Deliverable D4.23
Deliverable title: Case study Fisheries on Regionally-Integrated and Spatially-Explicit Fisheries and Ecosystem Management (RISE-FEM)
Due date of deliverable: 26 Actual submission date: 33

Name of lead beneficiary: IFREMER

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Dissemination level:

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1. Executive summary

A variety of ecosystem conservation principles and policies now frame the management of fishing activity and so do the spatial planning of different sectorial activities. These framework policies are additional to classical fishery management. There is a risk that the policies applying on the marine system in different sectors are not coherent from a fisheries point of view. This COFASP Case Study envisaged how to integrate multiple objectives of different policies into fishery management scenarios. The spatial management of fishing activity has the potential to meet the multiple objectives of the various policies currently enforced, on a habitat basis. In the past decade, spatially-explicit management measures have been implemented and spatially-explicit ecosystem models developed. Here we reviewed the state of the art in Regionally-Integrated and Spatially-Explicit Fisheries and Ecosystem Management (RISE-FEM) from both the Northern and the Mediterranean perspectives. To further improve scientific advice on spatial fisheries management in order to meet multiple objectives, three research needs were identified:

- Develop Management Strategy Evaluation (MSE) for multiple-objective and multiple-sector spatial management schemes
- Improve knowledge on and evaluation of functional habitats
- Develop spatially-explicit end-to-end models with appropriate complexity for spatial MSE

2. Introduction

2.1. Context and objectives

The ecosystem approach to fisheries (EAF) is about balancing the exploitation of resources with the conservation of ecosystem functions, notably those that sustain these resources. Eco-regions and habitats within eco-regions correspond to particular scales at which resource dynamics and ecosystem health can be matched. An EAF thus entails developing spatially-explicit management tools and integrating fisheries and ecosystem objectives regionally within one single management scheme. The objective of the RISE-FEM Case Study of the EraNet COFASP is to link integrated fisheries and ecosystem management together with marine spatial planning (MSP). The Case Study will aim at aggregating within one single framework methodological approaches that are currently used in isolation, namely

- integrated-ecosystem assessment,
- spatially-explicit end-to-end modelling,
- GIS-based spatial planning optimization,
- and governance/management scenario testing

as well as at applying these methods to a number of pilot eco-regions. The ultimate goal of the RISE-FEM Case Study is to foster new governance schemes, notably through scenario testing, entailed by the ecosystem approach to fisheries and the Marine Strategy Framework Directive (MFSD) in particular example eco-regions.

2.2. Why organizing an Open Meeting?

The RISE-FEM Case Study is timely as these ideas have been around within the scientific community for a while already. However, linking integrated fisheries and ecosystem management together with spatial planning is challenging both conceptually and methodologically. Therefore, a careful planning of the upstream research needed to reach this objective is required. The RISE-FEM Case Study aims at producing a Joint Science Programme (JSP) between interested COFASP partners based on a review of the current state-of-the-art in the 4 above mentioned methodological approaches as well as in their coupling. This JSP is meant to contribute to the scientific content of the COFASP 2016 joint funding call in order to generate funds for developing the identified research plan.

The state-of-the-art review was based on a 2-day open meeting gathering scientists in the fields of ecosystem assessment and modelling, spatial planning and governance together with managers and stakeholders.

2.3. Content and program of the Open Meeting

The main philosophy of the meeting was to invite expert scientists as speakers asking them to review the state-of-the-art in their field of expertise as well as to identify gaps and needs for future research. The meeting was based on presentations by these invited keynote speakers and discussion panels (see Annex II for the list of participants, the Open Meeting agenda, and short bio-sketches of invited speakers). It was subdivided in 4 sessions corresponding to the 4 methodological approaches identified as being used in isolation but necessary to reach regionally-integrated and spatially-explicit fisheries and ecosystem Management

- Session 1: Integrated ecosystem assessment
- Session 2: Marine spatial planning, with specific focus on fishing effort and human activities allocation
- Session 3: Spatially explicit ecosystem (end-to-end) modelling
- Session 4 : Governance at the eco-region scale, including Marine Protected Areas and linking different policies (e.g. Common Fisheries Policy (CFP) and Marine Framework Strategy Directive (MSFD))

Two speakers per session were invited in order to cover a southern European and a northern European case study area. Each invited speaker gave a one-hour keynote speech and the two presentations of each session were followed by a one-hour discussion between participants. These discussions resulted in the identification of joint global research priorities as the basis for a JSP defining common methodological approaches to be developed and applied to specific eco-regions. An additional day following the workshop was opened to COFASP partners only in order to build on the workshop reviews and to draft these research priorities.

3. Linking ecosystem health assessment over defined habitats and spatial planning across sectors including spatial management of fishing effort

3.1. Session 1: Integrated ecosystem assessment (IEA)

3.1.1. Integrated Ecosystem Assessments in support of the ecosystem approach to fisheries management: Northern Case Studies - Andrew Kenny (CEFAS, Lowestoft, UK)

Two examples of IEA were presented in order to illustrate how methodological approaches evolved over the last 10 years. The first example was ICES IEA in the North Sea. ICES regional IEA Working Groups have been established in the 2000s and developed methodological approaches that are mainly data driven since then. In contrast, advisory Working Groups have been developing a policy-driven approach based on subjective expert judgment to produce impact matrices relating human pressures to ecosystem components. It is important to recognize that both approaches are part of the same solution and that IEA is neither a Traditional Status Reporting that mostly describes state nor a sectorial assessment focusing on a specific human activity or natural resource, but a holistic approach covering the different trophic levels of the ecosystem in interaction with physical environment and human activities. Data driven IEA developed for the North Sea is based on the analysis of a collection of data time series covering these different ecosystem components: the physical environment (oceanographic data), primary production and plankton (Continuous Plankton Recorder data), fish (fish landings by species and fish stock assessment), top predators (sea birds data). These gridded data are then used to identify

1. spatial patterns in both the physical/abiotic environment and biota based on multivariate clustering techniques and to relate these together; and
2. temporal changes (shifts and/or cycles) in ecosystem state based on multivariate ordination techniques.

Drivers of temporal changes through connections between ecosystem compartments can then be identified using simplified ecosystem models where main ecosystem components are summarized by multivariate ordination axes that are then correlated between each other to reveal bottom-up and top-down controls. Analyses on the North Sea highlighted long-term cycles between top-down control and bottom-up forcing.

In conclusion, this approach brings a better understanding of the North Sea ecosystem dynamics but, it remains a difficulty in using understanding directly in support of management advice. There is a need in this respect to develop mixed fisheries, multispecies assessments models, along with simplified ecosystem models to better apply this understanding.

