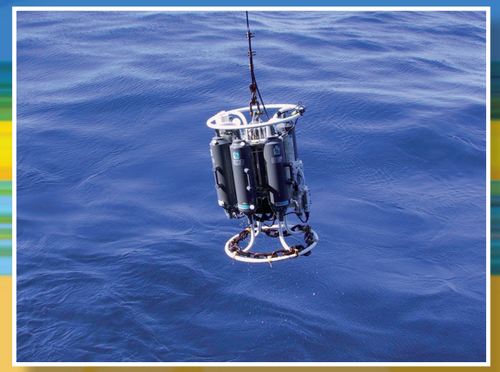
# EFARO's View on the Future of European Fisheries and Aquaculture Research



EFARO secretariat – Haringkade 1, PO Box 68, 1970 AB IJmuiden, Netherlands
Legal Address: 155, rue Jean-Jacques Rousseau, 92138 – ISSY-LES-MOULINEAUX, FRANCE
www.efaro.eu

**European Fisheries and Aquaculture Research Organisations**

EFARO

# Abstract

## EFARO's View on the Future of European Fisheries and Aquaculture Research

The European fisheries and aquaculture sectors contribute substantially towards food supply and consumer welfare within the region and with other regions, as well as providing many other socioeconomic benefits such as securing livelihoods in remote rural areas. Fisheries and aquaculture may affect the marine ecosystem and they are affected by the ecosystem. The 'ecosystem approach to the management of human activities' must be fully integrated and implemented into the principles, objectives and operational framework of the Common Fisheries Policy and the new overarching European Maritime Policy, under which research, scientific advice and knowledge-based management regarding capture fisheries and aquaculture play key roles. Thus, there is a critical need for a major effort to advance research, particularly concerning ecological and environmental, economic and social factors, within a prudent, long-term management ('governance') system, for sustainable development to continue without exhausting living resources, and so contribute to the future viability of the European fisheries and aquaculture sectors. It is imperative that this research should be far-sighted, responsive and adaptive in anticipating the future potential challenges facing European fisheries and aquaculture.

The association of **European Fisheries and Research Organisations (EFARO)** hereby puts forward its view on the future of European fisheries and aquaculture research, based on the outcome of the European Community funded FP6 project ***'The Future of European Fisheries and Aquaculture Research'*** (FEUFAR, coordinated by EFARO) which established and analyzed five 'foresight' scenarios considering the potential development of the European fisheries and aquaculture sectors to about 2020. With the advent of the FEUFAR project, the European Commission charged the FEUFAR project with the development of a strategic, future orientated research agenda. EFARO organized and lead the project including assembling the research consortium, ensuring input to the project from wide-reaching stakeholder consultations, and extensively disseminating the project outcomes. The research agenda identified by the FEUFAR project as crucial for meeting emerging and future challenges facing European fisheries and aquaculture comprises *five main research areas*:

1) Fisheries: a) Gear and operational technology; b) Management and governance; c) Valorization of currently underused components of the catch; and d) Basic research on populations of lower trophic level resources.
2) Aquaculture: a) Development of diversified, healthy seafood for consumers; b) Decreasing the environmental impact of aquaculture; c) Combatting pathogens and diseases; d) Development of non-food products; and e) Improvement of rearing system technologies.
3) Ecosystem considerations: a) Climate change; b) Marine protected areas and habitat enhancement; c) Coastal zone management; and c) Modelling ecosystems.
4) Consumer preference and market development: a) Consumer development from fish and other bio-resources; b) Consumer health; c) Traceability; and d) Certification and branding (labelling).
5) Socioeconomics and governance: a) Socioeconomics analyses and impact assessments; and b) Governance.

Of these, areas 3) to 5) form elements common to both fisheries and aquaculture.

Additionally, *three cross-cutting themes* are highlighted as being of major importance in providing a foundation for the priority research areas: 1) Data collection and analysis; 2) Risk management; and 3) Outreach.

EFARO emphasizes the vital importance of scientific support for fisheries and aquaculture related policy provided by such research in advancing the knowledge base needed to provide the best available scientific advice for implementing ecosystem-based management and elaborating new, prudent policies. Attention is also drawn to various essential actions concerning complementary development of the European Research Organization necessary to support the science community's capacity to maximize both the quality and quantity of the research outputs. These include a wider 'mix' of partnerships in research planning and funding; timely and responsive infrastructure funding and operational access; novel and high-quality education and training of science-related personnel; enhanced interdisciplinary collaboration and understanding including better integration of the 'human dimension' into research; and new approaches to networking, knowledge dissemination and communicating complex research insights among diverse stakeholders.

European Fisheries
and Aquaculture
Research Organisations


# EFARO's View on the Future of European Fisheries and Aquaculture Research

This text prepared for EFARO by Chris Hopkins
Based on: *van Hoof, L., A. Payne, M. Evrard, V. Lamblin, G. Tserpes, C. Cahu, L. Antoine, A. Iversen and J. Pinnegar, (2009) "The Future of Fisheries and Aquaculture: Final Report", In FEUFAR project report, EFARO, IJmuiden.*

Pictures courtesy of T. Linkowski, Ifremer, IEO, IMARES, O. Giovanardi, J. Pinnegar, M. Evrard.

Graphic Design by R. van Esschoten (www.divingduck.nl)

Coordinated for EFARO by L. van Hoof

# Table of contents

# EFARO's view on future european fisheries and aquaculture research

## 1.1 Preamble

The association of European Fisheries and Aquaculture Research Organisations (EFARO) is an integrated community of research institutes which specializes in fishery and aquaculture research supporting sustainable development through the provision of sound science for the people of Europe.

The European Commission has formal competency in fishery management under the Common Fisheries Policy. Marine science has formed an important part of the European Community's (EC) Framework Programmes (FP) for Research and Technological Development (RTD) since the 1970s and addresses many wide-ranging issues such as Ocean Observation and Forecasting, Food Quality and Safety, Ecosystem Sciences, and Transport. Research into how to increase the competitive use of marine bio-resources for the production of food and industrial materials, understanding of marine ecosystem functioning in a changing environment, prediction of future ecosystem patterns and protection of the marine environment and biodiversity are at the heart of the EC's research actions, and provide essential scientific support for major EC policies.

It is EFARO's remit to advocate appropriate scientific support for the EC's fisheries and aquaculture policies. In 2006, EFARO produced the publication 'Trends in European Fisheries and Aquaculture Research'. With the advent in August 2007 of the EC FP6 funded project ***'The Future of European Fisheries and Aquaculture Research' (FEUFAR)***, the Commission charged the FEUFAR project with the development of a strategic research agenda. EFARO organized, lead and coordinated the project including assembling the research consortium, ensuring input to the project from wide-reaching stakeholder consultations, and extensively disseminating the project outcomes.

The European fisheries and aquaculture sectors contribute substantially towards food supply and consumer welfare within the region and with other regions, as well as providing many other socioeconomic benefits such as securing livelihoods in remote rural areas. Fisheries and aquaculture may affect the marine ecosystem and they are affected by the ecosystem. The ecosystem approach to the management of human activities[1] (EAM) must be fully integrated and implemented into the principles, objectives and operational framework of the Common Fisheries Policy (CFP) and the new overarching European Maritime Policy, under which research, scientific advice and management regarding capture fisheries and aquaculture play key roles. Thus, there is a critical need for a major effort to advance research about ecological and environmental, economic and social factors, within a prudent, long-term management ('governance') system, for sustainable development to continue without exhausting living resources, and so contribute to the future viability of the European fisheries and aquaculture sectors. It is imperative that this research should be farsighted, responsive and adaptive in anticipating the future potential challenges facing European fisheries and aquaculture.

In Section 1 of this document, EFARO's view is put forward on the future of European fisheries and aquaculture research, based on the outcome of the FEUFAR project which established and analyzed five 'foresight' scenarios considering the potential development of the European fisheries and aquaculture sectors to about 2020. This future orientated research agenda comprises five main priority areas, and three cross-cutting support areas, as highlighted below. The FEUFAR scenarios and the associated research priorities have been developed in close collaboration with scientific experts and stakeholders representing the complete fisheries and aquaculture sectors.

1 Defined at the June 2003 First Joint Meeting of the Helsinki and OSPAR Commissions as 'the comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity'.

The following provides a short overview emphasizing:

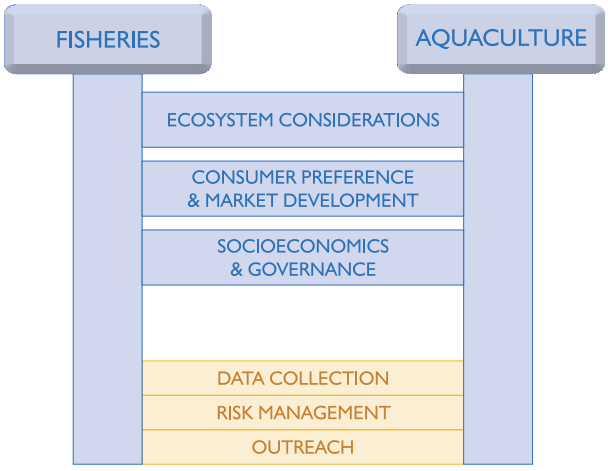
a) The research agenda priorities;
b) The crucial importance of scientific support for policy; and
c) Complementary development of European research organization needed for effective implementation of the research priorities.

Further information on the FEUFAR project is provided in Section 2 including more justification of the specific research agenda priorities (c.f. Section 2.6).

## 1.2 Research agenda priorities for fisheries and aquaculture

It should be noted that there is no particular order of the following ***five specific research areas***, but the order of the topics per area is ranked according to priority. Also, the number of priorities per area is not an indication of the importance of the specific area of research. One should recognize that many priority areas are not independent ('stand-alone') as various linkages and synergies occur between them. Moreover, three cross-cutting themes also are highlighted as being of major importance for underpinning the priority research areas. The relationship of the five specific research areas and the three cross-cutting research areas is shown in Fig. 1 and should be kept in mind.

*Fig. 1.*
*The aquaculture and fisheries research 'house' showing the two primary research pillars ('Fisheries' and 'Aquaculture') with three common research 'beams' ('Ecosystem considerations', 'Consumer preference', 'Socioeconomics and governance'). Three cross-cutting support areas ('Data collection', Risk management', 'Outreach') form the 'foundations' of the house.*




The following provides a summary of the content of the research agenda. Specific details are provided in Section 2.6.

**1) Fisheries**

***i) Gear and operational technology***
Making fishing gears and practices more efficient and able to mitigate by-catch and discards, limiting ecosystem impacts and improving selectivity, while also improving fuel consumption when fishing.

***ii) Management and governance***
Advancing strategic, multiannual (*i.e.* medium to long-term), multispecies (e.g. multi-stock, predator – prey) – multifleet (e.g. fleet size, fishing gear and operations), and ecosystem health approach to the scientific advice underpinning management. Also, better comprehension of the socioeconomics of fishing communities and find ways involving fishers to correct obstacles causing failures in policies and governance.

***iii) Valorization of currently underused components of the catch***
Measures to optimally use all the current catch-waste for human benefit, not only for direct human consumption but also by utilization in meal, pharmaceutics and medications, or other applications.

***iv) Basic research on populations of lower trophic level resources***
Increased knowledge on life cycles, distributions and environmental interactions (e.g. climate change), of lower trophic biota which play a key role in food webs sustaining fisheries resources and top-predators.

**2) Aquaculture**

***i) Development of diversified, healthy seafood for consumers***
Selecting new, diverse aquaculture species (native and introduced) and improvement of already farmed species with traits advancing the health and welfare of cultivated species and human consumers.

*ii) **Decreasing the environmental impact of aquaculture***
Minimizing use, losses and emissions of various pollutants, antibiotics and medicaments, loss of 'escapee' organisms (e.g. fish), and spread of pathogens and diseases. Also advancing innovative feeds and dietary ingredients that reduce reliance of farmed fish on fish-meal and fish-oil from wild fish-stocks.

