al 2014) and size-based models that are formulated with trait definitions (Scott et al 2014) are other approaches that show high degrees of potential as multi-species assessment tools. It may also be beneficial for future research projects to invest in developing the Australian equivalents of the Charmingly Simple Model (CSM; Pope et al 2006), multispecies Schaefer model (ICES 2007) and emulators such as the T-ONS model (MATIS 2018) was developed to meet this need. These kinds of 'simpler' or 'rapid' models are extremely transportable and stakeholder friendly, making them ideal for the co-creation process. The short run time of these models allows for on the fly initial examination of potential multispecies management strategies in workshops, with multiple iterations/thoughts on potential strategies occurring within the workshop (rather than across multiple workshops months apart) allowing for rich dialog amongst participants and convergence or definition of more sophisticated, nuanced and attractive strategies than is possible with larger slower models. Such an approach does not mean abandoning what has already been invested in the larger models, as (i) they can highlight things missed with simpler representations (Fulton et al 2015) and (ii) because the emulators (e.g. T-ONS) are statistical 'mimics' trained on the larger models and so require the knowledge and output gained from those larger models in the first place. As identified in MareFrame the strength of the modelling approach comes through diversity and complementarity – a lesson Australian researches have been championing for close to two decades.

One area where Australia can benefit from a MareFrame like approach is the improved adoption of database technologies in support of fisheries and EBFM. Australia fisheries scientists, managers and other interested parties are in need of easily accessible information repositories for rapid reporting of the state of stocks and environmental conditions and for parameterising multi-species and ecosystem tools used in support of fisheries management. While MareFrame opted for a distributed approach – providing a database structure that could be deployed locally/regionally, rather than having a single centralised database – the much smaller researcher population, the smaller quantities of available data and the greater geographic extent in Australia argues for a more centralised approach. Such an undertaking seems a natural extension of the IMOS and AODN initiatives – though it would require significant funding and ongoing maintenance, which is in part why it has yet to have happened. Nevertheless, the significant technical barriers that prevented the vision metamorphosing into reality in the past have lowered and the time is ripe to make it a reality by leveraging off of new computing technologies, sensor technologies, artificial intelligence and machine learning (including lessons from 'big data' analytics). Collaboration on a truly interoperable system (in a similar vein to the MareFrame database) rather than simply supporting data portals may be a good joint collaboration for the various members of the Research Providers Network.

Australia, like MareFrame, has also been outing significant effort into developing accessible modelling tools that facilitate model creation and use. Indeed, a number of the MareFrame tools have now been incorporated into the Atlantis Rtools packages (https://github.com/Atlantis-Ecosystem-Model). FRDC and CSIRO have also previously funded visualisation platforms for model output libraries (www.csiro.au/seaview/index.html), similar in intent to the MareFrame DSF. Although the MareFrame package has greater interactive capacity – especially in terms of the multi-criterion decision analysis and Bayesian Belief Networks and that (or something similar) may be a useful future EBFM development for Australia.

The SESSF was one of the first fisheries in the world (if not the first) to use ecosystem models in a management strategy evaluation framework to explore options for EBFM (Fulton et al 2014) and those models continue to be used to provide insight into EBFM questions (Smith et al 2015, Fulton et al 2018b). This means that there is a growing familiarity within that fishery on how such modelling approaches can usefully provide medium-long term management advice, as well as stimulate learning and create 'opportunities for stakeholders to search for strategic and policy relevant solutions and to position themselves in an EBFM context' (Nielsen et al 2019). These previous Australian EBFM exercises have used the traffic light and amoeba plot approaches MareFrame used in presenting results across scenarios (e.g. Dichmont et al 2013, Fulton et al 2014), but have taken a more informal approach to how they supported the trade-off analysis across different stakeholder objectives and indicators. The multi-criterion decision analysis approach has its own sets of strengths and weaknesses (Kujawski 2003, Montibeller and Franco 2010, Velasquez and Hester 2013; and as seen in the various MareFrame case studies), but does appear to provide a useful potential approach for use in conjunction with model simulations to provide combined support for a participatory approach to scenario-based EBFM planning exercises (Nielsen et al 2019), as does the 'N dimensional Potato' approach (where unpalatable options are pared away by the different groups and the remaining options then become the basis for a discussion of feasible and mutually tolerable solutions; Pope et al 2019).

Decision support tools

There is a blurring of modelling and decision support tools and both are (formally or informally) components of larger decision support frameworks – both in MareFrame and in Australia. Many of the points made above for ecosystem models also apply here. There is a great value-add opportunity around providing visualisation platforms that ease access to information and allow for interactive learning. Such platforms revolutionise user capacity (witness what has happened globally since the advent of smart phone technology) and significantly value add to existing knowledge bases.