The second example was based on NAFO's Ecosystem Approach to Fisheries Management (EAFM) in the North West Atlantic developed since 2009 and its application to deep sea fisheries. The roadmap for EAFM implementation in NAFO is based on a 3 steps framework:

1. Assess the effects of the environment on stocks, which requires defining appropriate spatial management units, based on ecosystem state and multispecies assessment;

2. Assess the effects of the fisheries on stocks, based on stock assessment;
3. Assess the effect of the fisheries on the ecosystem, based on risk assessment.

The example was focusing on the 3rd step for deep sea fisheries to illustrate the impact assessment method developed by NAFO. The approach relies on assessing Significant Adverse Impacts (SAI) on Vulnerable Marine Ecosystems (VMEs), here mainly impact on deep sea habitats and biogenic reefs. The principle is to produce maps of fishing intensity based on VMS data and maps of biomass of VME species at the same spatial resolution and to assess the interaction or overlap between fishing pressure and biomass of VME species. The latter is done by plotting VME biomass accumulation against fishing intensity: above a certain fishing intensity, biomass accumulation levels off meaning that most biomass has been fished out. The areas corresponding to fishing intensity below this threshold and high biomass accumulation are at potential SAI risk whereas those above, i.e. areas of high fishing intensity yielding low VME biomass correspond to past SAI and are no longer at risk. The two types of areas can be mapped for each VME species to provide basis for conservation through spatial management of fisheries. In conclusion, the impact assessment approach developed by NAFO is largely applied and operational, but it brings no understanding of the processes and is very demanding in terms of interactions with stakeholders to agree on spatial management measures.

To summarize, the data-driven ICES approach is good for ecosystem status reporting, understanding system dynamics and defining appropriate spatial management units, but it requires a more applied framework to be of direct use for management advice and negotiating the trade-offs with stakeholders. In contrast, the impact assessment NAFO approach has an applied framework for developing EAFM which defines spatial management units with each step addressing specific assessment needs which requires impact assessment methods, but it requires a lot of time and effort to implement integration and requires working closely with stakeholders to agree on management options and understanding the trade-offs –the more stakeholders the greater the impediments.

3.1.2. Methodology and Southern case studies - Small pelagic fish in the Mediterranean: What we can get from what is not directly observed. Marianna Giannoulaki (HCMR, Irakleion, Crete, Greece)

Small pelagics (SP) represent 50% of the catches in the Mediterranean Sea. They are characterized by high inter-decadal variability linked to climatic cycles, a short lifespan and a high relative fecundity. They are at a mid-trophic position in the food web and exert a wasp-waist control in marine ecosystems. Their schooling behavior favors fisheries using purse seines (majority) as well as midwater pelagic trawlers on fishing grounds from 50 to 200 m depth. The main fishing season is concentrated in spring-summer and some seasonal closures may happen in some countries. Management is mainly based on technical gear specifications and minimal landing size for 4 species (anchovy, sardines, mackerel, horse mackerel). There are no internationally established TACs but some may be nationally established for local GSAs (geographic sub-areas). The current status of SP in the Mediterranean is that 83% of assessed stocks are overfished and characterized by a strongly truncated age- and size-structure. Given their current status, measures aiming at rebuilding the age and size-structure of the stocks are considered as necessary. Protecting nurseries and spawning grounds as part of an EAFM can be valuable tools to reach this goal.

The idea behind is that “if you lose the habitat, you lose the fish”. Habitat suitability maps may provide a tool to protect these habitats. Work was based on the combination of data from acoustic surveys (since 2008), pelagic and bottom trawl surveys, and ichthyoplankton surveys that are traditionally used for stock assessment together with environmental data derived from satellite imagery (physical environment + primary production indicators). Maps of environmental factors and SP species distribution were combined through statistical models to obtain habitat maps at the scale of the whole Mediterranean. The idea was that it is better to go global rather than regional. This approach provided annual probability maps and habitat location for the main SP species: anchovy, sardine, Mediterranean horse mackerel and chub mackerel. Focusing on different seasons of the year allows producing maps of spawning grounds (summer) and nurseries (late autumn).

Habitat suitability maps produced are then useful for a suite of applications:

- large-spatial-scale maps allow to have an idea of the habitat in areas where surveys are scarce or there are gaps;
- they provide key information for spatial prioritization and to identify priority conservation areas thus helping in evaluating existing Fisheries Restricted Areas(FRAs) /Marine Protectec Areas (MPAs) and defining new FRAs/MPAs;
- they allow including spatial information on SP fish life-stage distribution to minimize discards of undersized individuals in the marine spatial planning framework;
- they can provide inputs to Individual Based Models (IBMs) and tests of the effect of future climate change scenarios;
- they can provide inputs to ecosystem models with spatial perspective;
- finally, they can be used as covariate in other habitat suitability models, e.g. in species distribution models based on prey-predator relationship like the interaction between small pelagics and dolphins. The advantage in this specific case is that the probability maps are available at a much larger scale which matches the available records for dolphins.

In conclusion, habitat suitability maps are important tools to minimize discards of undersized individuals, as input to IBMs that could help in evaluating the effects of climate variability on the distribution, abundance and life-history of SP, to apply integrated stock assessment spatial models to advance and support multi-objective approaches for fisheries management, and to promote the establishment and management of marine protected areas within a marine spatial planning framework.

3.1.3. Discussion

To implement integration requires a lot of time and effort and a more applied framework. Also working closely with stakeholders is necessary to agree on management options and understanding the trade-offs.

- Data limitation. Benthic data are now available for the recent years and will be incorporated. Yet, it is worth mentioning the differences in environmental data between the northern and southern parts of the Mediterranean basin. The knowledge of the variations in the environmental parameters in both areas will be valuable for a better understanding of the ecosystem dynamics as a whole.

- Weight of the variables is an important aspect but it has not been dealt so far. It is a work in progress. So far no weight on the variables.

- How to identify which are the best species indicators, more resilient, more fragile? Probably some of the key species are already gone?

- EU policies are note very adaptive. Policy needs to change so these types of assessments can be applied. So far still using single stock assessment.
- Science lead models have also implications. Data can be biased if not collected with a clear question in the beginning! Missing data may prevent the development of appropriate models supporting management advice.
- The FRAs must be evaluated into the MSP framework and it is necessary to examine up to what degree essential fish habitats are being protected or not. In addition to this, the establishment and management of marine protected areas within a marine spatial planning framework has to be taken into account and evaluated.