*iii) **Combatting pathogens and diseases**[2]*
Prevention, eradication and control research to tackle infectious aquatic pathogens and diseases not only affecting the species/biota array in today's intensive and extensive aquaculture industry but also to mitigate emerging and prospective disease challenges involving cultivation of new species/biota.

*iv) **Development of non-food products***
Adding value to products by development of non-food uses, including better separation of numerous bioproducts, efficient waste transformation, and improved biomass conversion. Also, use of new/unexploited species for novel non-food products and services.

*v) **Improvement of rearing system technologies***
Due to marked spatial competition in coastal areas, and to diminish pollution affecting aquaculture, systems involving inshore recirculation, seafood detoxification, offshore farming and integrated multitrophic aquaculture are needed.

**3) Ecosystem considerations**[3]

*i) **Climate change***
Knowledge about the impacts (detrimental and beneficial) of climate change on ecosystems and bio-resources sustaining the fisheries and aquaculture sectors, understanding how these sectors will be affected by climate change and developing strategies for mitigation and adaptation. Also studies focusing on the non-native/invasive biota which may be introduced or established due to climate change.

*ii) **MPAs and habitat enhancement***
Improved understanding is needed, in the context of fisheries and aquaculture, of the effect of marine protected areas (MPAs) and their potential benefits, encompassing key biological resources and habitats, and advancing knowledge concerning the enhancement of crucial habitats.

*iii) **Coastal zone management***
Progress on approaches, methodology and tools for integrated coastal zone management (ICZM) and marine spatial planning, mainly from the perspective of fisheries and aquaculture, to reconcile various objectives and tackle cumulative effects of human activities. Also, matching particular human activities to the most suitable locations depends on advances in impact assessments.

*iv) **Modelling ecosystems***
Modelling represents an important way to synthesize knowledge of marine ecosystems, providing an analytical tool to explore and understand the forces/pressures driving ecosystem-related dynamics. Advances are called for to assess and predicting the impact of natural and human induced pressures, and management decisions on the ecosystem, including its bio-resources and human socioeconomics.

**4) Consumer preference and market development**

*i) **Product development from fish and other bio-resources***
Progress in developing new and diverse products, from fish and other bio-resources for food (e.g. novel foodstuffs and ingredients) and non-food (e.g. pharmaceuticals and neutraceuticals) uses, for securing the growth and competitiveness of the fisheries and aquaculture industries.

*ii) **Consumer health***
Documenting human nutritional/health benefits of eating safe seafood, advancing knowledge about contamination and infection of seafood (e.g. chemical pollution and biological agents), and providing risk-benefit analyses for seafood consumption. Advancing control measures (e.g. to assay and diminish toxins and contaminants) and strategies providing low and high cost, yet healthy, products for various consumer demands.

*iii) **Traceability***
Traceability of seafood for ensuring consumer confidence that seafood is, for example, safe and originates from known and approved sources and harvesting/processing methods, and for use by control

2 This topic has been inserted by EFARO in addition to the listed topics arising from the Heraklion Workshop held by the FEUFAR project. The insertion emphasizes the importance of an otherwise omitted research topic.

3 This title has been modified by EFARO from that originally used (i.e. Ecosystem Approach) in the FEUFAR project outcomes in order not to give the impression that only this section deals with the Ecosystem Approach.

authorities (e.g. counteracting IUU fisheries and related transshipments of products). Numerous RTD problems must be solved concerning methodology, practical implementation and validation.

*iv)* ***Certification and branding (labeling)***
Research establishing and verifying certification schemes (*e.g.* ecolabelling, organic production) and standards to attain sustainable practices for fisheries and aquaculture. These potentially offer a market- and information-based system for products which are harvested from sustainable resources, and that are healthy, safe and of good quality, and promote good animal health and welfare standards.

**5) Socioeconomics and governance**

*i)* ***Socioeconomic analysis and impact assessment***
Diverse analytical studies and impact assessments involving socioeconomics relevant to fisheries and aquaculture. These should recognize and predict how the development of bio-resources and the governing regulations affecting harvesting and production impact the broader fishing and aquaculture sectors (*e.g.* employment, income, and overall wealth and health) including relating to a community's identity and perspectives on the future of fishing and aquaculture activities.

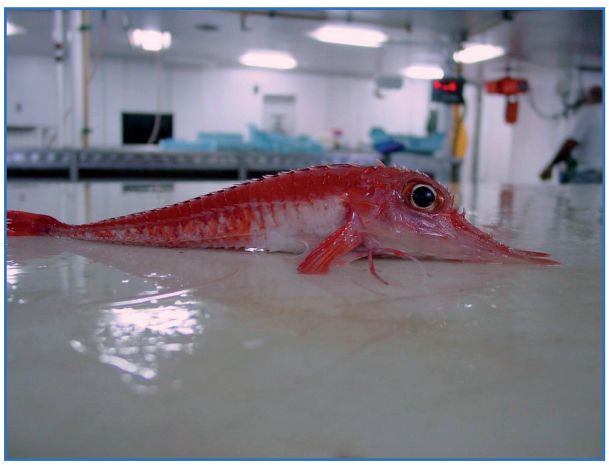
*ii)* ***Governance***
Investigating how policies, regulations and incentives affecting fisheries and aquaculture are produced and the conditions leading to governance success or failure. Evaluations how governance influences the use of ecosystem resources and services, and to diagnose the grounds for governance failure, thereby applying 'lessons learnt' for producing successful policies and innovations. Correcting obstacles to success often hinges on developing approaches and methods bringing together the vital triangle of stakeholders, managers and scientists to develop and support key policy.

In order to support the above-mentioned specific research priorities, the following ***cross cutting themes*** are emphasized:

**1) Data collection and analysis**
Data on socioeconomic aspects of fisheries, aquaculture, recreational fisheries and ecosystem goods and services are rarely available or easily accessible. Besides collection/access to data, a research issue concerns the need to build a 'knowledge base', spanning basic and applied research, to improve understanding of how 'systems' work. These systems range from individuals to populations and ecosystems, and from economic agents to how socioeconomic communities work. This knowledge base is extensive, inclusive and multidisciplinary. The data should be of good quality and accessible for both researchers and stakeholders.

**2) Risk management**
Risks and uncertainties related to fisheries and aquaculture systems act on different scales and impacts, including climate change, invasive species, pathogens and parasites, and harmful algal blooms, through to uncertainties in stock assessments and policy impacts. Risk analysis should be a basic component of impact assessment of policies and as the basis for developing policies. The meaningful incorporation of uncertainty and risks into ecosystem management is in its infancy. A framework should be developed to enable the inclusion of uncertainty and risk in policy development and the assessment thereof throughout fisheries, aquaculture and the related ecosystem.

**3) Outreach**
Demonstration and promotion activities are crucial for numerous fisheries and aquaculture research issues. Besides the scientific development of communication and dissemination techniques and skills, it is essential that the understanding and application of the 'message' from important research outcomes is conveyed in a way that is suitable for comprehension, dialogue and feedback involving the recipient user/stakeholder.



## 1.3 The importance of scientific support for fisheries and aquaculture related policy

***EFARO emphasizes that:***

a) The fundamental role of the above-mentioned research is to provide scientific support for policy development and implementation, including effective and adaptive management, regulatory and mitigation/remedial measures to achieve sustainable fisheries and aquaculture.
b) Fisheries and aquaculture policy occurs within a context of uncertainty and risk due to imperfect knowledge. Research has a vital role in reducing the extent of the uncertainty and risk. The best available research and scientific evidence is required to underpin the required knowledge inputs for the entire management and regulatory process. This knowledge is essential in the design, implementation and evaluation of policies, and also to achieve effective mitigatory measures for harmful human activities.
c) The targeted research is particularly connected with supporting the implementation of the ecosystem approach to the management (EAM) of human activities, hereunder fisheries and aquaculture, as the cornerstone policy for sustainable use of the seas and conservation of healthy ecosystems. Dependent on the EAM, as an evolutionary and adaptive process, are the Common Fishery Policy (CFP), the Water Framework Directive (WFD), the Marine Strategy Directive (MSD), and not least the overarching Maritime Policy designed to realize the full economic potential of oceans and seas in harmony with the environment.

***EFARO also stresses that:***

- The research highlighted here should not be included simply as a general 'fisheries and aquaculture' topic in the entirety of the EC's Framework Programmes for RTD, as it is unlikely to receive sufficient critical mass (*i.e.* attention and funding) to deliver the required comprehensive, scientific support.
- Further interdisciplinary integration and progress towards 'Mode 2 Science' is essential as implementation of the EAM depends on novel transnational, pan-European integration of research outputs across the natural, technological, social, economic and political sciences (see next section). This will put a substantial demand on the current and desirable 'mix' of disciplines involved in order to integrate governance principles such as openness and transparency, accountability, and participation in scientific advisory processes within the context of the EAM-related paradigm.
- With a shift towards management goals such as not exceeding precautionary levels of harmful impacts for various human activities or industry sectors, promoting results-based management, *etc.*, the customers of science-based advice may expand from government to include industry and other stakeholders. This potentially requires a fundamental change in the organization of 'marine' research and the way in which scientific advice in support of policy is planned, funded and rendered (see next section).

In the following, attention is drawn to a number of associated 'key messages' related to the organization of European research which merit consideration and action.

## 1.4 Complementary development of European research organization

Trends in European research organization are apparent related to the various scenarios affecting the future of fisheries and aquaculture. Evolution of the European research organization is essential in order to optimally support the capacity of the science community to maximize both the quality and quantity of the research outputs from the above-mentioned specific and cross-cutting priorities. These should support the promotion of the positive trends related to fulfilling the aims of the European Research Area. ***EFARO specifically draws attention to actions that will facilitate or address the following fundamentals:***

a) An appropriate 'mix' of sources (*e.g.* private, public, national, European) and allocations (*e.g.* basic and applied research) regarding research planning and funding, including new, more varied and collaborative sectoral partnerships (*e.g.* public – private, academia – industry).
b) Enhanced funding and access to modern research infrastructures including more effective procurement planning and sharing strategies.
c) Novel education and high-quality training to produce research scientists, technicians and research managers with a wider, interdisciplinary and intersectoral knowledge of ecosystem-based science, advice and management. Efforts should tackle the typically limited interdisciplinary collaboration, and lack of understanding, between natural, technological, economic, social and political sciences.
d) Lack of inclusion and funding of the social, economic and political sciences severely limits integration of the 'human dimension' into research that is traditionally dominated by the natural sciences.
e) New approaches are required for networking, knowledge dissemination and communicating complex research insights, to effectively build confidence and credibility among diverse stakeholder groups.

# 2 Annex: Synthesis of the FEUFAR project

## 2.1 The project - scope and aims

The FEUFAR (*Future of European Fisheries and Aquaculture Research*) project goal has been to define the research needed - in the medium term of about 10 years (2020) - to permit exploitation and farming of aquatic resources set against the context of key challenges and risks for meeting sustainability requirements. The main outputs identify the key challenges, strategic options and the research needs of fisheries and aquaculture in European waters and in waters in which European fleets operate under bilateral or multilateral agreements. Thus, the FEUFAR outcomes are expected to contribute to the development and subsequent implementation of the European Maritime Policy and to further strengthen the European Research Area through anticipation of research needs in the field of marine fisheries and aquaculture.

The principal objectives of the FEUFAR project has been to: a) Provide a comprehensive inventory of existing foresight ('futures') analyses worldwide; b) Build scenarios ('outlooks') of potential future developments of the European fisheries and aquaculture system, taking into account ecological, economic and societal driving forces; c) Define key challenges, strategic options, and paths towards a more sustainable future, with emphasis on the research needs required to take one there; d) Generate input to the process by organizing an inclusive platform for discussion; and e) Disseminate the results on a wide scale.

## 2.2 Project partners and collaborators

The FEUFAR ***project partners*** comprised: Wageningen IMARES (Institute of Marine Resources & Ecosystem Studies, Wageningen, Netherlands) *Project Coordinator*; CEFAS (Centre for Environment, Fisheries & Aquaculture Science, Lowestoft, United Kingdom); Fiskeriforskning (Norwegian Institute of Fisheries & Aquaculture Research, Tromsø, Norway); Futuribles (Paris, France); HCMR (Hellenic Center for Marine Research, Heraklion, Greece); IFREMER (Institut français de recherche pour l'exploitation de la mer, Brest, France); Marine Board, ESF (European Science Foundation, Strasbourg, France).

