UNCOVER report

The Potential for Success of Recovery Strategies for Fish Stocks & Fisheries – Options and Constraints

Final Activity Report

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UNCOVER

UNderstanding the Mechanisms of Stock Re**COVER**y

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PRIORITY TP 8.1
Integrating and Strengthening the European Research Area – Scientifc Support to Policies
SPECIFIC TARGETED RESEARCH OR INNOVATION PROJECT

Final Activity Report

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UNCOVER: The Potential for Success of Recovery Strategies for Fish Stocks/Fisheries - Options and Constraints[1]

ABSTRACT:

The UNCOVER project '*Understanding the mechanisms of stock recovery*' has produced a rational scientific basis for developing Long-Term Management Plans (LTMPs) and recovery strategies for 11 of the ecologically and socio-economically most important fish stocks/fisheries in the Norwegian and Barents Seas (Northeast Arctic cod, Norwegian spring-spawning herring, Barents Sea capelin), the North Sea (North Sea cod, Autumn spawning herring, North Sea plaice), the Baltic Sea (Eastern Baltic cod, Baltic sprat) and the Bay of Biscay and Iberian Peninsula (Northern hake, Southern hake, Bay of Biscay anchovy). UNCOVER's objectives were to identify changes experienced during stock depletion/collapses, to understand prospects for recovery, to enhance the scientific understanding of the mechanisms of fish stock/fishery recovery, and to formulate recommendations how best to implement LTMPs/recovery plans.

This UNCOVER report is aimed at a knowledgeable readership comprising, in particular, scientists, scientific advisors and administrators/managers in the fishery and environmental fields. The report provides an overview of the project's aims and scope, approaches and methodologies, and detailed documentation of the deliverables and results which places these in relation to current and emerging challenges, constraints and opportunities.

UNCOVER emphasizes that it is essential to set 'realistic' long-term objectives and strategies for achieving successful LTMPs/recovery plans. It is recommended that such plans ideally should include:

1) Consideration of stock-regulating environmental processes;
2) Incorporation of fisheries effects on stock structure and reproductive potential;
3) Consideration of changes in habitat dynamics due to global change;
4) Incorporation of biological multispecies interactions;
5) Incorporation of technical multispecies interactions and mixed-fisheries issues;
6) Integration of economically optimized harvesting;
7) Exploration of the socio-economic implications and political constraints from the implementation of existing and alternative recovery plans;
8) Investigations on the acceptance of the plans by stakeholders and specifically incentives for compliance by the fishery;
9) Agreements with and among stakeholders.

UNCOVER has provided imperative policy support underpinning the following fundamental areas: a) Evolution of the Common Fisheries Policy with respect to several aims of the 'Green Paper'; b) Contributing to the Marine Strategy Framework Directive with respect to fish stocks/communities; c) Furthering the aims of the 2002 Johannesburg Declaration of the World Summit on Sustainable Development regarding achieving Maximum Sustainable Yield (MSY) for depleted fish stocks. This has been done by contributing to LTMPs/recovery plans for fish stocks/fisheries, demonstrating how to shift from scientific advice based on limit reference points towards setting and attaining targets such as MSY, and furthering ecosystem-based management through incorporating multispecies, environmental and habitat, climate variability/change, and human dimensions into these plans.

[1] Recommended citation: UNCOVER Final Activity Report (2010). The potential for success of recovery strategies for fish stocks/fisheries – Options and constraints. UNCOVER (FP6-2004-SSP4)

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1 INTRODUCTION TO THE UNCOVER PROJECT

1.1 The aims and scope of the UNCOVER project

1.1.1 The UNCOVER project

The UNCOVER project, funded under the EU's 6th research framework programme (FP6), aimed to develop a rational scientific basis for developing recovery strategies for EU fish stocks that are outside SBL. The principle objectives of UNCOVER were to: 1) Identify various changes experienced during stock decline in order to understand the prospects of their recovery; 2) Enhance the scientific understanding of the mechanisms of fish stock recovery; and 3) Formulate recommendations for fisheries managers how best to implement successful stock recovery plans.

The overall UNCOVER goal was, however, objective (3) by defining and recommending recovery strategies in the above defined precautionary framework.

To fulfill *inter alia* this objective, UNCOVER has taken a multidisciplinary approach to: a) Synthesize and integrate relevant information from previous and ongoing research programmes; and b) Evaluate and develop recovery strategies that incorporate biological, environmental, and technical and socio-economic factors. Regarding scientific support for policy, UNCOVER will: i) Help the EU and its Member States to meet obligations for the restoration and sustainable management of fish stocks/fisheries according to the 2002 World Summit on Sustainable Development's (WSSD) Johannesburg Plan of Implementation, the European Community's (EC) Common Fishery Policy (CFP) and Marine Strategy Framework Directive (MSFD); ii) Underpin development of an ecosystem approach to fishery management by improved understanding of the environmental/ecosystem and human activities affecting stock status and recovery; and iii) Contribute to the CFP's aim of improving economic stability for the fishing industry.

The recovery strategies developed in UNCOVER have been specific to four particular 'Case Study' Areas (1: Norwegian Sea and Barents Sea; 2: North Sea; 3: Baltic Sea; and 4: Bay of Biscay and Iberian Peninsula), each with its own ecosystem, important fish species, and ways of fishing. These represent ecosystems that vary significantly in structure and productivity due to differences in climatic influences, physical properties, species composition and species interactions. They encompass a wide range of physiological and population limiting conditions and processes, and are subject to differing harvesting intensity and strategy and represent a broad array of socio-economic conditions.