3.2. Session 2: Marine spatial planning, with specific focus on fishing effort and human activities allocation

3.2.1. Methodology and Southern case studies - Marine Spatial Planning: allocation of fishing effort and other human activities in Southern case studies (Mediterranean) - Fabio Grati (CNR-ISMAR, Ancona, Italy)

Abstract: The Mediterranean Sea is a semi-enclosed highly biodiverse basin where more than 90% of the harvested stocks are overexploited. In this area spatial planning with fisheries plays a key role to reduce the impact of this activity on the resources and the ecosystem. The presentation focused on recent studies dealing with spatial management of coastal (e.g. small-scale fisheries) and offshore (e.g. trawlers) fisheries in South Europe. In addition, a review of the current state-of-the-art on this task and the identification of research gaps and needs was provided.

3.2.2. Methodology and Northern case studies - Mapping fishing activity and impacts to support environmental assessment and management - Simon Jennings (CEFAS, Lowestoft, UK)

Abstract: This talk explored the characterisation of fishing footprints in shelf seas from VMS data and the consequences for the fishing industry, environment, marine conservation and interaction with other sectors. The strengths and weaknesses of different methods of footprint characterisation were described as were the uses of data on fishing intensity and distribution to estimate habitat sensitivity and recovery time. Disconnects between the availability and resolution of offshore and inshore data were described, along with consequences for management.

3.2.3. Discussion

The discussion focused on how MSP can serve the EAFM (Ecosystem Approach to Fisheries Management) and whether spatial management measures can meet the objectives of various policies. MSP is a process taking place largely outside the scientific community that ends in a trans-sectorial governance scheme. MSP prioritizes areas for different sectors and fisheries are at the end of the queue far behind energy. When an MSP is in place, does it support sectorial management and is EAFM more effective then? MSP would also need to meet the objectives of other policies? In particular, could MSP be defined with an ecosystem approach? Frequent evaluations of the performance of MSP regarding different policies would be needed. In effect, displacement of fishing activities may result in negative effects elsewhere. Spatial management measures are often implemented at small spatial scale and it is still to be demonstrated how they scale up at population level or even at ecosystem status over eco-regions. Also, closing areas to fishing to protect habitats requires more knowledge on how pressure of fishing gear translates into impact.

Various policies (MSP, MPA, IUCN vulnerable species) can result in the implementation of spatial management measures. Spatial measures can be external to fisheries or internal to the fishing sector (discard ban, nursery) and as well based on ecosystem structure. The mapping of tradeoffs of spatial measure on different objectives could allow evaluating different management scenarios as shown on Figure 3.1.

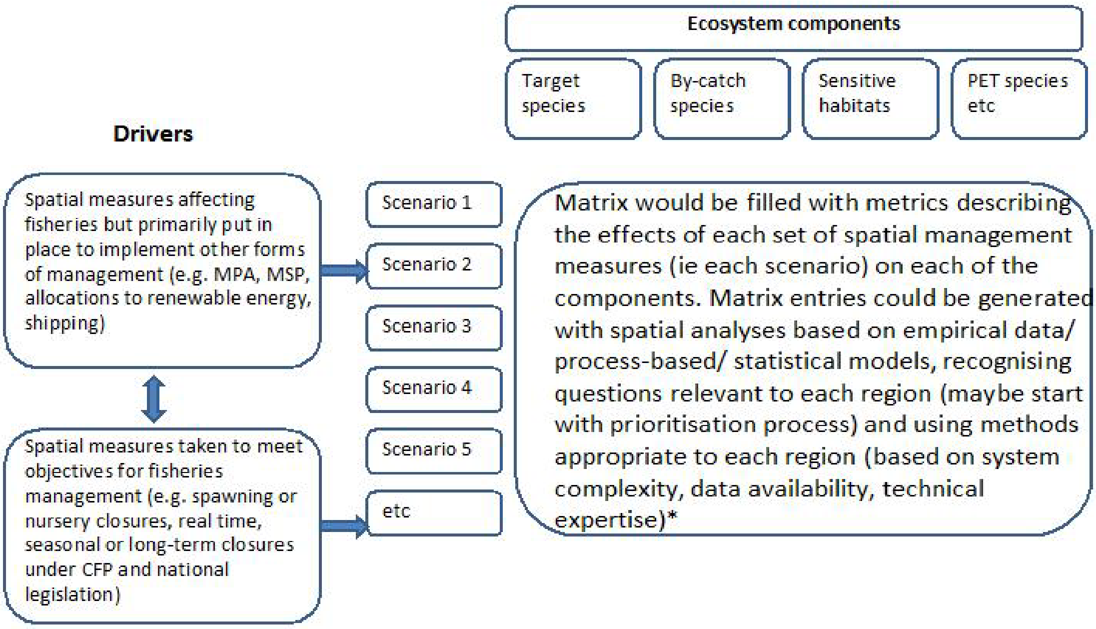

Figure 3.1: Building management scenarios to meet different policies. Looking across the matrix would allow looking at tradeoffs between effects on different components.

4. Governance schemes by eco-regions engaging with all actors including monitoring strategies at different scales addressing different policies

4.1. Session 3: Spatially explicit ecosystem (end-to-end) modelling

4.1.1. Methodology and Northern case studies - Spatial end-to-end models to address the effects of management scenarios on ecosystems - Morgane Travers & Marie-Savina Rolland (IFREMER, Boulogne-sur-mer, France)

In the last decade, a strong multi-disciplinary effort was put in the development of end-to-end (E2E) models to address the effects of multiple and interacting pressures on marine ecosystems. The main characteristics of E2E models are (i) to combine oceanographic dynamics with those of organisms ranging from microbes to high-trophic level organisms, including humans, in a single framework and (ii) to simulate long-term plausible scenarios of the impacts of global change on marine ecosystems under current possible management options. E2E models are based on the coupling of existing disciplinary models(physical, biogeochemical, fish, fisheries and economic models). They allow accounting explicitly for the dynamical forcing of climate and human impacts on marine biodiversity at multiple trophic levels and offer the possibility to test cumulative impacts at multiple temporal and spatial scales. 3 main different approaches of E2E models are currently available:

- Trophodynamics networks such as Ecopath with Ecosim and Ecospace or Linear Inverse models;
- Biogeochemically-based models such as Atlantis or ERSEM;
- Modelling platforms coupling different kind of models such as OSMOSE, SEAPODYM, or size spectrum models.

These models can be seen as a synthesis of existing data and knowledge for the ecosystem of application and allow identifying information gaps.

There has been an intense development of E2E models in Europe through FP7 programs over the last 5 years, e.g. MEECE (Marine Ecosystem Evolution in a Changing Environment) and VECTORS. Two of the previously mentioned approaches, OSMOSE and Atlantis, were developed for the eastern English Channel ecosystem and were presented in this talk. The eastern English Channel is an extremely busy ecosystem, where different human activities such as fishery, maritime traffic, recreational activity, wind farms, marine protected areas and aggregate extraction are at stake. These two E2E models were used on this area to answer two main questions:

- What is the impact of exploitation and environmental change on the ecosystem?
- What are the ecological and utilization consequences of conservation measures and access restriction to the maritime domain based on spatial dimension?