The project partners formed the '**project team**' of experts. The main inputs to and outputs from the project have been the focus of vigorous collaborative effort, including comprehensive discussions and rigorous critique, and finally accord between the project team, '***peer experts***' and '***stakeholders***' on developing priorities in the field of capture fisheries and aquaculture. The peer experts and the stakeholders were constituted from relevant fisheries and aquaculture related organizations from within the European Union (EU), the European Economic Area (EEA) and elsewhere (see also Section 2.4).

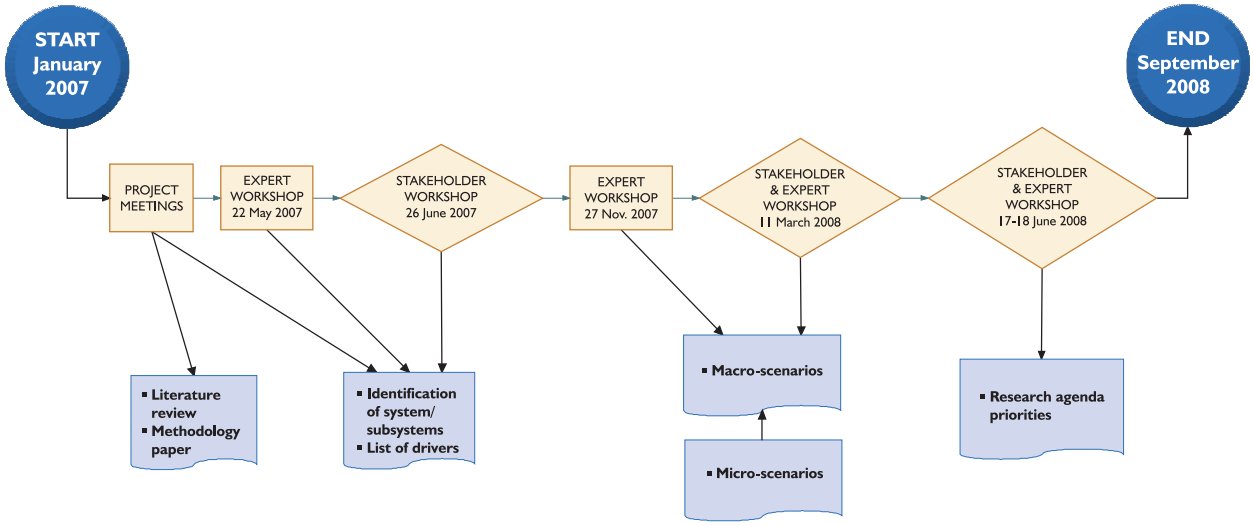
The methodology basically consisted of the following main steps with respect to fisheries and aquaculture:

i) Describing the system with respect to the project's goal and the driving forces influencing the system;
ii) By constructing hypotheses about the driving forces (economic, ecological, societal and managerial/ governance), developing potential scenarios ('outlooks') for the future potential trajectories of the system. These scenarios provide the basis for identification of vital future issues (core challenges);
iii) Based on the particular scenarios, identify appropriate research to meet the challenges.

In this document, a summary is provided of the main features concerning how the FEUFAR work was conducted, the methodology applied (Fig. 1), and the outcomes.

Detailed information concerning the FEUFAR project is found on the website: http://www.feufar.eu/.

*Fig. 1.*
*The FEUFAR project's approach and its main phases.*




## 2.3 The foresight analysis methodology and approach

The FEUFAR project has applied a foresight analysis using scenarios, building a step-by-step analysis of the most important factors that may influence the future of fisheries and aquaculture. The process of foresight analysis was embedded and founded on two core pillars. The first pillar was the development of a series of scenarios. These scenarios have been built by an analysis of the main factors (e.g. ecological, environmental, economic and social, policy and management) influencing fisheries and aquaculture. The second pillar was the involvement of peer experts and stakeholders to provide quality assurance of the project outcomes, and ensure consultation and feedback from diverse groups that are directly or indirectly involved in the fisheries and aquaculture sectors. This results in a research agenda that is logically argued and based on an analysis by all relevant interest groups in addition to the work of the project team. Hence the priorities described in the research agenda have both a scientific analytical basis and societal reference. The main output of the whole exercise, as highlighted in Sections 2.5 and 2.6, outlines the major challenges, strategic options and research needs concerning European fisheries and aquaculture.

### 2.3.1 Identifying the system, its drivers and developmental scenarios

A world-wide 'state of the art' literature examination was carried out concerning existing foresight ('horizon scanning') analyses covering fisheries, aquaculture and related marine science and technology. This activity primed the project by providing an analytical review of potential lessons learnt and best practices in order to identify common themes, perceived threats and worthwhile approaches of relevance to the project's goals. An assessment was made as to which threats and challenges may be considered relevant and important within a wider European context. A search of the global 'futures' literature revealed more than 26 studies pondering on the future of the fisheries and aquaculture sectors. These demonstrated significant congruency among the studies as well as providing an initial, potential list of topics for future research.

Based on the literature review and an Expert Workshop held in Brussels (Belgium) on 22 May 2007, the perceived system was divided into seven *subsystems*[4] (areas) which were deemed to cover the 'world' of fisheries and aquaculture. For each of the subsystems a list of *drivers*[5] (variables) influencing the subsystem was established. These drivers are the building blocks of the system and the resulting scenarios ('outlooks'). A system of about 50 drivers was set as a manageable limit, and eventually 42 drivers were chosen.

4 A *subsystem* is a sub-section of the overall system, with a unique list of drivers. Together, different subsystems describe all relevant aspects of an area under investigation, in this case the European fisheries and aquaculture industries. Each sub-system has a direct logical link with the other sub-systems.

5 *Drivers* are the parameters that describe or influence the fishery and aquaculture systems. They are a mix of factors and actors acting on or affected by the factor. A trend itself is not a driver but rather a hypothesis about the development of a particular driver.

Identification of the drivers was performed in three steps. First, a list of likely drivers, with preliminary indicators[6], was assembled by the project team in early February 2007, and taken home for further work and thorough discussion. Second, peer experts were invited to validate and refine the list at an Expert Workshop held in May 2007. Third, the list was completed and refined with the help of stakeholders at a Stakeholder Workshop held in June 2007. The same question was asked of the participants in both workshops: *What are the main factors that drive the future of fisheries and aquaculture to the year 2020?* In both cases, the participants started with a blank sheet by building their own list from scratch, formulating their own groupings and building them into subsystems. After initial brainstorming, the list of drivers was discussed and improved upon. At the end of each of the two meetings the lists were merged with the project team's list. By the late June 2007 Stakeholder Workshop, the final set of 42 drivers and the seven subsystems was agreed (Section 2.5.1). The system definition was elaborated into an internal working document, with each driver documented and discussed, and for each driver various developmental hypotheses outlined. Also, for each driver, the most important indicators related to that driver, how the specified driver evolved over the past 20 years and hypotheses generated regarding the driver's development forward to 2020 were elaborated.

'Futures' and scenarios were developed as the next stage in the process. They consider how recent past, current (today) and emerging changes may become tomorrow's reality. They include attempts to analyze the sources, patterns, and causes of change and to map alternative futures. These studies often involve the development of 'scenarios', which are narratives (stories) establishing alternative possible futures, as an important tool. So, scenarios are imagined futures, providing an account or synopsis of various projected trajectories, from today's baseline (*status quo*) status for the system (*i.e.* fisheries and aquaculture) and its component subsystems. Consequently, it is possible to consider a range of plausible but potentially equally relevant development alternatives/options including optimistic or desirable and problematic or undesirable futures. Thus, scenarios should not come singly as a forecast would, but in sets of alternatives. Scenarios draw on both qualitative and quantitative knowledge concerning the main driving forces (*i.e.* drivers) acting on the various component subsystems

making up the overall system. The prime purpose of scenario building is to support strategic planning and enable decision-makers to explore the major, alternative futures, thereby clarifying intervention options and possible consequences.

In the FEUFAR project, after defining the system's boundaries and subsystem components, and documenting the associated drivers, the first step in the scenario process was to develop micro-scenarios[7], forming the basic 'hypotheses' for constructing the second step macro-scenarios . Besides establishing various potential, alternative trajectories and developments for the whole system, the five eventually selected macro-scenarios[8](see Section 2.5.2) provided the foundation for predicting the future research needs.

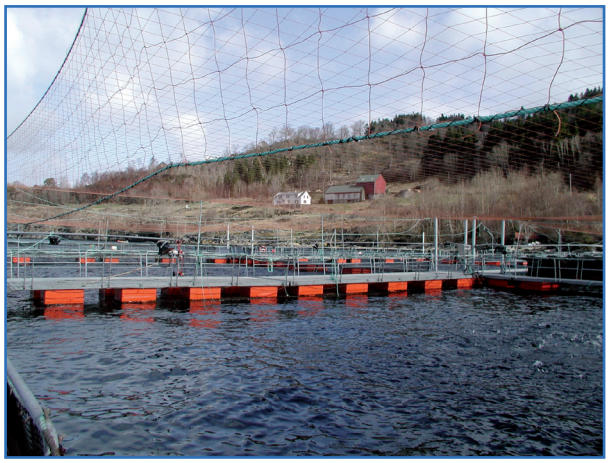
### 2.3.2 From scenarios to research agendas to meet emerging and future needs

In order to deduce from the five selected scenarios what fisheries and aquaculture research would be needed, a combined Stakeholder and Expert Workshop was organized in Heraklion (Greece) on 17-18 June 2008. During the first day, experts and stakeholders made a list of research topics for each scenario. The participants were asked to envisage the different 'worlds' described in each scenario and deduce the research topics that would best fit the storyline, including research that would promote the positive trends or reduce the negative impacts.

6 An *indicator* is a way to measure, indicate or point out/to the condition of part of a system/subsystem. It acts as a gauge to determine whether that condition is improving or deteriorating. They rarely occur independently of each other and require analysis and solutions that address their interconnected nature.

7 A *micro-scenario* is a scenario for a single subsystem based on a unique combination of hypotheses, with one hypothesis for each of the drivers of that subsystem. Based on the hypothesis developed for each of the drivers for each of the subsystems, a set of micro-scenarios was developed for each subsystem. An Expert Workshop was held in Brussels (Belgium) on 27 November 2007 during which focus was given to translating the identified drivers, and hypotheses about the potential future development of the identified drivers, into a set of micro-scenarios.

8 A *macro-scenario* (global scenario), is a scenario for the full system based on the unique combination of micro-scenarios. A combined Stakeholder and Expert Workshop was held in Brussels (Belgium) on 11 March 2008 to translate the many identified micro-scenarios about the potential future development of the subsystems into a set of relatively few macro-scenarios covering all parts of the fisheries and aquaculture system.



Thus, the first day ended with five extensive lists of research topics, one for each scenario. The second day was dedicated to assessing and determining the research topic priorities. Participants had to rank, in groups, the top five research issues for each area and provide the criteria and justifications used to rank the priorities. Great attention was given to using methods (e.g. mixing and re-arranging groups and their constituent members) to allow all points of view to be put forward in a fair and equitable way. The project team summarized these research priorities in the different areas with their related arguments to establish an agreed, prioritized research agenda for fisheries and aquaculture (see Section 2.6).

## 2.4 Consultation, feedback and dissemination involving peer experts and stakeholders

An essential ingredient for the FEUFAR project's credibility has been the integrated participation and dissemination of results - by ensuring the awareness, engagement and guidance - of a wide range of 'Experts' and 'Stakeholders'. This participation has included scientists and scientific administrators, representatives of research funding agencies, advisers, managers and regulators at the national and international levels, industry and environmental associations and other non-governmental organizations related to fisheries and aquaculture. This involvement spanned both formal (e.g. workshops mixing various interest groups) and informal activities (e.g. access to the project intranet to view emerging documents and provide feedback) over the course of the project. Five consultation workshops were organized at strategic times in the FEUFAR project's progression to specifically address targeted purposes (Fig. 1). The outcome of the final, June 2008 workshop resulted in the agreed research priorities ('research agenda') presented in Section 2.6.