A number of decision support tools – inspired by MareFrame experience – could be of value in Australia, including

- centralized information sources on Australian fisheries - the kernel of which likely already exists in the Status of Australian Fish Stocks website (www.fish.gov.au/Reports), the prototype Australian Fisheries Health check portal (Hobday et al 2016), and the WhichFish webpage (http://whichfish.com.au/)
- visualization platforms that provide a dashboard and infographics for exploring and communicating management options – seaview (http://www.csiro.au/seaview/index.html) is an early example but much more is now possible – with the Norwegian (www.barentswatch.no/en) and Chilean aquaculture industries investing significantly in this area over the past few years to extend it to real time tactical tools as well as strategic planning tools (Steven et al JOO in review; Figure 13).
- interactive tools – similar to the MareFrame multi-criteria decision analysis and Bayesian belief network plug-ins to their DSF (https://mareframe.github.io/dsf/)
- expansion of the socioeconomic tools available to Australian fisheries – for example, the Socio-Economic Impact Assessment (SEIA) procedures developed by MareFrame may be usefully adapted for Australia. Recent work looking at vulnerability of Australian federal fisheries to climate change has highlighted the need for a clear process for the non-ecological aspects of the system and while that work has found a useful route using ‘impact pathways’ the SEIA may be a useful future tool for doing the kind of in-depth benchmarking that have in recent years provided US fisheries with a strong foundation for future planning around climate impacts to fisheries communities (Colburn et al 2012, 2016).

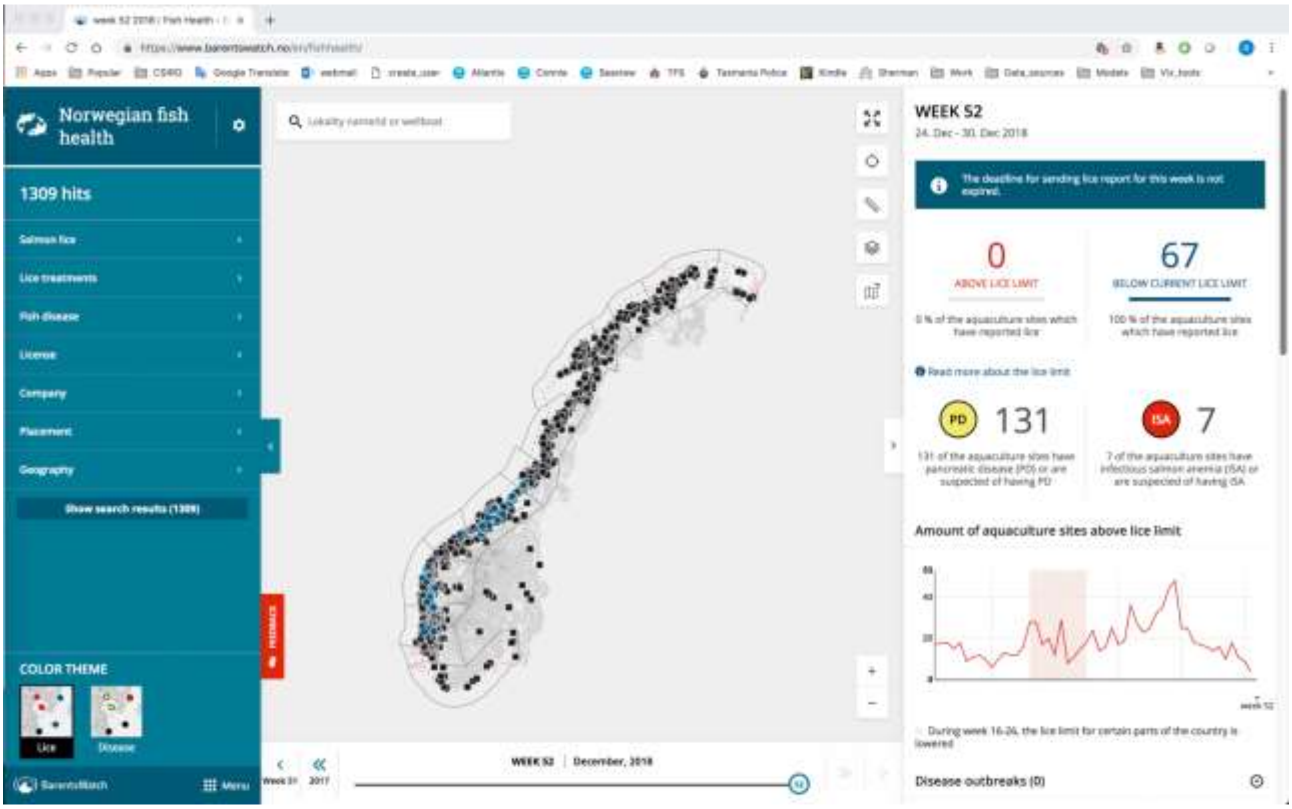


Figure 13: Example screenshot of BarentsWatch website – from www.barentswatch.no/en

Education resources

Australia has some of the world's best fisheries scientists and shows some of the most forward thinking natural resource managers – who are already attempting to be pre-prepared for climate impacts on fisheries (for example). Nonetheless, there is still significant scope for improving the general education levels of resource managers and industry members and consultants in Australia around EBFM – what it is and how to do it. The kind of 'master class' developed by MareFrame provides an excellent template that could be applied in Australia – in collaboration with an Australian university. Indeed, there is scope for a range of such courses, not just for fisheries science, but in new observing technologies, the effective use of information platforms, EBFM and risk assessment protocols.