OSMOSE is an spatialized multispecies and size-structured Individual-Based Model (IBM) that describes trophic interactions between fish as depending on size-based mechanisms and that is coupled with a biogeochemical model. It was used to explore some management objectives, notably Maximum Sustainable Yield (MSY) in a multispecies context, i.e. while accounting for trophic interactions and mixed fisheries. Results showed that there is a trade-off across MSY of different species. CombiningOSMOSE with habitat models and climate change variability also allows assessing the effect of management in a varying environment and the combined effects of fishing and climate. To conclude, OSMOSE is a “not too complex” E2E approach using classical parameters that focuses on predation and food web dynamics and allows the ranking of important processes as well as exploring management targets in a multispecies context. It could notably provide insights for more operational Stochastic Multi-Species (SMS) models.

Atlantis represents the ecosystem by subdividing it in spatial units (boxes) on the basis of multivariate information on its components (depth, sediments, benthic habitat, fish communities, nursery ground, 12 miles + Exclusive Economic Zone (EEZ)). It starts from the physics and plankton dynamics with 40 functional groups describing the eastern English Channel food-web and 21 fishing classes describing the fishing fleet. Parameterization and calibration is very time consuming and difficult to achieve. It is generally based on comparing predicted and observed catch, biomass of stock assessment or survey index. Its application for testing the impact of management scenarios on fishing effort through either spatial allocation based on using the current Marine Protected Areas as no take areas, or a global reduction of fishing effort of about 20%, or both was presented. Results show that MPA closure has much less effect on biomasses of the different functional groups than global fishing effort reduction, and that the response is variable across groups. MPA closure scenario only represents a decrease of roughly 5% of fishing on average, much less than 20%, because of fishing effort reallocation. Reallocation was modeled through the coupling of Atlantis with a random utility model describing fishing fleet behavior. To conclude, ATLANTIS is a rather complex approach gathering various information types in a single framework but it can address multiple uses management issues. In this specific case, it allowed showing that spatial measures alone are not efficient for managing fish stock biomass if there is no effort reduction at the same time.

There is a constant methodological development in the field of E2E models either by integrating new modules or by coupling with other tools, e.g.:

- Atlantis was coupled with random utility models to describe fishermen behavior;
- Ecopath with Ecosim and Ecospace(EwE-E) was coupled with habitat models;
- EwE-E was coupled with spatial conservation planning software such as MARXAN.

The latter is very useful to investigate expected ecological and utilization consequences of MPAs designed through spatial conservation prioritization tools such as MARXAN based on meeting biodiversity conservation targets while minimizing the impacts on stakeholders. Current research gaps and needs for E2E models can be classified in 3 categories:

- Methodological developments with the need for
    - Robust methods for calibration of unknown or poorly known parameters;
    - Sensitivity analyses to identify sensitive parameters and/or processes and provide a range of confidence around simulations;
    - Addressing management questions through model ensemble approach.
- Ecological developments or research on specific aspects of ecosystem functioning and particular processes such as
    - Pelagos-benthos coupling;
    - Zooplankton as the "to" of end-to-end;
    - Fleet dynamics related to resource communities;
    - Determinants of fishermen behavior and fish movements.
- Scenarios and other uses
    - Direct management applications are still not developed but are really being considered currently and would require robust modelling approaches with quantified uncertainties.

4.1.2. Methodology and Southern case studies – Cosimo Solidoro (OGS, Trieste, Italy)

E2E models integrate physical, biogeochemical and ecological processes related to food-webs. E2E models are typically the modeling expression of an "ecosystem approach" as they aim at considering all ecosystem components, and the interactions among them and abiotic factors. The integration of both low and high trophic level components in E2E models allows appreciating bottom-up and top-down control of food webs thus bringing a better understanding of the system. E2E models enable to assess the relative importance of different stressors/forcing variables, notably variability in physical processes and/or nutrient dynamics (impacts on low trophic levels) vs the effects of variability in fishing activities (impacting on high trophic levels). They are important in predicting indirect effects of anthropogenic stressors in high-trophic-level dynamics and in projecting impacts of climate change both through cascading effects. Putting E2E models in a broader perspective brings several important remarks. In general, models may be a way to identify first principles that may guide management and this is precisely what E2E models can do by having an ecosystem perspective and embarking different stressor/forcing variables. However, these models are not very good at providing precise predictions but rather at providing understanding, which can be used to advice managers.

A number of issues are related to E2E modelling. The first one is model selection. It has to be kept in mind that a model is always a (ideal) representation of reality and that the choice of the type of model depends on the main purpose given the trade-offs between realism (functionality), accuracy (performance), and generality. This brings the question of how complex a model should be and how simple it can be given its purpose. Nature is complex by essence and the aim should be to keep the model as simple as possible so that it is tractable and as complex as needed so that it is relevant. Most E2E models focus on the vertical dimension, i.e. along the trophic-level dimension to encompass top-down and bottom-up processes, but the horizontal dimension, i.e. biodiversity and the associated processes of competition, symbiosis, etc., is often forgotten. Which modelling approach should then be used among the numerous possibilities available? Convergence between different modeling approaches can be shown such as between food web models based on functional groups (EwEE for instance) and size spectra models that may converge to similar complexity (and borrow solutions/parametrization from one another).

A second issue is related to variability in temporal and spatial scales. The compartments of the food web fall on a line from short time scale and small spatial scale for low trophic levels to long time scale and large spatial scale for high trophic levels. So an E2E model needs to integrate all these scales in a single framework. This difficulty can be solved through a modular approach, i.e. by coupling different models with different temporal and spatial scales, notably biogeochemical models coupled with food web models. Two different approaches are possible for this coupling: either one way forcing of one model on the other or full two-way coupling including dynamical feedbacks between the 2 models. An example of the extension of EwE-E models to low trophic levels including nutrients is available (Libralato&Solidoro, 2009) and shows how the variability signal is transferred from low to high trophic levels through time, thus highlighting that a synoptic vision of the world at a single point in time is not adapted in such cases.