## 2.5 The resulting 'foresight' system, drivers and emerging scenarios

The FEUFAR project has identified a foresight system for fisheries and aquaculture based on seven subsystems and 42 drivers which influence these (Table 1). Variations in these drivers, acting alone or together in various groups, determine the future development (trajectory) and sustainability of the overall system.

Scenarios were developed to provide diverse perspectives on how the future alternative 'worlds' of European fisheries and aquaculture may look, against which a list of research priorities should be established in order to address a range of challenges inherent in the respective scenarios. A set of different micro-scenario *hypotheses*, or 'possible futures', for each of the 42 identified drivers was elaborated by the FEUFAR project. For each of the highlighted seven subsystems associated with European fisheries and aquaculture, a 'story' emerges matching one hypothesis involving each of its drivers. Thus, the micro-scenario (mini-story) presents a possible development of the specific subsystem. The various micro-scenario hypotheses (see FEUFAR project reports for details) formed the foundation for building a small number of selected full-system scenarios (macro-scenarios).

Five macro-scenarios for the whole European fisheries and aquaculture system were eventually established by connecting in a logical way the micro-scenarios of the different subsystems. Illustrative narratives were prepared for each of these macro-scenarios and are detailed in the appropriate FEUFAR project reports.

*Table 1.*
*The European fisheries and aquaculture system comprising 42 drivers under seven subsystems.*

| | | | |
|---|---|---|---|
| **WORLD CONTEXT** | | **ECOSYSTEMS** | |
| A1 | Climate change including ocean productivity | E1 | Pollutants and contaminants including nutrients |
| A2 | International agreements (e.g. Kyoto Treaty, Johannesburg Summit, WTO) | E2 | Recruitment processes |
| A3 | World security including demography | E3 | Invasive organisms |
| **REGULATION** | | E4 | Escapement |
| B1 | EU policies (e.g. CFP, WFD, Maritime Policy, Marine Strategy) | A5 | Impact of gears on habitats and biota including deep sea |
| B2 | Governance policies including stakeholder cooperation | **PRODUCTION** | |
| B3 | Management tools including subsidies, relative stability, property rights | F1 | Marine 'ingredients', by-products, bio-prospecting |
| B4 | National policies | F2 | Fleet structure/size, and technology including selectivity, discards |
| B5 | Politics | F3 | Stock/resource development |
| **SEAFOOD MARKETS AND ECONOMICS** | | F4 | Fish feed development and availability |
| C1 | Product diversification | F5 | Aquaculture hardware technologies |
| C2 | Processing | F6 | Aquaculture species diversification |
| C3 | Distribution channels (e.g. value) | F7 | Genome manipulation, breeding and selection |
| C4 | Consumer choices (e.g. prices, ethics, preferences, health and safety) | F8 | Health and welfare of bio-resources |
| C5 | World production of finfish and shellfish by region | F9 | 'Seed' availability (e.g. tunas, eels) ranching |
| C6 | EU trade within world trade in fish and fish products | F10 | Health risk of seafood |
| C7 | Costs and earnings for fisheries including risks | **RESEARCH** | |
| C8 | Costs and earnings for aquaculture including risks | G1 | Sources and allocation of funding |
| **SOCIAL DYNAMICS** | | G2 | European research governance (e.g. organization) |
| D1 | Recreational fisheries | G3 | Access to infrastructures (e.g. databases, laboratories) |
| D2 | Public perception of fisheries and aquaculture | G4 | Research training and management |
| D3 | Activities in coastal areas including employment prospects | G5 | Information flows including individual property rights |
| D4 | Competitive use of coastal areas | | |
| D5 | Fishing/aquaculture community attitudes to future | | |
| D6 | Social capital (e.g. skills, expertise) | | |

The five macro-scenarios for the full system, developed by the FEUFAR project, have been called:

- **S1 - Doomsday** (*Negative impact of EU fisheries and aquaculture on world ecosystems*):
- **S2 - Delicatessen** (*Fish a healthy food – new opportunities for European fisheries and aquaculture*):
- **S3 - Regionalism** (*Local solutions for marine bio-resources*):
- **S4 - Responsibility** (*An adult world*):
- **S5 - 1984 - Big brother** (*Total European regulation and control to maintain seafood production*):

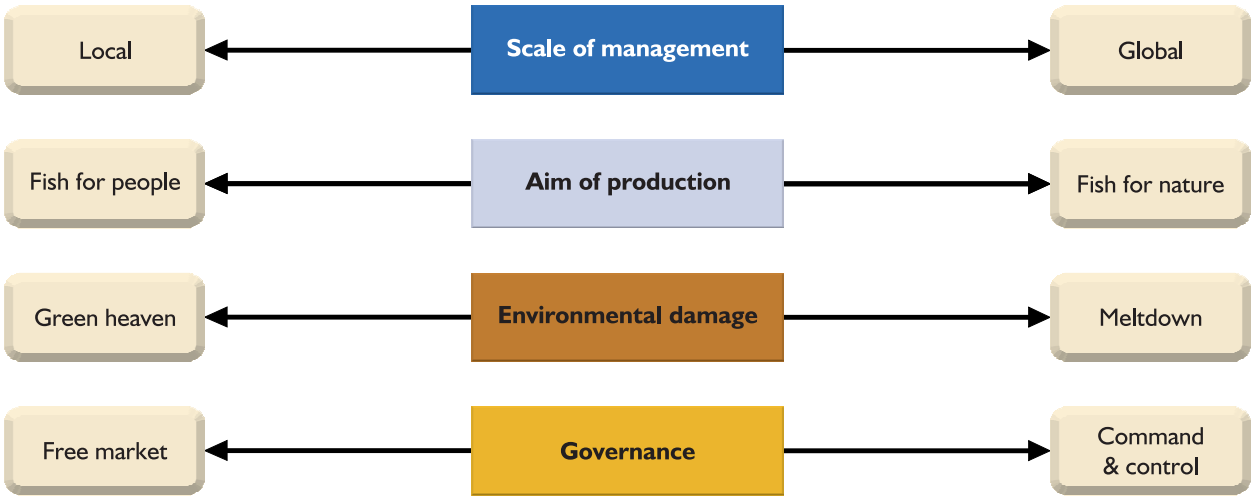
Each of these scenarios allows one to envisage different possible futures ('worlds') forward to about 2020 from a common baseline starting point which is the current situation of the fisheries and aquaculture sectors (Table 2).

*Table 2.*
*The principal attributes of the five selected future scenarios for fisheries and aquaculture.*

| Scenarios | S1: Doomsday | S2: Delicatessen | S3: Regionalism | S4: Responsibility | S5: 1984 – Big Brother |
|---|---|---|---|---|---|
| Scenario attributes | ▪ Rich countries scavenge the world for seafood products<br>▪ Management does not reduce fishing capacity or overexploitation<br>▪ Stocks and bio-recourses collapse<br>▪ Research paid by the customer does not solve the problem<br>▪ By 2020, a decline in aquaculture results from a lack of fish-feed and intensive use of antibiotics<br>▪ Marine pollution and disease ('mad-salmon') is rampant<br>▪ Greatly elevated ocean-temperature (climate change) affects all ecosystems<br>▪ Environmental 'good practice' restrictions are lifted to obtain short-term economic gain<br>▪ Policies are not enforced | ▪ EU prevents overfishing by high-tech surveillance<br>▪ Long-term resources important for the EU<br>▪ Seafood nutritional quality is what counts<br>▪ 'Clean' seafood (gain on health-spending) also from marine 'ingredients' and enhanced species/product diversification in aquaculture<br>▪ High-tech processing industry<br>▪ Traceability as a trade barrier to protect aquaculture investments<br>▪ Fresh, natural, local fish/seafood is a luxury<br>▪ Stocks and recruitment ultimately recover | ▪ Imports from aquaculture, not overseas fishing grounds<br>▪ EU regional seas ecosystem-based regulation - coastal countries manage fisheries<br>▪ High-frontier research, applied research for locals<br>▪ Demand for locally labeled products<br>▪ Stocks depend on the local regulations and size of the region<br>▪ Regional specialization - tourism and MPAs or aquaculture and energy<br>▪ Expensive fish – diversification of aquaculture, plus traceability and control | ▪ Consumer demands only products from sustainable sources<br>▪ Fishers recognize that they need to conserve stocks/bio-resources<br>▪ Non- (or less) polluting aquaculture; replacement of fishmeal and fish-oil by vegetable sources or herbivorous species<br>▪ Fishers deploy less harmful gears and practices<br>▪ Subsidies at the right place for the right purpose<br>▪ Fishing quotas owned and traded, but some bought by NGOs and recreational fishing operatives (solving overcapacity)<br>▪ Participatory management of both fisheries and aquaculture | ▪ Green scenario<br>▪ Fleets are under control (high-tech surveillance) and stocks van recover<br>▪ Efficiency in fishing, but standardization of products<br>▪ Understanding of species - ecosystem relationships, to develop aquaculture<br>▪ Technology-driven and technocratic system<br>▪ Blinding international agreements on bio-diversity and climate change<br>▪ EU maritime police force (EMPF)<br>▪ Research and rigorous monitoring (surveillance, monitoring, technology) |

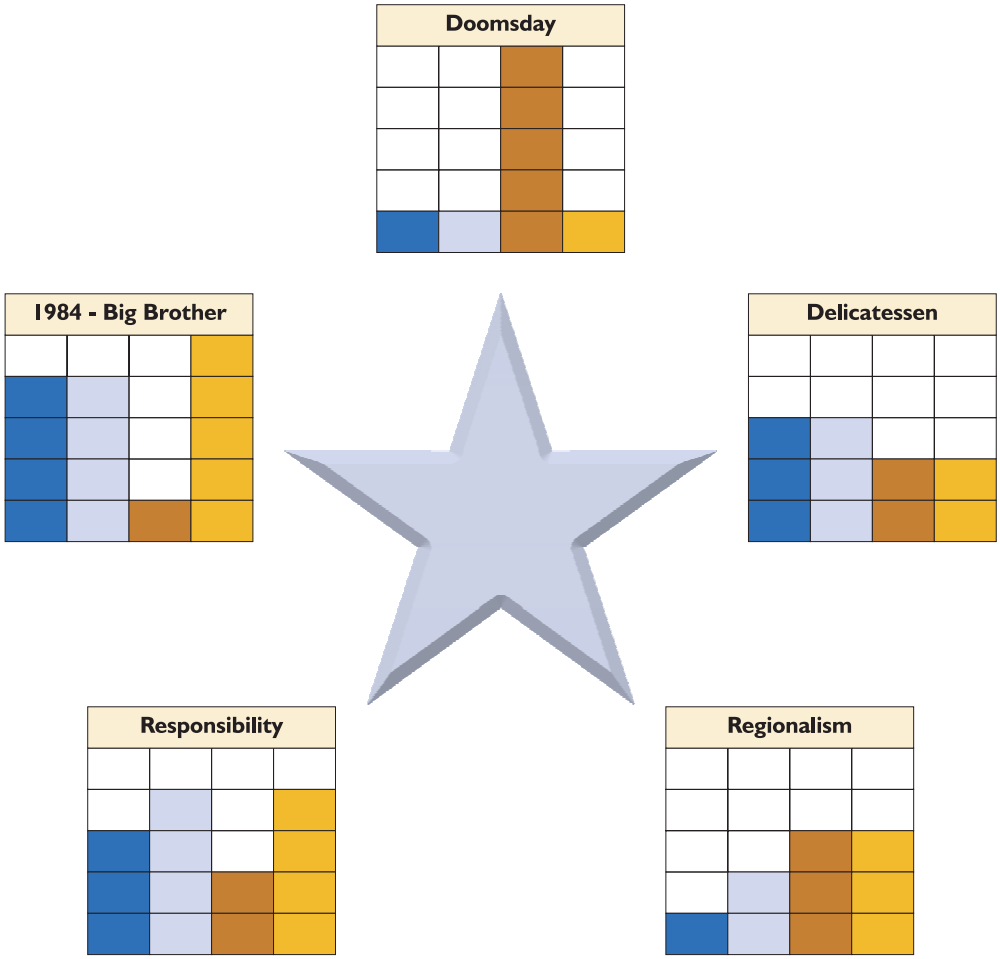
The five scenarios can be differentiated along four basic axes: a) 'Scale of management' varying from managing/regulating issues at a global-international scale or at an international-regional scale or even a national-local scale; b) 'Aim of production' ranging from being centered on feeding people or on conservation of the ecosystem; c) 'Environmental damage', spanning societal awareness/preferences concerning the environmental status; and d) 'Governance' ranging from free market to strict government planning/control (Fig. 2).