More broadly (and something MareFrame only lightly touched upon) there is significant scope in Australia for education of the general public on Australian fish stocks and ecosystems, their status and management. The media and social media platform hosted rhetoric on the state of Australian fisheries is often heavily influenced by overseas or global commentary, which can be disconnected from the local reality. It would benefit both the broader community and fisheries in Australia if the discourse was more firmly linked to good local objective information on the status of Australian stocks.

General Barriers to Ecosystem Based Management

The policy brief and roadmap drawn up by MareFrame, as well as a number of peer reviewed articles by MareFrame researchers, identified a number of roadblocks to the successful implementation of EAFM in the EU. While Australia is a single nation not a multi-national conglomeration, there are lessons relevant to Australia to be learnt from these EU observations.

Ramírez-Monsalve et al (2016a) observed that one of the significant impediments to EBFM in the EU is the multi-jurisdictional nature of resource management there – with maritime policies drawn up and implemented across multiple governmental levels (van Tatenhove 2013). The same is true in Australia – thought between the states and the Commonwealth, rather than between nations. The lack of coordination between jurisdictions causing mismatches in coverage, expectations of industry and management effectiveness, especially as species range shift with climate change (Bates et al 2014, Sunday et al 2015, Fulton et al 2018b). Centralisation of decisions for shared stocks in a co-management authority may be an option going forward (Fulton et al 2018b).

In the context of the EU there has been a realisation that they needed to shift their management to the appropriate regional scales. This is similar to the large scale definition of fisheries in Australia, which match ecosystem scales rather than focusing on individual stocks. Continuing to match those ecosystems as they shift with climate makes sense, even if it requires some cross state coordination. Although we may need to go even further, recognising interactions between large-scale fisheries in the same region – e.g. pelagics and demersals (such as between the Small Pelagics Fishery (SPF) and the SESSF) – this is because "creation of separate management plans for the demersal and – presumably – pelagic fisheries in this area does not make sense" (Holt in Ramírez-Monsalve et al 2016a). A common challenge facing the EU and Australia is how to reform management plans so they are cognisant of the interactions between multiple stocks. The EU has started to tackle this by suggesting sets of F-ranges to represent target exploitation rates of the key stocks, this is a first step attempt to move away from the blanket requirement to use single species B_{MSY} as a target reference point. In Australia we are already observing that in mixed (multi-species) fisheries some species will underperform versus expectations. As multispecies plans recognise that not all species can be at a simple uniform reference point (whether that is B_{MSY}, B_{MEY}, or B_{48} etc) it will be an inevitability that some stocks (and fisheries) will benefit more than others. This will be a potential source of conflict in both Australia and the EU and in neither location do existing institutions have transparent mechanisms in place to deal with such conflicts. This is an important institutional challenge to an EAFM (Ramírez-Monsalve et al 2016a).

An additional step required in both Europe and Australia is harmonisation of environmental and fisheries legislation and policy – in both locations institutional gaps remain between the two topic areas (Jennings et al 2014, Ramírez-Monsalve et al 2016a). Asymmetries between the policies hamper attempts to advance

EAFM/EBFM and create confusion and frustration of expectations from different bodies. In Australia, there has been effort to align harvest and bycatch policies, but ensuring consistency will be an ongoing need. Based on past experience in Australia, there may be little appetite to go further to the creation of a multi-industry, multi-jurisdiction spanning agency. Such an approach was unpalatable during the short-lived existence of the National Oceans Office (Vince et al 2015) and there is equally strong resistance to the concept in Europe. It is clear that worldwide we cannot wait for the establishment of new decision-making processes and agencies to deliver EAFM, but must instead focus on pragmatic tools and other innovations (Ramírez-Monsalve et al 2016a).

A transition to EAFM will not be rapid – the current incomplete implementation has already taken two decades – and this is in part because it is one of very many concerns on the plates of industry members and managers alike. They have their own day-to-day fires to put out, let alone tackling such apparently longer term question – there are high transition costs of shifting attention and scales (Freire-Gibb et al 2014). EAFM cannot be proposed "just because" there has to be tangible benefits to provide short term motivation to shift (Scheveningen group in Ramírez-Monsalve et al 2016a). This concurs with the experience of many groups trying to support EAFM/EBFM exercises – where it is clearly evident that short-term thinking dominates the industrial, institutional and legislative context (Jennings and Rice 2011, Jennings et al ref). Thankfully there is growing evidence that there are significant payoffs to implementing EBFM (Fulton et al 2018a).