The prediction of the effects of changes in precipitation patterns due to climate change on the Venice lagoon ecosystem was presented as a first example of application of such coupling. Changes in precipitation patterns and therefore in timing and volume of freshwater and nutrient delivery to coastal wetlands will impact on the biogeochemistry and – in turn- on the ecosystem in the lagoon of Venice. Regional IPCC scenarios (A2 and B2) were statistically downscaled at the level of the lagoon. Resulting predictions of nutrient input and sea-boundary of the lagoon were used as boundary conditions for a biogeochemical model of the lagoon coupled with an EwE model of the local food web to assess propagation of the effects under the 2 scenarios. Projections showed that changes in the seasonality of nutrient inputs to the coastal system have effects that propagate up the food web with roughly a 2-year delay. Most importantly, differences of propagation of extreme values were observed between the two scenarios with opposite changes in some food web components, goods and services. These results highlight the need to account for extreme events in models.

As a second example of application, the potential use of E2E models in operational Integrated Ecosystem Assessment was presented. Based on various physico-chemical and biogeochemical parameters obtained as GIS layers, a biogeochemical model coupled with an EwE model at the scale of the whole Mediterranean sea was used to hindcast the last 3 months in the Mediterranean according to a rolling scheme: every 3 months. Such tool can provide information on compartments that cannot be sampled, which can then be used for IEA. Results also showed that perturbations can propagate both bottom-up and top-down because of memory time (i.e. recovery) of high trophic levels that extend after the end of the perturbation at low trophic levels.

A third example of E2E model use is the prediction of the effects of fisheries management scenarios in the context of multiple stressors. An application to the Adriatic sea was presented were a biogeochemical model was used as forcing conditions in terms of phosphate pool dynamics at the basis of a food web model on top of which various fishing fleets or métiers were added. The effects of various management scenarios, either by single commercial species or by fishing fleet/métier, were then evaluated under 3 different climatic scenarios: the current climate regime as reference and two scenarios down scaled from IPCC scenarios A2 and B2. Results allow (i) evaluating the effects across compartments and the corresponding trade-offs, notably between different exploited species, and (ii) identifying synergistic and antagonistic effects of various stressors, here climate change and fishing mortality. The dynamics of biodiversity indices can even be considered as nearly all biocenosis compartments are included, at least above a certain trophic level.

E2E models can also be used in a spatial context. First, they can be useful for comparing functioning of various ecosystems in the same maritime basin. EwE food web models of 5 different areas in the Mediterranean and the Black sea (Gulf of Lions, North Adriatic, North Aegean, Western Black Sea, and Eastern Black Sea) were standardized according to a common structure and extended to include nutrient (phosphate) dynamics forced by a biogeochemical model. Characteristics of ecosystems' health, namely vigor, organization and resilience were compared according to food web metrics. Second, E2E models can be spatialized at the scale of a single ecosystem. The Venice lagoon food web model was spatialized using EwEE and forced by average fields of nutrients obtained from biogeochemical models. Results allowed predicting the spatial distribution of the various functional groups represented in the model.

Research priorities related to E2E models can be organized into three main items

1. Consolidating existing models in the sense of
   - extending the number of applications in the Mediterranean area;
   - but also, from a more methodological point of view, generalizing integrated food web approaches i.e. integrating complete feedbacks from food web models to biogeochemical/hydrodynamic models and reciprocally (two-way coupling). Integrated approaches should also extend to socio-economic modules, bioenergtic modules at the individual level, etc.
2. Improving access to data: E2E models are data hungry, which require for
   - making data available public, organizing them in public database, etc.;
   - developing new calibration methods.
3. Developing new, more realistic models such as
   - IBMs
   - Trophic spectrum models.

4.1.3. Discussion

The discussion concentrated on how end-to-end models could be useful to provide advice for integrated fisheries, ecosystem and biodiversity management over eco-regions. Spatially-explicit end-to-end models allow considering combined pressures including climate drivers, fishing mortality or nutrient inputs on ecosystem dynamics and are therefore appropriate tools to scenario test ecosystem trajectories. Implementing the use of such models in a management context requires a process including scoping, stakeholder engagement, and shared modelling platforms and skills at eco-region level. A list of questions useful for management that these models can answer would be useful to tailor their application in practice over particular eco-regions such as for instance, fishing effort allocation scenarios to mitigate discards or preserve vulnerable or essential habitats. Developing models as a set of libraries on shared platforms could allow constructing models by assembling modules thus adjusting model complexity to advisory requests. Also regional modelling feeds naturally into integrated ecosystem assessments but data streams are difficult to establish due to the variety of skills necessary and the lack of an implementation process at eco-region level.

End-to-end models are also useful to explore the relatedness of indicators for MSFD integrated assessments. Currently the debate is as much about research developments to improve models as on how to implement them in a management context. The integration of managers in E2E models needs to be carefully implemented by the scientist and not by the managers.

The use of models for management advice needs to be integrated in a specific process, with different stages starting from the joint identification of management questions, setting the legal context, identifying gaps, etc.

Research needs for model development include coupling ecosystem compartments with different dynamics, fish and fishermen displacement, increasing zooplankton realism to represent food for fish.
Research needs for reliable model use include calibration methods, sensitivity analyses and model comparisons as well as communicating model results.

4.2. Session 4: Governance at the eco-region scale, including Marine Protected Areas and linking different policies (e.g. Common Fisheries Policy and Marine Framework Strategy Directive)

4.2.1. Northern case studies - Pierre Petitgas (IFREMER, Nantes, France) on behalf of François Gauthiez (Agence des Aires Marines Protégées, Brest, France)

Three issues were addressed: the variety of EU policies applying on the marine system, the governance bodies at UE and national levels, and the role of science in the process. The ecosystem approach impedes to envisage integrated management strategies at the eco-region level. Such integrated strategy applies across sectors and thus requires setting up interaction platforms at regional level between administration, scientists, stakeholders and society. The role of science in such governance scheme is to inform on ecosystem status and on the consequences of management options. The variety of policies have nested objectives and therefore some management options could address several policies in one go. To facilitate governance between countries, the administration in each country needs to be organized to have competence for decision making at eco-region level on integrated management.

4.2.2. Southern case studies - Fisheries governance in the Mediterranean and Black Sea - Miguel Bernal (GFCM-FAO, Rome, Italy)

The General Fisheries Commission of the Mediterranean (GFCM) of the United Nations Food and Agriculture Organization (FAO) is a regional fisheries management organization in charge of managing the exploitation of Mediterranean and Black Sea living resources. Its main objective is to ensure the conservation and sustainable use of living marine resources in its area of application. GFCM Members adopt measures and decisions based on the scientific and technical advices provided by the GFCM subsidiary bodies, and once adopted, such decisions become binding to anyone carrying out fishing or fisheries-related activities in the Mediterranean and Black Sea. Practical examples were presented showing how management plans were co-constructed between parties and implemented with FRAs. For the anchovy in the Adriatic Sea, areas were closed seasonally to fishing. In the strait of Sicily, MPAs were established for the shrimp fishery aiming to protect the hake population. MPAs were also implemented to protect red corals. Management plans of GFCM also apply in international waters and on fleets coming from outside the Mediterranean Sea. FRAs as spatial management tools for fisheries management still require to be evaluated. The next step is the definition of indicators of fish stocks for Good Environmental Status (GES) in the framework of UNEP-MAP.