*Fig. 2.*
*Differentiation of the macro-scenarios along the four coloured axes.*




Each of the five scenarios has been characterized with a histogram reflecting the different emphasis placed on each of the above-mentioned four axes (Fig. 3). It is notable that the 'Doomsday' and '1984 - Big brother' scenarios have virtually opposite weightings of their characteristics. To a lesser extent, the moderate 'Delicatessen' and 'Regionalization' macro-scenarios also show different weightings of their characteristics.

*Fig. 3.*
*Characteristics of five scenarios for future development of European fisheries and aquaculture seen in histograms showing the weightings of four axial contributions (coloured) (c.f. previous figure for details).*



All scenarios, except S1 'Doomsday', are judged to provide sustainable 'visions' for the development of European fisheries and aquaculture. It is important to emphasize that scenarios S2 – S5 are considered as plausible, alternative 'visions' of how the system may develop, without any special preference expressed for a particular one. It is uncertain to what extent the actual future will explicitly resemble any particular one of these scenarios. In reality, the future may either fall between or be an amalgam of some of these scenarios.

For each of those scenarios ('worlds'), research topics were highlighted which would: (i) best fit the storyline leading to a given 'world'; (ii) promote positive trends highlighted by the storyline; and (iii) counteract the negative trends also highlighted by the related storyline. From the perspectives of these five scenarios, a responsive and adaptive research agenda comprising five research priorities and three cross-cutting priorities has been identified. These research agenda priorities are presented and elaborated in Section 2.6.

## 2.6 Research agenda priorities

Five main priority areas of research have been identified via the FEUFAR project: 1) Fisheries, 2) Aquaculture, 3) Ecosystem considerations, 4) Consumer preference and market development, and 5) Socioeconomics and governance.

There is no particular order of the research areas, but the order of the topics per area is ranked according to priority. However, the number of priorities per area is not an indication of the importance of the specific area of research. It also should be kept in mind that many of these priority areas are not independent ('stand-alone') as linkages and synergies may occur between various priority areas. Additionally, three cross-cutting themes have been highlighted as being of major importance to the priority research areas: 1) Data collection and analysis; 2) Risk management; and 3) Outreach.

### 2.6.1 Fisheries

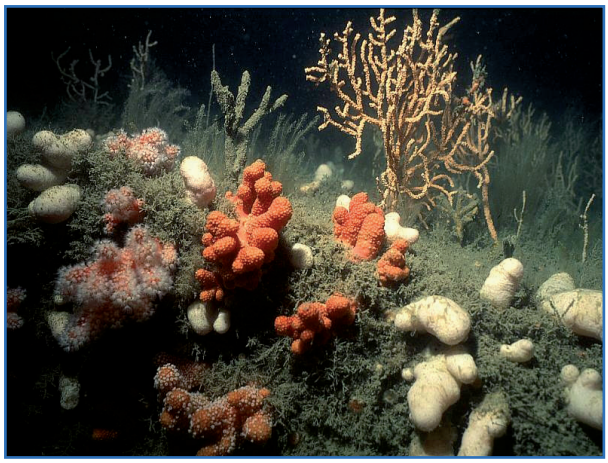
The 2003 CFP reform promotes an ecosystem-based approach to fisheries, science, advice and management, rather than the existing stock-by-stock approach, including integrating environmental protection, more long-term resource management, and tackling by-catch/discarding and illegal catches. A fundamental challenge is to avoid overexploitation by achieving an appropriate balance between fishing effort/mortality and the available living resources, thereby increasing the potential for long-term maximum sustainable yields and also substantially limiting the ecosystem impacts.

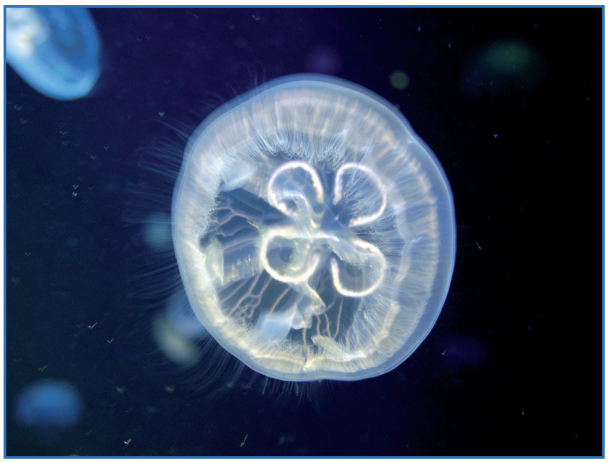
Within this priority area, four main research topics are highlighted: a) Gear and operational technology, b) Management and governance, c) Valorization of currently under-used components of the catch, and d) Basic research on populations of lower trophic level resources.

***Gear and operation technology***

a) *Developing environmentally friendly gear and practices which only entrap the target resources.*
The ecosystem approach to fisheries management requires that the detrimental ecosystem impacts of all fishing gears must be minimized. No fishery, or the ecosystem on which it depends, can be sustainable without adequate mitigation of the problems arising from by-catch and discards, and the degradation of benthic habitats. Consequently, towed gear that unselectively catch and retain everything in their path or detrimentally impact habitats, and passive (*i.e.* non-towed) gear that catch or entangle all that passes in the vicinity have no place in the future sustainable fisheries. Thus, there is a need for research further developing and substantially improving the implementation of technical measures, including selectivity and technological devices, as well as fishing practices, and measures to avoid 'ghost fishing, that minimize by-catches and discards of non-target and undesired sizes of target species, ensure better survival of animals escaping from the gear, and reduce physical impacts on the seabed and vulnerable habitats.

b) *Research into the development of more fuel-efficient technology.*
Improving fuel efficiency by, for example, the development of new technologies and greater use or even improved design of passive, more target-specific gears is becoming increasingly desirable, in response to the cost of wild-fish capture escalating through rising fuel prices. Associated with RTD into better gear is technical research into enhanced ship hull and propulsion design, lowering the carbon/emissions footprint of the current fleet and making optimal use of environmentally friendly energy sources.





***Management and governance***

a) *Operationalizing multiannual, multispecies - multifleet management models and approaches.*
Progress towards long-term, fisheries management, including credible measures for recovery of depleted stocks, requires an emphasis shift from the current primarily tactical, year-to-year (*i.e.* short-term) single stock, biologically dominated advisory and management system to the strategic, multiannual (*i.e.* medium to long-term), multispecies (*e.g.* multi-stock, predator – prey) – multifleet (*e.g.* fleet size, fishing gear and operations) modeling and management approach. This should potentially counteract the annual quota-trading debacle of the December Council of Ministers' meeting by facilitating the desired enduring stability of the CFP through better matching fishing capacity/effort to the available fishery resources. Additionally, there is a need to develop and apply an interlinked framework of scenarios ('what-if outlooks') considering potential future developments, including fishery system indicators supported by a suite of models, for evaluating fisheries management options for achieving sustainable fisheries in a potentially variable environment (*e.g.* driven by climate change and variability). However, these promising developments and models need to be further integrated, parameterized and better operationalized (*e.g.* due to crucial data being either insufficient, or not made available, for many stocks, species and fleets) for eventual adoption into the scientific advisory system. Accordingly, broad spectra research is required on multispecies and multifleet issues, and ecosystem health, including assessing the ecological impact or 'footprint' of fisheries. It is important to communicate the outcomes and address the uncertainty inherent in such developments, approaches and models in a clearly understandable manner.

b) *Further basic research into the socioeconomics of fishing communities.*
The successful implementation of ecosystem-based fisheries management depends to a great extent on integrating human society as a major component of ecosystems. It is important not only to account for how fishing affects the resources and the ecosystem, but also how resource development, and policy and management options impact the socioeconomy of fishing communities. The research issues to be addressed are numerous. These include development of bioeconomic analyses and models of fishing (*e.g.* fleets) explaining the spatial and temporal variations in exploitation of fishery resources, assessment of the market and non-market value of resources use, and the cost – benefit of conserving, protecting and restoring ecosystem resources. The research will provide key indicators of the economic and social conditions (*e.g.* employment, income and wealth) of fishing communities so as to better predict the likely socioeconomic consequences (*e.g.* cost – benefit) of, for example, different resource development scenarios and management plans. Based on analyses of fisheries systems, it is desirable to prescribe ways, such as co-management and co-ownership approaches involving fishers, to correct obstacles that lead to failures in governance processes and policies.

c) *Develop monitoring and enforcement technology beyond the current VMS and VDS.*
While the development of Vessel Monitoring System (VMS) and Vessel Detection System (VDS) technology has helped enforcement in many areas of the world, the technology is still essentially in its infancy, and there is a clear call for its future development and application. This will entail investment in further RTD and involve close collaboration with fishers.

d) *Artificial habitat creation and better understanding of fish behaviour.*
The creation of artificial habitat has often proven beneficial for aggregating resources so that they can be more efficiently (in terms of fuel) harvested. On the other hand, these habitats can conserve and even enhance the spawning, recruitment and growth of certain fish and shellfish stocks. The dynamics of these systems are not yet well understood, nor are the behavioural patterns of migrato-ry fish attracted to new habitats.

***Valorization of currently underused components of the catch***

Whatever is attained by mitigating by-catch and discards, some form of wastage will always remain and most of this currently is simply returned to the sea. Although this may enhance some food chains and resources, it can also distort the relative flow and balance of parts of the food web. We are bound to use optimally all of the current waste from the catch, and so research towards this end, for human benefit, becomes crucial. The use of such waste need not mean direct human consumption, as there will certainly be other benefits that accrue from its utilization in meal, pharmaceutics and medications, or other applications.

***Basic research on populations of lower trophic level resources***

Upper trophic level resources are commonly overexploited and gradually being driven to extinction. Yet we know very little about the populations and communities of the smaller biota which still survive and that are increasingly becoming the main protein source available to less affluent human communities. The precautionary approach requires that we manage these resources cautiously until the necessary data are collected for their sustainable management. This requires investment on acquisition, assembly and archiving of data which currently is deficient. Allied to this is the need for more basic research on life cycles to understand, and eventually predict, the responses of stocks and species to climate change, and hence the consequences of climate change on the distribution and availability of living resources to fisheries.

### 2.6.2 Aquaculture

European aquaculture must continue to evolve to maintain the availability of safe and healthy seafood and generate employment. The main objective of aquaculture is to produce high quality, diversified seafood, and even non-food products, while causing minimal environmental impacts.

Within this priority area, four main topics are highlighted: 1) Development of diversified, healthy seafood for consumers, 2) Decreasing the environmental impact of aquaculture, 3) Combatting pathogens and diseases[9], and 4) Development of non-food products, and 4) Improvement of rearing system technologies.

***Development of diversified, healthy seafood for consumers***

Today aquaculture production relies on a few species, such as salmon, sea bass, oysters and mussels. Market saturation for these species results in falling prices. As the market demand is for a variety of species, diversification is needed. Species diversification is expected according to the region's characteristics. This diversification requires two major kinds of scientific support:

a) *New species for aquaculture.*
The biology of native species as well as potentially beneficial introduced species must be investigated. Research advances are needed concerning understanding their reproduction, larval development, growth, health and welfare. This includes low trophic level species, in particular algae and molluscs, which will certainly expand in Europe.

b) *Species improvement (from farmer and consumer viewpoints).*
The growth, flesh characteristics (e.g. lipid quantity and quality including levels of omega-3 fatty acids), and reliable production of marine species already farmed in Europe can be improved substantially. These aspects include research on selective use of

9 This topic has been inserted by EFARO in addition to the Heraklion Workshop outcomes to emphasize the importance of an otherwise omitted research topic.

breeding, sterility, and hybrid and triploid strains. Research is also needed on genetics associated with improving desirable physiological and biochemical traits that advance both the health of cultivated species and human consumers. Research on genetically modified fish and shellfish for purposes such as benefiting consumer health (*e.g.* omega 3 fatty acids, vitamins and micro-elements), should be considered.