The situation is made even more complex when there are conflicting objectives – requiring managers to balance ecological sustainability, economic viability and social viability. The presence of multiple trade-offs between these aspects complicates the identification of suitable (mutually satisficing management strategies) that also satisfy policy requirements (Neilsen et al 2019). Successfully presenting the trade-offs; transparently finding compromises; integrating social, economic and ecological indicators/data, highlighting uncertainty as appropriate while simultaneously avoiding information overload, remain the holy grail of decision support science (Hyder et al., 2015, Nielsen et al 2019). Even when stakeholders are willing to engage there is the need for expectation management, as ecosystem models work on different time scales and cannot replicate the apparent levels of certainty that are characteristic of the traditional single species projections that experienced stakeholders are most familiar with (Degnbol 2015). These models are used in a different way and stakeholders must be guided into that new use, so that they are comfortable with it and can use it well. Nielsen et al (2019) suggest that marrying simulation models and multi-criterion decision analysis in a participatory approach may be a good way to do this; one which will also stimulate learning and create opportunities for stakeholder dialog that allows for a more productive exploration of EBFM alternatives.

Lastly, as has been the experience elsewhere in the world – Australia included - Ramírez-Monsalve et al (2016b) concluded that the social dimension of EBFM is currently being short changed. There is a dearth of suitable indicators (and available data), which means at present these aspects are often overlooked or stand the highest chance of being traded-off against ecological and economic aspects of any suggested management actions. If the policy demand for sustainability ecologically, economically and socially is to be met in full there must be ongoing efforts to address this (as already initiated by FRDC's Human Dimensions Research Subprogram).

Implications

The majority of the work undertaken in MareFrame obviously has an EU focus. However, the broad lessons are directly applicable to Australia and will be of direct benefit to a number of ongoing initiatives around the implementation of EBFM – such as multispecies harvest control rules, cumulative impact assessments, review of ERAEF and the adaptation of Australian fisheries for climate change impacts. In addition, modifications to Atlantis undertaken as part of the MareFrame work are now available in Australia and the modelling tools developed by MareFrame have also been adapted into the packages available to Australian users.

The recommendations listed above should also help guide EBFM research and implementation in Australia over the next decade.

Recommendations & Further Development

As laid under *Discussion of the Outcomes of MareFrame* and particularly the section titled *Potential for Australia* there are a number of lessons for Australia that MareFrame provides. Likewise, there are a number of technologies that would be of direct benefit to Australia if implemented here. The complete list of actions that may be beneficial includes:

- Ongoing harmonization of environmental and fisheries policy
- Further work on EBFM indicators and tactical management tools (e.g. multispecies harvest control rules)
- Renewal of information on ecosystem status and connections (some data is now many decades old) and development of a pragmatic monitoring scheme (beginning with a review of the potential provided by new sensor technologies)
- Looking into ways to broaden engagement and co-creation (including general information dissemination to the broader community)
- Trialing a combined Simulation-Multi-Criterion Decision Analysis approach to exploring EBFM solutions; potentially employing the "N dimensional potato" process
- Expanding the number of multispecies and emulator models available for doing tactical fisheries assessments
- Major collaboration between members of the Research Providers Network around delivery of a database and reporting framework that can be used to query all available information on Australian ecosystems and fisheries (this would be a natural outgrowth of IMOS and the AODN with significant value-add potential)
- Development of new interactive visualization and decision support tools – these can be linked to the database and/or simulation results to allow for exploration of all available knowledge on the fisheries and EBFM implementation.
- Master classes on fisheries science, ecosystems, new observing technologies, the effective use of information platforms, EBFM and risk assessment protocols
- Development of informative social indices and data streams
- Application of the Socio-Economic Impact Assessment (SEIA) procedures to provide a complete understanding of the socio-economic dependence and vulnerabilities of Australian fishing communities (for planning and future proofing purposes).

Extension and Adoption

In addition to this report, the lessons are being folded into the appropriate ongoing projects – e.g. multispecies harvest strategies (FRDC project 2018-021), cumulative impact assessments and the review of ERAEF (FRDC project 2018-020), adaptation of Australian fisheries management for climate change impacts (FRDC project 2016-059). The recommendations will also be used as a basis for shaping future research funding proposal priorities.

Project materials developed

No written or online materials other than this report have been generated by the project. However, Atlantis code modifications and an expanded list of Rtools for implementing ecosystem models have been folded into the existing code repositories so they will be available for future use.

Appendices

Appendix 1 – References

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