4.2.3. Discussion

The discussion concentrated on testing the efficiency of FRAs as a fisheries management tool. To properly evaluate the footprint of fishing effort, VMS data are needed and access to fine resolution data on fishing location is key. To design FRAs, knowledge on fish spatial distributions at different life stages is necessary. To test the effectiveness of FRAs, spatially explicit end-to-end models will be required. If there is evidence that inside MPAs conservation objectives can be achieved, the positive effect of MPAs at fish population level is still unclear and needs further testing. Models and data streams will need to be tailored to give answers to pragmatic management questions. An open question is the re-allocation of fishing effort. The evaluation of the effectiveness of FRAs will probably be site specific.

5. Conclusion - Joint Science Programme

5.1. Global research priorities

Fishing activity impacts not only fish stocks but also other compartments of the ecosystems (e.g. predator and prey populations of commercial fish stocks, seabed, marine mammals, and birds) that need to be included as management objectives. Fishing is also not the only activity sector at sea with potential conflicting interests between sectors in terms of space or natural resources use. There are now many regulations that directly or indirectly affect fishing activity at the International (Johannesburg Earth Summit 2002: stocks at MSY, networks of MPAs), European (CFP, MSFD) or national/regional level. Thus fisheries management has multi-purposes and objectives and implies trans-sector considerations under the ecosystem approach (Fig. 5.1). Designing and evaluating management measures that address multiple objectives and sectors is the current challenge at sea. In addition of being multi-objectives and trans-sectors, an ecosystem approach to fisheries management is by essence place-based and calls for a regionalisation of management strategies. Regionalised management strategies require considering the spatial aspects of ecological processes and sector activities as well as to develop spatial management measures. Spatial management has the potential for being multi-purpose as it can address fisheries and ecosystem management objectives and trans-sector regulation simultaneously.

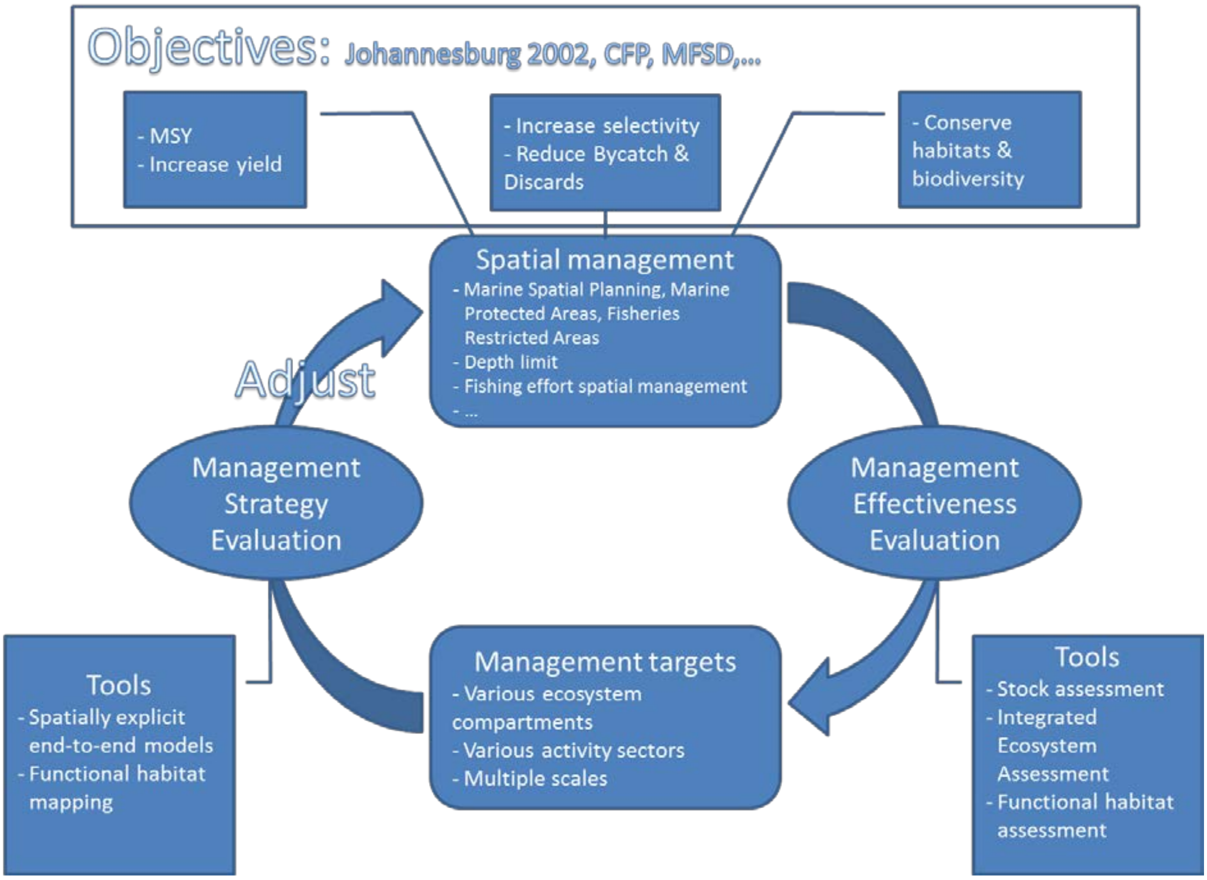

Figure 5.1 : Cycle of Management Effectiveness Evaluation and Management Strategy Evaluation applied to spatial management of fisheries under the ecosystem approach

Developing effective spatial management schemes requires (i) setting up a cycle of Management Strategy Evaluations (MSE) and Management Effectiveness Evaluations (MEE) specifically tailored for spatial management and addressing multiple objectives, sectors and spatial scales (Figure 5.1) and (ii) the development of tools accounting for spatial processes and characteristics in addition to more traditional ones such as stock assessment (Figure 5.1). Two particularly important aspects when implementing MSE and MEE are first to consider potential trade-offs across objectives (or ecosystem compartments), space (or spatial scale) and sectors, and second to include a human (socio-economic) compartment in the ecosystem. Regarding MSE and MEE tools in a spatial context, two areas need to be further developed: the knowledge on functional habitats and spatially-explicit end-to-end models. Functional habitats affect fish stocks' productivity as well as that of other ecosystem compartments potentially affecting multiple sectors. Their identification, the quantification of their contribution to productivity and the assessment of how they are impacted by human activities is therefore critical for implementing spatial management measures and associated MEE and MSE. Likewise, spatially-explicit end-to-end models represent a novel framework for spatial MSE while accounting for trade-offs between multiple objectives, sectors and spatial scales.