***Decreasing the environmental impact of aquaculture***

Although aquaculture benefits are many, the environmental impacts remain potentially substantial. It is necessary to investigate, identify and understand the nature and causes of these impacts, and to develop and apply relevant mitigatory measures. The main criticism of aquaculture concerns various kinds of 'pollution'. To combat this targeted research must minimize losses and emissions of organic materials, nutrients and chemicals, including antibiotics and biocides; 'escapee' organisms that may impair natural gene pools and transfer diseases, and compete for food and habitats with wild stocks; and pathogens and diseases that may spread and reach the surrounding ecosystem. Related to this, three main areas of research are highlighted:

a) *Alleviating the pressure on wild stocks of fish*
Research should advance the use of alternative dietary ingredients that reduce the current reliance of carnivorous farmed fish on fish-meal and fish-oil from vulnerable wild fish-stocks, while maintaining the human health benefits of eating farmed seafood. This will focus on new fish-feed sources from currently non-exploited marine invertebrates and algae, and terrestrial vegetable-derivatives. The research may cover, for example, selection and breeding of fish strains with high feed conversion efficiency and an elevated growth capacity on these new feeds, while limiting loss of feed constituents and faeces polluting the environment.

b) *Diminishing use of antibiotics and pharmaceuticals*
Although the use of antibiotics and pharmaceuticals in aquaculture has decreased considerably in the last decade, farmed organisms are still susceptible to pathogens and parasites. Accordingly, antibiotics and pharmaceuticals are still used for prevention, especially during critical life stages/periods. But their use can result in major risks such as their passage and persistence through the food chain, including to humans, and stimulating resistant strains of pathogens. Research is needed on alternative, safe, effective and environmentally friendly therapeutic measures such as, for example vaccination, feeding with prebiotics and probiotics, use of immunostimulants, herbal remedies, and good husbandry practices.

c) *Decreasing genetic pollution of wild stocks from escapement of farmed fish*
Concern about escapement of farmed fish and associated genetic impacts on wild stocks has brought restrictions on aquaculture industry development, and is likely to grow as demand for genetically improved stocks expands to meet production goals. Research to remediate these problems needs biological research that renders individuals functionally sterile outside of hatchery conditions, and technological research on the design and application of good farm, cage/pen or pond constructions for providing secure containment appropriate for the prevalent environmental conditions.

***Combatting pathogens and diseases***

Disease outbreaks continue to threaten aquaculture operations in many European regions. Broad prevention, eradication and control research is needed to tackle infectious aquatic pathogens and diseases that not only affect the current species/biota array in today's intensive and extensive aquaculture industry but also to mitigate emerging and prospective challenges involving cultivation of new species/biota. This includes evaluation and improvement of international and national codes/guidelines; diagnostics, therapy and health management strategies; and biosecurity, surveillance and information dissemination and early warning systems.

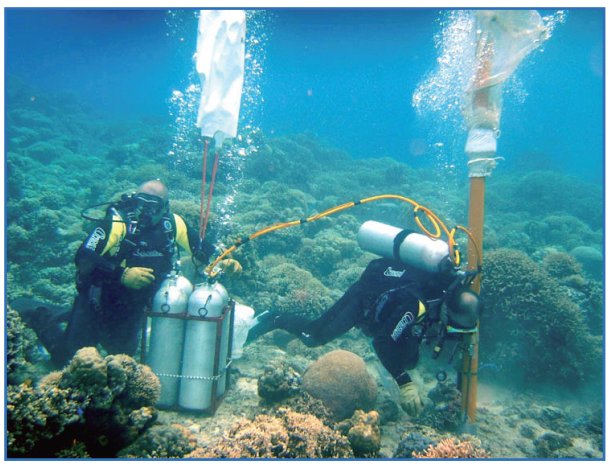
***Development of non-food products***

The necessity to further exploit the potential of adding value to current aquaculture products through the development of non-food uses is widely acknowledged. There is also the recognition that sustainable aquaculture implies striving towards improved utilization rather than wastage, including reduction of the volume and types of waste by value-added secondary or by-products. Thus it is imperative that research is conducted on better separation of numerous bioproducts, including efficient waste transformation, and improved biomass conversion, in

order to provide useful and valuable goods and services. Also, use of new/unexploited species for a range of novel non-food products and services arising from aquaculture will increase industry diversification. This requires a range of fundamental and applied research crossing many disciplines:

a) *Production of molecules or components*
Emerging and future demands are diverse, spanning pharmacology and medicine (*e.g.* drugs for treating cancer and arthritis from sponges and mussels, respectively), biotechnology (*e.g.* enzymes from fish viscera and other organs, invertebrates, microalgae and seaweeds; food additives such as omega-3 fatty acids, carotinoid pigments and antioxidants from microalgae, and chitosan from crustacean shells). Paramount is the research requirement concerning the identification, supply (*e.g.* culture, extraction, processing), and application of novel aquaculture products both from current and new aquaculture species. Success in this field builds on research providing sound ecological, metabolic and biochemical knowledge to understand how, and in which environmental conditions, the production of this material can be enhanced.

b) *Production of biofuels*
The production of biofuels (*e.g.* bio - ethanol, - diesel, and – gas) from marine bio-resources is strategically important. They provide a renewable, and thus sustainable, alternative to our current reliance on non-renewable fossil fuels. The latter are a major source of emissions causing climate warming. The use of marine biomass, mainly as plant materials, for fuel production presents several potential advantages over using terrestrial biomass. These include the typically quicker production rates of marine algae (*e.g.* microalgae, and seaweeds such as kelp) compared with land plants, carbon dioxide absorption rates significantly faster than in woody land plants and most land crops, and the non-competitive use of arable land for human-food crops. Despite these likely benefits, much novel research is needed on the production of marine biofuels via intensive and extensive aquaculture. Research is needed on selection and use of fitting biomass species (*e.g.* developing and securing raw materials to enhance productivity) and application of large-scale cultivation and harvesting systems adapted to local conditions. Core research technologies must be developed for each step of the production process, building on basic and applied research from ecology, physiology, biochemistry and genetics to optimize conditions for ideal growth and biomass yield.



c) *Cleaning zones/localities from pollution*
Bio-remediation provides innovative, environmentally safe and effective approaches to clean up pollution. Polluted zones/localities include oil spills in surface waters and inter-tidal areas (*e.g.* beaches and rocky shores), hazardous substances (*e.g.* heavy metals and persistent organic pollutants) in 'hot-spots' such as estuaries, harbours and ship-building yards, and even areas of excessive organic fall-out around fish farms. Some bacteria can take-up, trap and/or breakdown, for example, heavy metals, and hydrocarbons including oil and fuels, solvents or petroleum-based substances. Various filter-feeding and sediment ingesting organisms (*e.g.* mussels, oysters, sponges, sea-squirts, and polychaete worms) can remove detritus which cause eutrophication effects and hazardous substances thereby enhancing marine environmental quality. Intensive and extensive aquaculture-related research can produce and set-out the appropriate organisms for particular types of remediation. In some cases (*e.g.* bivalves and worms forming dense aggregates or biological reefs) after they have accumulated toxic substances, they may be removed from the locality. When good environmental quality has been achieved, potentially valuable species (*e.g.* oysters and mussels) may be harvested.

***Improvement of rearing system technologies***

A large proportion of farming currently is conducted in coastal cages or pens. Considering the high competition in the use of coastal areas, and in order to diminish pollution arising from aquaculture, inshore recirculation systems, offshore cages and integrated multitrophic aquaculture systems will develop. Moreover, coastal pollution (*e.g.* from eutrophication and hazardous substances, harmful algal blooms and coliform bacteria) may affect the sanitary quality of some seafood farmed along the coast, requiring detoxification systems. Related to this, four main areas of research are highlighted:

a) *Integrated systems*
These systems combine multitrophic, polyculture of marine biota so that the by-products (*e.g.* waste food and excreta) from certain traditional, fed-biota (*e.g.* fish such as salmon, sea bream) are utilized as

inputs (*e.g.* nutrients/fertilizers or food) for other biota which extract inorganic material (*e.g.* seaweeds removing soluble nitrogen) and organic material (*e.g.* removal of detritus by filtering mussels and oysters, and scavenging shrimps). Such systems exhibit great potential to increase the ecological and economic self-sustainability of aquaculture by, for example, providing ecological biomitigation services (*e.g.* limiting eutrophication), increasing product diversification and promoting the acceptability of aquaculture in the public eye. A range of research topics spanning RTD are needed. These include pertinent selection and proportions of species/biota in the habitat considering their ecosystem functions, devising appropriate technologies for designing and managing the physical components of such systems (*e.g.* spatial containment/distribution of biota in proximity to each other), and assessing their economic value or potential, and public acceptance.

*b) Systems for detoxification*

Commercially important filter-feeding shellfish, like mussels and oysters, may be prone to contamination due to periodically ingesting harmful algae containing phycotoxins and certain bacteria, which may threaten the health of humans eating the seafood. As the natural decontamination of shellfish may take weeks or months, it may lead to major financial losses for seafood producers. Accordingly, research is needed to understand the accumulation of such contaminants and detoxification mechanisms in different shellfish species so as to accelerate detoxification and better control the detoxification process. This benefits higher quality products, reducing waste and remediation times, and helping ensure more constant supplies.

*c) Offshore farming*

The prospective location of large-scale aquaculture operations, spanning intensive and extensive farming of food and non-food products, in close proximity to offshore (open ocean) renewable energy systems (*e.g.* wind, tidal, wave) may offer several benefits of synergy and scale. The benefits of such location of aquaculture offshore may include, for example, greater available space, the nearby availability of 'green' energy, and less environmental impacts than generated from coastal aquaculture. The latter may result from the dilution and dissipation of aquaculture wastes due to strong currents and wave action, as well as the normally less polluted environment of offshore compared with coastal areas. Other benefits may accrue from allying the mooring of aquaculture

cages/pens to the various stable structures required for siting massive renewable energy systems in deep waters. But there is a need for research to comprehensively tackle a wide range of technological, biological, logistic, policy, management and regulatory, and judicial (*e.g.* under EU and international legislation) challenges, including risks and accountability, connected with achieving safe and environmentally responsible aquaculture in high or extreme exposure environments within or outside EEZs.

*d) Recirculation systems*

Recirculation aquaculture systems (RAS) potentially represent an environmentally friendly way to farm fish. As they are ideally closed-loop systems, they have several expected benefits over open systems due to controlling loss or transfer of wastes, pathogens and parasites, and escapees from the farmed environment to the wild. However, owing to the promise of being able to achieve high feed conversion ratios while better controlling pathogens and parasites, there will be a temptation to maximize fish stocking densities. So, several research issues must be solved regarding RAS connected with fish growth and welfare. These require that fish 'shall be farmed without detrimental effects on their welfare, including health taking into account their biological characteristics, the scientific evidence and the practical experience available, and the farming system used[10]'. Also 'new methods of husbandry, and new design of equipment and enclosures for fish should be comprehensively and objectively tested from the point of view of fish welfare, including health[11]'.

10 Article 2, Recommendation Concerning Farmed Fish, Standing Committee of the European Convention for Protection of Animals Kept for Farming Purposes. Entered into force on 5 June 2006.

11 Article 6, Recommendation Concerning Farmed Fish, Standing Committee of the European Convention for Protection of Animals Kept for Farming Purposes. Entered into force on 5 June 2006.

### 2.6.3 Ecosystem considerations[12]

The EAM is a cornerstone policy for promoting sustainable use of the seas by humans and conservation of healthy marine ecosystems. The EAM considers the ecosystem with humans as an integral component, with the goal of maintaining ecosystems in a healthy, productive and resilient condition so as to provide ecosystem goods and services for human benefit. Sound ecosystem-based management must be founded on comprehensively and credibly integrating scientific data and knowledge involving the interactions between the ecosystem and environmental components, including the cumulative impacts of various human activities. Many aspects of research connected with supporting the EAM are also addressed under other priority areas of the research agenda. However, under the heading of this specific priority area, four main topics are highlighted: a) Climate change, b) MPAs and habitat enhancement, c) Coastal zone management, and d) Modelling ecosystems.

***Climate change***

Climate change will increasingly impact, over the coming decades, upon the biological, economic and social aspects of fisheries and aquaculture. As climate change impacts may vary between detrimental and beneficial depending on the regional environment, it will pose challenges and provide opportunities. It is important to identify, predict, mitigate and adapt to the scale and magnitude of the change acting on the ecosystem and the dependent fisheries and aquaculture activities. The climate forcing also depends on the degree to which other pressures (*e.g.* excessive 'extractive' harvesting, pollution including eutrophication, and habitat degradation) are also causing stress. The research concerning climate change related to marine fisheries and aquaculture will focus primarily on three topics:

a) *Addressing the impacts, both detrimental and beneficial, of climate change on ecosystems sustaining fisheries and aquaculture.*
Some ecosystems and their biota may suffer and some may benefit. Research should reflect interactions with relevant human pressures, and focus on the changing status and trends of biological resources (*e.g.* distributions and migrations, reproduction and recruitment, growth and productivity, food availability, multispecies interactions and food-webs) and their habitats (*e.g.* carrying capacity for key stocks/biota including hydrodynamic and oceanographic environment affecting their viability). Considerations should be extended to higher level predators (*e.g.* birds and mammals) which play important roles in fisheries and aquaculture systems.

b) *Understanding how the fisheries and aquaculture sectors will be affected by climate change and developing prudent strategies for mitigation and adaptation.*
Research is needed on how these sectors may optimally respond to climate affects on the (re)distributions and productivity of both 'old' and 'new' biological resources. Fisheries and aquaculture management policies should better incorporate the effects of climate change and variability in establishing harvesting levels, rules and practices, and developing prudent adaptive strategies and mitigatory measures. There is a call to move from seeking to maximize yield to increasing adaptive capacity. Overall, there is a convincing case for tackling the prevailing excessive exploitation of many resources in capture fisheries and extensive aquaculture. In addition to increasing their resilience to climate change and decreasing their variability, this may facilitate achieving two other desirable goals, viz. achieving longer term sustainable yields from such resources and reducing 'greenhouse' gas omissions in their harvesting.

c) *Non-indigenous and invasive organisms which may be introduce/become established due to climate change.*
Climate warming is predicted to facilitate wider establishment of more cosmopolitan non-indigenous organisms. In aquaculture, intended introductions have provided exploitable resources with major socioeconomic benefits. In fisheries, some unintentionally introductions are now the targets of lucrative harvesting. But, many unintentional, invasive introductions (*e.g.* pathogens and diseases, harmful algal blooms, and 'comb jellies') have spread between aquaculture across regions, from aquaculture to the wild and vice versa, and from the wild across regions, with serious repercussions. Novel research is needed on assessing and predicting the benefits and risks from

12 This title has been modified by EFARO from that originally used (i.e. Ecosystem Approach) in the FEUFAR project outcomes in order not to give the impression that only this section deals with the Ecosystem Approach.

non-indigenous and/or invasive organisms, devising techniques and models for impact assessments/risk analyses, early-warning systems and combatting measures. Knowledge is needed of ecology and life histories, multispecies interactions, ability to colonize various habitats, vectors of unwanted introductions, benefits/risks concerning ecological and socioeconomic impacts, and best-practices for containment/eradication.

***MPAs and habitat enhancement***

Marine protected areas (MPAs) are potentially important coastal and offshore areas in which certain uses are managed or regulated to conserve the natural resources, biodiversity and human livelihoods. Attention is also directed at the conservation of habitats essential to the biological resources which depend on the habitats for their viability. Degradation, fragmentation and eventual habitat loss, together with threats to their faunal and floral communities, prevail due to human pressures and climate change. Thus, research will focus primarily on two topics, which are closely related, in the context of fisheries and aquaculture:

a) *Understanding the effect of MPAs, encompassing key biological resources and habitats.*
Research should address how to design and put into effect MPAs, from the short to the long term, suitable to achieving key ecosystem-based management goals. These goals are related, for example, to rebuilding and maintenance of spawning stock biomass, protection of juveniles, sustaining ecologically important species and habitats, and regulating levels of 'extractive' exploitation of biological resources. It is desirable to scientifically investigate and devise management plans related to human access and use, including associated responsibilities, for the parts/whole of such areas. Indicators/metrics should be devised for measuring the success of MPAs including the human socioeconomic consequences.

b) *Advancing knowledge concerning the enhancement of crucial habitats.*
It is necessary to explore the scientific basis, via trials and experiments, for developing and evaluating the effectiveness of techniques and practices for restoring, creating, or enhancing habitats for important biological resources. This includes collecting and analyzing information and data on the characteristics of particular pelagic and benthic habitats, including the distinguishing features of their biological communities and their surrounding environment that are necessary to conserving healthy, self-sustaining biological resources.

***Coastal zone management***

Integrated coastal zone management (ICZM) and marine spatial planning can reconcile different and competing objectives, and tackle the cumulative effects of human activities. Seen from fisheries and aquaculture perspectives, it is essential that their operations are spatially situated and managed in suitable areas based on knowledge of the prevailing environmental conditions and the status of the biological resources. It is paramount that human activities, including fisheries and aquaculture, do not detrimentally impact the prevalent ecological quality objectives. Likewise, human encroachment, including the location of marine constructions/installations, causes the loss of sea area and reduces the production potential for 'natural capital'. Thus, research will focus primarily on the following topics regarding fisheries and aquaculture:

a) *Advancing methodology concerning environmental impact assessments.*
These should evaluate impacts from and on the fishing and aquaculture sectors. For example, environmental impact assessments for approval or licensing new fishing and aquaculture activities (*e.g.* fishing and aquaculture targeting new species, using new gears or practices) in new areas. There is a need to bridge the land – sea interface and focus on where impacts at sea affecting fisheries and aquaculture must be better accounted for in managing land-based encroachment (*e.g.* building artificial islands, port extensions, wind-mill parks, oil/gas rigs, and marinas). Relevant methodology should be elaborated for conducting such assessments.

b) *Developing and applying tools for spatial planning, including zonation for matching particular activities to the most suitable areas.*
These include development and application of geo-referenced information systems including, for example, surveying and mapping of habitats and ecosystem assets ('goods and services') and/or human sectoral interactions, and models and tools to sup-

port integrated assessments and decision-making. Demonstration activities are desirable via case studies.

c) *Analyses of fishing operations using vessel monitoring systems (VMS) and vessel detection systems (VDS) such as satellite data acquisition.*
This should provide better understanding and prediction of fishing behaviour and operations including the distribution of fishing effort by fishing fleets/gear types in space and time. The fisheries policy benefits include matching fishing effort to the available resources and combating illegal, unreported and unregulated (IUU) fishing.

d) *Investigations of the spatially related interactions between fisheries and aquaculture.*
The borders between traditional fisheries and aquaculture are being eroded due to wild-stock enhancement schemes and the rise of extensive aquaculture including sea-ranching. There are both challenges and prospects, including areas for optimizing synergistic interactions while minimizing the potentially antagonistic ones. A common issue is one of limited resource availability while globally the human population is increasing, coupled with declining/inappropriate space and environmental quality.

***Modelling ecosystems***

Modelling represents an important methodology for synthesizing our knowledge of marine ecosystems. Models provide a potentially precise, focused, and quantitative analytical tool to explore and understand the forces/pressures driving ecosystem-related dynamics. Thus, they form an essential tool for assessing and predicting the impact of natural and human induced pressures, recent as well as projected, and management decisions on the ecosystem and human society. Research will focus primarily on the following topics connected with fisheries and aquaculture:

- Advancing the development and integration of multispecies fish stock models into ecosystem models, with a view to bridging the gap between fisheries and ecosystem models with linkages to lower (*e.g.* plankton and benthos) and higher (*e.g.* seabirds and marine mammals) trophic levels. There is also a need to better link such models to meteorological, oceanographic and hydrological forcing (e.g. climate change) which affects, via the ambient environment, the biology (*e.g.* spawning and recruitment, feeding and growth), multispecies interactions (*e.g.* predator-prey dynamics) and spatial and temporal distributions of key biota.
- By extension, these models may be elaborated to evaluate various management options for achieving sustainable fisheries and aquaculture. An example is for modeling the full fishery system from interactions involving the living resources and fishing fleets, to the ecological, economic and sociological consequences under varying management regimes and environmental trajectories (*e.g.* changes in climate change and nutrient-load management goals).
- Other model applications include, for example, to assess and predict: the potential ecosystem impacts of introduced ('alien') organisms; the carrying capacity for extensive aquaculture (*e.g.* stock enhancement and sea-ranching); and how the ecosystem 'goods and services' associated with fisheries and aquaculture, including seafood, are affected by pollution and nutrient loads, and *vice versa*.

Currently many models are in existence but they need to be better integrated or 'nested' together, the data to parameterize the models is frequently insufficient, and they require to be practically operationalized in management situations. In all instances, there is a need to communicate, in a clear and easily understandable way, the outcomes of the models, potential options affecting decision-making, and levels of risk and uncertainty.

## 2.6.4 Consumer preference and market development

Increasingly, seafood consumers want access to varied products and to know that they are safe and healthy, as well as where the product has originated from and that the harvesting and processing of products conform to good practices (*e.g.* legal and ethical). Within this priority area, four main topics are emphasized: a) Product development from fish, b) Consumer health (as a basis for fisheries and aquaculture research in general), c) Traceability, and d) Certification and branding (labelling).

***Product development from fish and other bio-resources***

Much of the seafood produced in Europe consists of standardized goods, restricting the value added from a limited source. Developing new and diverse products, to fit the modern environmentally aware or convenience

oriented consumer, as well as high-value niche markets at the local and global levels, is vital for securing the growth and competitiveness of the seafood industry. This requires research about consumer values, attitudes and behaviour, on food processing to improve or maintain quality, taste and texture, to ensure food safety, and to develop new products from by-products ('waste to taste'). Moreover, the non-food use of marine components, and novel ingredients for functional food, pharmaceuticals and neutraceuticals needs RTD to progress bioprospecting so as to elaborate ingredients from fish and non-fish marine resources, as well as research on biotechnology to explore new and novel uses of compounds.

***Consumer health***

The consumption of safe and sustainable seafood products is vital for human health, food security and socioeconomic welfare. It also provides incentives to conserve the good quality and sustainability of the environment and ecosystems which maintain the exploited resources. There is a related, general need to improve the collection, analysis and dissemination of scientifically credible knowledge about the health, safety, quality and sustainability issues connected with the harvesting, production and processing, retailing and consumption of seafood products. Key research requirements related to fisheries and aquaculture are:

- Identifying and documenting the human nutritional and health benefits of consuming safe seafood products.
- Advancing knowledge concerning contamination and infection of seafood products by chemical pollution and biological agents (e.g. bacteria and parasites), and providing risk-benefit health analyses for seafood consumption.
- Developing quick and effective operational approaches and technologies concerning quality control regarding ensuring freshness, and to detect, assay and diminish toxins, contaminants and residues.
- Elaborating and assessing strategies for providing both low and high cost, yet still healthy, seafood products to fulfill the reasonable demands of consumer groups of different affluence.