Three research topics are therefore proposed as priorities to help develop a framework of spatial approaches to multi-purpose management of fisheries, ecosystems and trans-sector activities.

1. Develop MSE and MEE for multiple-objective and multiple-sector spatial management schemes:
   - methods to construct scenarios with multiple objectives (corresponding to multiple ecosystem components including the socio-economic one);
   - methods to evaluate trade-offs between multiple objectives, sector and spatial scales;
   - methods to test the effectiveness of small scale measures (e.g. MPAs) at global population/ecosystem/regional scale and, reciprocally, of large scale measures at small scale.
2. Improve knowledge on and evaluation of functional habitats:
   - identify functional habitats for fish populations and map them;
   - understand and quantify how local functional habitat uses affect global population's productivity and ultimately fishing yield;
   - estimate the impacts of fishing on functional habitats and evaluate their status.
3. Develop spatially-explicit end-to-end models with appropriate complexity for spatial MSE:
   - approaches to adjust model complexity in order to implement multiple objectives MSE (e.g. CFP and MSFD);
   - include trade-offs across objectives, sectors and space by dynamically coupling spatially-explicit end-to-end models and spatial management schemes;
   - methods to model movements of fishes and fishing boats in link with spatial management measures (e.g. MPA, fishing effort spatial regulation,…) as well as human behaviour (socio-economic aspects).

Of course, the combination of models and methods developed may have to be tailored to the different regions of application as one will not fit them all. These developments should therefore be undertaken in various geographical areas because of varying characteristics.

5.2. Innovation in the research priorities

The main innovative aspect in the research priorities identified above lies in developing MSE for ocean management as a whole (i.e. including fisheries but also other sectors and conservation objectives) and making it operational in a spatially-explicit context. In effect, such integrated management will be spatially-explicit. This requires first completely rethinking MSE and associated MEE in terms of trade-offs between components (i.e. objectives, sectors and spatial scales) rather than in terms of optimum for each single component as traditionally done. Research in this respect has been relatively weak and novel developments will be for identifying these trade-offs, evaluating them, and accounting for them in management strategy implementation and evaluation. Given the regionalisation and spatialisation of management strategies implied by such trade-offs, habitats are a critical aspect. Most research in the field focused so far on habitat description and mapping. However, accounting for the trade-offs between various ecosystem components or spatial scales impacted or used by different sectors requires understanding the ecological functionality of habitats and how these contribute to diversity and productivity of the ecosystem components. In this respect again most has to be done. Finally, MSE relies strongly on the availability of models including the various components covered by the strategy evaluated. Although the last decade saw the development of end-to-end models, only a few of them are spatially-explicit and the complexity required to make these tools operational represents the upcoming challenge. Together with movement models of both fish and fishing fleets they represent knowledge gaps and key bottlenecks for progressing the management of ecosystems and maritime activities. Habitat functionalities and movement models for the fish and the fishing fleets represent knowledge gaps and key bottlenecks for progressing the management of ecosystems and maritime activities.

Annex I

5.3. List of Participants

Surname	Name	Insitute	City	Country	As
Andonegi	Eider	AZTI	Sukarrieta	Spain	COFASP
Bernal	Miguel	GFCM-FAO	Rome	Italy	Invitee
Dunn	Euan	NSAC	Stevenage	UK	Invitee
Ernande	Bruno	IFREMER	Boulogne/mer	France	COFASP
Fabi	Gianna	CNR, ISMAR	Ancona	Italy	COFASP
Giannoulaki	Marianna	HCMR	Irakleion	Greece	Invitee
Grati	Fabio	CNR-ISMAR	Ancona	Italy	Invitee
Jennings	Simon	CEFAS	Lowestoft	UK	Invitee
Kapiris	Kostas	HCMR	Anavyssos	Greece	COFASP
Kenny	Andy	CEFAS	Lowestoft	UK	Invitee
Leocadio	Ana	DEFRA	London	UK	COFASP
Petitgas	Pierre	IFREMER	Nantes	France	COFASP
Scarcella	Giuseppe	CNR, ISMAR	Ancona	Italy	COFASP
Solidoro	Cosimo	OGS	Trieste	Italy	Invitee
Travers-Trolet	Morgane	IFREMER	Boulogne/mer	France	Invitee
Zampoukas	Nikos	DG RESEARCH, EC	Brussels	Belgium	Invitee

5.4. RISE-FEM Open Meeting Agenda

June 23: **Linking ecosystem health assessment over defined habitats and spatial planning across sectors including spatial management of fishing effort**
Room "Montoyer", 2nd floor

- *9:00-09:15 Welcome and Introduction*
  Pierre Petitgas and Bruno Ernande (IFREMER, Nantes and Boulogne/mer, France)

Session 1: Integrated ecosystem assessment

- *9:15-10:15 Methodology and Northern case studies*
  Integrated Ecosystem Assessments in support of the ecosystem approach to fisheries management: Northern Case Studies
  Andrew Kenny (CEFAS, Lowestoft, UK)

Coffee break

- *10:45-11:45 Methodology and Southern case studies*
  Small pelagic fish in the Mediterranean: What we can get from what is not directly observed. A case study from the South.
  Marianna Giannoulaki (HCMR, Irakleion, Crete, Greece)

- *11:45-12:45 Discussion*

Lunch

Session 2: Marine spatial planning, with specific focus on fishing effort and human activities allocation

- *14:00-15:00 Methodology and Southern case studies*
  Marine Spatial Planning: allocation of fishing effort and other human activities in Southern case studies (Mediterranean)
  Fabio Grati (CNR-ISMAR, Ancona, Italy)

- *15:00-16:00 Methodology and Northern case studies*
  Mapping fishing activity and impacts to support environmental assessment and management
  Simon Jennings (CEFAS, Lowestoft, UK)

Coffee break

- *16:30-17:30 Discussion*

June 24: Governance schemes by eco-regions engaging with all actors including monitoring strategies at different scales addressing different policies
Room "Montoyer", 2nd floor

Session 3: Spatially explicit ecosystem (end-to-end) modelling

- *9:00-10:00 Methodology and Northern case studies*
  Spatial end-to-end models to address the effects of management scenarios on ecosystems
  Morgane Travers & Marie-Savina Rolland (IFREMER, Boulogne-sur-mer, France)

- *10:00-11:00 Methodology and Southern case studies*
  Title to be announced
  Cosimo Solidoro (OGS, Trieste, Italy)