***Traceability***

The traceability of seafood is a hot research topic. It is needed to ensure consumer confidence that seafood is safe and originates from known sources. In European open-market conditions, and further away, traceability will be an obligatory prerequisite for efficient trade and use by control authorities (e.g. counteracting IUU fisheries and related transshipments of products). Traceability is part of the extensive documentation systems that record key links in the chain-of-custody stretching from catching/harvesting, to processing and retailing to

the consumer. There is a requirement to collect, store and transfer validated information. This may potentially cover the product's species and origin (e.g. stock, locality), catching/harvesting method, handling, production methods in the processing industry, additives and preservation methods, and other processes before it is sold. Numerous RTD problems still have to be solved regarding the three logical steps of methodology, practical implementation and validation.

***Certification and branding (labelling)***

With a plethora of labels already used for food, knowledge is required about what information consumers should be provided with or actually need, on what to label and at which level. Research is needed concerning establishing and verifying certification schemes (e.g. ecolabelling, organic production) and standards to promote and attain sustainable practices for fisheries and aquaculture. These potentially will offer a market- and information-based system for consumers of products that are harvested from sustainable resources, and which are healthy, safe and of good quality, as well as promoting good animal health and welfare standards.

### 2.6.5 Socioeconomics and governance

Successful development and implementation of policies supporting the EAM with respect to fisheries and aquaculture depend on better integration of the human dimension as part of ecosystems. This particularly concerns research to provide improved knowledge about the socioeconomic and governance aspects of how humans interact with ecosystems. Included is the need to assess society's preferences and priorities for conserving, protecting and restoring ecosystem resources and services sustaining fisheries and aquaculture. Within this priority area, two main topics are emphasized: a) Socioeconomic analysis and impact assessment, and b) Governance.

***Socioeconomic analysis and impact assessment***

The development of bio-resources and the governing regulations affecting harvesting and production operations impact the broader fishing and aquaculture sectors, *e.g.* employment, income, and overall wealth and health, and on changes in a community's identity, and its perspective on the future of fishing and aquaculture activities. So, it is critical to determine community vulnerability to negative repercussions of management plans and the resilience of the community to absorb or adapt to these repercussions, *e.g.* the economic vulnerability of the fishing and aquaculture sectors and the existence of alternative coastal and offshore activities within and outside these sectors. The compilation of representative fishing and aquaculture community profiles is an essential basis for conducting efficient socioeconomic impact assessments, for example, of management plans and actions, as well as being central for the analysis of how economic impacts can broadly be evaluated. Thus, there is a marked need for a wide-range of analytical studies and impact assessments involving general socioeconomic research relevant to fisheries and aquaculture. This will only be achieved by collecting and assembling data and producing analyses that explain and forecast human interactions with the natural components of ecosystems, and specifically the related socioeconomic consequences. So far, little attention has been devoted either to developing and applying the appropriate analyses or to providing the necessary funding for these. Beyond the socioeconomic aspects just noted, and those mentioned under the other research topics, a number of research needs are specifically highlighted below:

- Socioeconomic support for policy development and the assessment of policy implementation concerning analysis of the impact or consequences, for example, of: various subsidies, taxes or incentives; the effects of new management/regulatory approaches and actions; the potential benefits to local communities of various forms of co-management systems; MPAs as no-take or limited-take zones; and mitigation of the social effects of employment destruction in coastal communities.
- Development and application of socioeconomic research methods and analytical tools to integrate diverse stakeholder knowledge into the policy development discourse process, including gathering views regarding different preferences and priorities, and to promote understanding and build confidence among various user and stakeholder groups.
- Continuous, regular and novel research is called for into the socioeconomics of the harvesting, processing and marketing of bio-resources to optimize efficiency of production, profitability and employment prospects.
- Better recording and understanding of the socioeconomics of the coastal zone and its communities, including examining different options for use of coastal areas and bio-resources benefiting from various forms and applications of capture fisheries, recreational fisheries and aquaculture.

***Governance***

Governance processes produce national and international policies, regulations and incentives. These are the principal mechanisms for managing human conduct, by discouraging certain behavioural patterns and discouraging others. Developing the scientific basis for improving governance involves applying the tools of governance and socioeconomic analysis to investigate how policies and regulations are produced, and understand the conditions leading to success and failures. So, it is possible to prescribe ways to correct obstacles that lead to failure. Thus, the behaviour of individuals, stakeholder groups and government agencies can be analyzed to understand, explain and possibly predict to what extent underlying conditions promote failure or success. This requires social science (*e.g.* political science, economics, public administration, and judicial) research to evaluate how laws, regulations and processes influence the use of ecosystem resources and services, and diagnose the grounds for governance failure, thereby applying 'lessons learnt' for producing successful fisheries and aquaculture policies and innovations. Addressing governance issues has already become a stipulated feature of linking science and policy underpinning the EAM related to fisheries and aquaculture. In essence, the focus is on governance-related research to facilitate implementation of prudent policy. This often hinges on developing approaches and methods bringing together the vital triangle comprising stakeholders, managers and scientists to develop and support key policy. Beyond the socioeconomic aspects just noted, and those mentioned under the other research topics, a number of research needs are specifically highlighted below:

- Development of innovative, adaptive, context specific (*e.g.* local and regional) management tools and systems based on inclusion of stakeholders and geared to the creation and acceptance of shared knowledge. This wide theme embraces, for example, the

development of stakeholder – science partnerships and the accommodation of local knowledge and observations in the development of analytical tools. Another example is addressing the issue of multiple uses and users/stakeholders examining, for instance, aquaculture-fisheries-recreational fisheries in terms of spatial planning, their co-evolution and socioeconomic and environmental impact assessments.
- The further development and implementation of integrated coastal zone management, including optimization of use of instruments such as MPAs, optimal spatial location of activities and conflict resolution techniques.
- The hunt for more efficient and cost-effective methods of management and enforcement through enlarged legitimacy and compliance involving, for example, co-management arrangements, co-creation in policy development and multi-stakeholder evaluation of impact assessments.

### 2.6.6 Cross-cutting themes

Three cross-cutting themes are identified by the FEUFAR project: 1) Data collection and analysis; 2) Risk management; and 3) Outreach. These themes focus on generic issues affecting all sectors and themes. Implementing these cross-cutting themes is not so much a priority in research as much as a prerequisite to implement other more topical research issues.

***Data collection and analysis***

Currently, data on the socioeconomic aspects of fisheries, aquaculture, recreational fisheries and ecosystem goods and services are rarely available. The data include the number of persons involved, valuation, costs, earnings, and investments. Even where data exist, they are often neither publicly nor continuously accessible. These data are urgently needed for the development and assessment of policies. Besides these issues, there is a research issue concerning the need to build a 'knowledge base', spanning fundamental and applied research, to improve our understanding of how 'systems' work. These systems range from individual animals, to populations and ecosystems, and from individual economic agents to the way that socioeconomic communities work. This knowledge will be extensive, inclusive and multidisciplinary nature. The data underpinning the knowledge base should be of good quality and accessible for both researchers and stakeholders.

***Risk management***

Risks and uncertainties occur throughout the wider fisheries and aquaculture related systems. These act on different scales and impacts, including climate change, invasive species, pathogens and parasites, and harmful algal blooms, through to uncertainties in stock assessments and policy impacts. Risk analysis should be a basic component of impact assessment of policies as well as the basis for developing policies. Currently the meaningful incorporation of uncertainty and risks into ecosystem management is in its infancy. The research issue to address is the development of a framework that enables inclusion of risk and uncertainty in policy development and the assessment thereof throughout fisheries, aquaculture and the related ecosystem.

***Outreach***

The need for demonstration and promotion activities is paramount for numerous research issues. This entails not so much the scientific development of communication and dissemination techniques, but rather the understanding and application of the 'message' from important research outcomes. Easily identified issues concern, for example, the human health benefits from consuming fish and the promotion of seafood in the diet, and in general the communication of the results of scientific research to the wider public in a manner and format suitable for key target groups.

## 2.7 Development of European Research Organization

Each scenario as elaborated in the FEUFAR project allows one to envisage five different 'worlds' regarding the possible future development of fisheries and aquaculture (Section 2.5.2), with a research agenda built up of various research priorities (Section 2.6). Similarly, complementary developments of the European research landscape should occur in order to support and enhance the capacity of the science community to respond to the policy-related research needs outlined by the FEUFAR project. Such developments would support the promotion of positive trends within European research organization (*e.g.* progress towards the completion of the European Research Area) and counteract the negative ones

(*e.g.* reinforcement of the 'European paradox'[13]). These trends, matching the storylines of the five scenarios, are shown in Table 3.

In elaborating the research needs, the diverse roles and priorities of research institutes, universities and private research organizations were reviewed. This emphasized that a consistent development of the five basic building blocks of the European research organization (*c.f.* pillars of Table 3), so as to maximize both the quality and quantity of the research outputs from the specific and cross cutting priorities (*c.f.* Section 2.6) would have to foster:

a) Greater access to infrastructure interoperability and reciprocal, synergistic access to modern research infrastructures as crucial prerequisites. These include research vessels and associated marine equipment; observing, surveillance and monitoring systems; databases, computer centres and analytical or experimental laboratories; and integrated and interactive information systems. Throughout, proficient cooperation in procurement planning and sharing strategies are key words.
b) The right balance ('mix') of sources (*e.g.* private or public, European or national) and allocations of funding (*e.g.* for applied or basic research) for European marine research should be defined. Also, there is a call for closer collaboration in research planning across the above-mentioned sectors including, for example, public sector – private sector and academia – industry partnerships.
c) Incentives should be given to researchers and technical staff so that they can address the research priorities in the most appropriate way and carry out effective transfer of knowledge about outcomes.

- Today's researchers are primarily products of a sector-based approach (*e.g.* within discipline, institution or industry) to education and training. But many current and future challenges are complex requiring interdisciplinary and multisectoral solutions. So there is a call for novel education and training to produce professionals with a wider awareness and understanding of the diverse facets inherent in ecosystem-based science, advice and management in particular geographic areas.
- Lack of an interdisciplinary approach and traditional exclusion of the social, economic and political sciences, severely limits the ability to integrate the 'human dimension' into the research, advice and management needed to achieve sustainable fisheries and aquaculture. Also the social and economic sciences, entering into the new paradigm, are confronted by dealing together with similar tasks via common rather than different perspectives.
- High quality technical training (*e.g.* for laboratory and sea-going technicians) represents a priority area necessary for optimally supporting researchers and marine RTD in general.
- New approaches are required to networking, knowledge dissemination and communicating complex research insights, to effectively build confidence and credibility, and increase the number of stakeholders in the decision-making process (*e.g.* by more, effective and varied partnerships).

*Table 3.*
*Trends in European Research Organization in different scenarios about fisheries and aquaculture.*

| Scenarios / Pillars | S1: Doomsday | S2: Delicatessen | S3: Regionalism | S4: Responsibility | S5: 1984 – Big brother |
|---|---|---|---|---|---|
| Sources & allocation of funding for marine research | Drastic cuts in public research budget at national European levels. Shift from basic to applied research. | Dramatic increase in funding at European & national levels | Sift from applied to basic research. Fierce competition for international excellence. | Dramatic increase in funding at European & national levels. | Increase of European funding dedicated to marine fisheries vs decrease in national funding resulting in cut in available budget for marine fisheries research. |
| Organization of marine research | Shift from European Research Area (ERA) into European Research Open Market (EROM). | Full completion of ERA. | 'European paradox' worsened. | Full completion of ERA. | 'European paradox' addressed. |
| Access to infrastructures | Privatization of key research infrastructure facilities. | Interoperability & reciprocal access to modern research infrastructures. | No cooperation in use of research infrastructures. | Interoperability & reciprocal access to modern research infrastructures. | Ageing research infrastructures. |
| Research training & management | - | Attractive positions available to researchers. | Brilliant international careers for basic researchers vs locally bound career for applied researchers. | Attractive positions available to researchers. | The marine & fisheries research sector also faces job losses, but careers become more attractive. |
| Communication flows including intellectual property rights | Marketing of data. Decreasing public awareness. | New knowledge is created & communicated. Information is freely & widely available. | - | Creation of easy & free access platform to all European marine data.. | European virtuous triangle of information. |

13 The perceived failure of European countries to translate scientific advances into marketable innovations. Hence, the conjecture that EU Member States play a leading global role in terms of top-level scientific output, but lag behind in the ability to convert this strength into wealth-generating innovations.