Coffee break

- *11:30-12:30 Discussion*

Lunch

Session 4 : Governance at the eco-region scale, including Marine Protected Areas and linking different policies (e.g. Common Fisheries Policy and Marine Framework Strategy Directive)

- *14:00-15:00 Northern case studies*
  Title to be announced
  Pierre Petitgas (IFREMER, Nantes, France) on behalf of François Gauthiez (Agence des Aires Marines Protégées, Brest, France)

- *15:00-16:00 Southern case studies*
  Fisheries governance in the Mediterranean and Black Sea
  Miguel Bernal (GFCM-FAO, Rome, Italy)

Coffee break

- *16:30-17:30 Discussion*

June 25: Drafting of a Joint Science Programme
Room “Magritte”, 1st floor

COFASP partners only

- *09:00-12:00 Drafting of a Joint Science Programme*

Lunch

- *14:00-17:00 Drafting of a Joint Science Programme*

5.5. About the presenters (short CV)

Miguel Bernal

Fisheries Officer in Policy, Economics and Institutions Service Fisheries and Aquaculture Policy and Economics Division FAO Fisheries and Aquaculture Department. Till 2011 Miguel Bernal was Researcher in the Instituto Español de Oceanografía in the Centro Oceanográfico de Cádiz (Spain). He was a visiting scientist in the State University of New Jersey (Institute of Marine and Coastal Science, 2008-2010) and adjoint scientist in the Spanish National Research Council in Barcelona (Spain, 2010-2011). In 2012 was Head of Fisheries in the Instituto Español de Oceanografía in Madrid (Spain).

Marianna Giannoulaki

Dr Marianna Giannoulaki is a Senior Researcher of the Institute of Marine Biological Resources and Inland Waters at Hellenic Centre of Marine Research. She assumed her duties in October 2006. Marianna earned her doctoral and master's degrees in Marine Biology from the Biology Department, University of Crete, Greece. Her thesis work focused on the ecology and the spatial distribution of small pelagic fish in the Greek Seas based on acoustic survey data introducing the application of novel spatial analysis statistical techniques. Marianna’s scientific background and research interests are multidisciplinary focusing on population dynamics of small pelagic fish, physical/biological interactions in marine ecosystems, fisheries acoustics, spatial analysis techniques, determination of essential fish habitat and habitat suitability modelling, food web modelling as well as stock assessment modelling techniques. She is an active member of the stock assessment study groups in the Mediterranean region (i.e., GFCM, STECF, FAO-EastMed) being responsible for the application of stock assessment models for anchovy and sardine stocks in the Greek Seas providing essential information for management advice and the production of fishery management plans.

Fabio Grati

Degree in Natural Sciences in 1997 at the University of Trieste. Since 1992 collaborates with the CNR-ISMAR of Ancona on research projects related to the biology and ecology of artificial structures (artificial reefs and offshore platforms), and the small fishing gear selectivity. From 1997 to 2008 he worked with the CNR-ISMAR of Ancona with contracts of various kinds (scholarships, research grants and contract research for a fixed period) and in 2009 was hired as a researcher indefinitely. He was an active field research, both in the underwater sampling, both on board fishing boats and research vessels. Since 1998 he is member of the Italian Society of Marine Biology and since 2005 a member of the Italian Society of Biometrics.

Simon Jennings

Simon Jennings is a Chief Science Advisor at the Centre for Environment, Fisheries and Aquaculture Science (Cefas), Lowestoft. Through Cefas, he advises national and international bodies on marine environmental management, with a focus on issues relating to biodiversity and fishery-environment interactions. He is a former Chair of the International Council for the Exploration of the Sea, Advisory Committee on Ecosystems. Simon is also active as a research scientist, and works with colleagues to understand the structure and function of marine systems, to assess human and environmental impacts on populations, communities and ecosystems and to develop and apply tools to support marine environmental and fisheries management. Simon also holds a Chair of Environmental Sciences at the University of East Anglia, where he works for one day each week to develop and facilitate research collaborations between the University of East Anglia and Cefas; a contribution to the strategic alliance signed by these institutions in 2008. Simon is an Honorary Professor, University of East Anglia, School of Environmental Sciences.

Andy Kenny

Dr Kenny is a marine benthic ecologist with over 20 years of experience conducting research into the effects of various types of human activities on the seabed, e.g. marine aggregate extraction. He is working in CEFAS and he has published papers on seabed habitat mapping, ecological risk assessment and modelling ecosystems. He has also been the principal author for a chapter in a well-known academic handbook on “methods for sampling marine benthos” now in its 4th edition. More recently he has worked with NAFO and the EU on projects dealing with the management of deep sea fisheries.

Cosimo Solidoro

Presently he is working at the Department of Oceanography of the OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale), based in Trieste, Italy, where he is a senior scientist, deputy director of the oceanographic section and the head of the marine ecosystem modelling group (ECHO group). Research activities focus on numerical analysis and on synthesis, integration and modelling studies of estuarine, coastal and marine systems, with reference to Biogeochemestry and Marine Ecology, Climate Change Impacts, Ecosystem Approach to Fishery and Aquaculture, Sustainable Development, and Integrated Coastal Zone Management. Presently involved as coordinator or principal investigator in several national and international projects on oceanography and modelling of marine ecosystems. Member of the doctorate college for ‘Environmental and Life Science’ (University of Trieste).Italian national representative of IMBER (Integrated Marine Biogeochemistry and Ecosystem Research).Associate President of the International Society of Ecological Modelling (European chapter).

Morgane Travers-Trolet

Morgane Travers-Trolet is a Marine Ecology Researcher in the Laboratoire Ressources Halieutiques de Boulogne (IFREMER). Her research interests are on the Ecosystem approach to Fisheries, mainly for the North Sea and English Channel. With a particular interest for: prey-predator relationships and food web dynamics, end-to-end modelling, indicators, combined effects of environmental and anthropogenic factors on ecosystems.

Nikos Zampoukas

Nikolaos Zampoukas graduated in Biology and did an MSc and a PhD in Biological Oceanography in the University of Athens. He is working in the Water Resources Unit, Joint Research Centre, European Commission His research focused on ecotoxicology, benthic ecology, fish biology and biochemistry. He also worked as a conservation biologist in the region of Attica in Greece, as an environmental literacy educator in lifelong learning centres in Athens and as a science teacher in the European School of Brussels. In 2009 he joined the Joint Research Centre (JRC) of the European Commission where he is working on the scientific and technical support of the Water Framework Directive and the definition of Good Environmental Status for the Marine Strategy Framework Directive (MSFD). He is author and editor of JRC scientific and technical reports supporting the Common Implementation Strategy of the MSFD.