1.1.2 The challenge of maintaining 'sustainable' fish stocks: The 'road to recovery'

Many of the World's fisheries catches are in substantial decline due to overfishing, threatening not only the sustainability of the stocks and their associated ecosystems but also the social and economic sustainability of fishing communities, as well as the contribution of fisheries to human food supply (FAO, 2009; EC, 2009). The global imperative to rebuild depleted fish stocks emerged from the 2002 WSSD, whereby the adopted Johannesburg Plan of Implementation promotes the need to '*maintain or restore stocks to levels that can produce the maximum sustainable yield with the aim of achieving these goals on an urgent basis where possible not later than 2015*' (FAO, 2003). The European Commission recently recognized that: a) 88% of EC stocks are being fished beyond MSY, and that they could increase and generate more economic output if submitted to less fishing pressure for only a few years; b) 30% of these stocks are outside safe biological limits, and thus may not be able to replenish; and c) most of Europe's fishing fleets are either running losses or returning low profits (EC, 2009).

The precautionary approach to fisheries management was outlined by the UN's Food and Agriculture Organization (FAO) in which *inter alia* a set of limit or threshold reference points could be applied to promote long-term sustainability of fish stocks/fisheries (FAO, 1996). The PA implies that risks and uncertainties are taken into consideration in scientific advice and management (FAO, 1995).

Therefore, since 1998, the advice provided by the International Council for the Exploration of the Sea (ICES) on fisheries management has consisted of a dual system of 'limit and 'precautionary approach' reference points, the latter providing a buffer to safeguard against natural variability and uncertainty in the assessment, and ensuring that limit reference points are avoided with high probability. Traditional fish stock assessments mainly consider uncertainty in observations and processes (*e.g.*, recruitment) whereas uncertainty about the dynamics (*i.e.*, model uncertainty) has a larger impact on achieving management objectives. As the 2002 WSSD commits signatories to maintain or restore to levels with that can produce maximum sustainable yield (MSY) by 2015, there is a pressing need to develop a new form of management advice, which can be incorporated into long-term management plans (LTMPs), and associated recovery plans for depleted stocks, based on targets rather than limits. As an important part of this process, management strategy evaluations (MSEs) play an essential role in developing LTMPs that are robust to uncertainty (Kell *et al.*, 2006; Kelly *et al.*, 2006). Starting at the end of 2009, ICES has taken steps to change the form of its advice to accommodate the needs of its Member Countries and client regulatory Commissions who desire to implement MSY-related management (ICES, 2010).

1.1.3 Evolving policy and science issues

Major science and policy issues that should be taken into account in developing prudent fish stock/fishery management and recovery plans in the European Regional Seas, also taking into account the aims of the Johannesburg Plan of the 2002 WSSD previously mentioned, include:

- <u>Further development of the precautionary approach</u>. The contemporary view of sustainability is moving further in the direction of precaution, such that managing to achieve targets (*e.g.,* fishing mortality limit of the target of MSY or its proxy) well removed from the risk-based reference points should result in more stable scientific advice, as well as healthier stocks and more sustainable fisheries (Punt and Smith, 2001; Quinn and Collie, 2005; Punt and Donavon, 2007).
- <u>The 2003 and ongoing reform of the European Community's (EC) Common Fisheries Policy (CFP)</u>. This process has_emphasized that the ecosystem approach to the management of human activities[2] (EAM) must be fully integrated and implemented into the principles, objectives and operational framework of the CFP (EC, 2009) and the new overarching European Maritime Policy (EC, 2008), under which research in support of policy, scientific evidence-based advice and management regarding capture fisheries play

[2] June 2003 First Joint Meeting of Helsinki and OSPAR Commissions definition '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'.

essential roles. There is an emphasis shift from the current primarily *tactical*, year-to-year (*i.e.,* short-term) single stock management approach towards a longer-term *strategic* approach. This involves credible strategies for multi-year management plans (*e.g.*, LTMPs) including effective recovery strategies for depleted stocks, which take better account of multispecies interactions in the ecosystem, relevant human dimensions (*e.g.,* socio-economics, governance), mitigation/adaptation to climate change and variability, and *a priori* evaluation of the efficacy of proposed strategies (EC, 2009).

– The EC's Marine Strategy Framework Directive (MSFD). This forms the environmental pillar of the EC's Maritime Policy, focusing on the application of an integrated EAM so as to achieve 'good environmental status' (GES) of the EC's marine waters by 2021 and to protect the resource-base upon which marine-related economic and social activities depend (EC, 2008). Marine Strategies for European Regional Seas will include a detailed assessment of the state of the environment, a definition of GES and the establishment of clear environmental targets and monitoring programmes. The MSFD has 11 high-level descriptors related to GES, of which descriptor 3, for example, aims for: '*Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock.*' The importance of Marine Protected Areas (MPAs) in achieving GES is highlighted. The CFP, including its reform, is required '*to take into account the environmental impacts of fishing and the objectives of the Directive*'.

1.1.4 Recovery or rebuilding: a question of definition, time-frame and understanding

Stock recovery is increasingly recognized as not being synonymous with stock rebuilding. The term **recovery** tends to be used relatively indiscriminately and often simply denotes recovery of bulk biomass, *i.e.*, stock tonnage. On the other hand, **rebuilding** should be regarded as a more complex and challenging goal to achieve, aiming to reconstitute a previously evident age-structure which has been truncated by excessive fishing pressure, modified or lost behavioural traits (*e.g.*, the extent and pathways taken during migrations) as a result of altered demography (*e.g.*, communal memory or experiences previously resident in parts of the stock which have been decimated), changed structure of the stock's gene pool and evolutionary mechanisms resulting from diminution of the gene pool arising from substantial depletion or collapse of the stock due to overfishing. Such rebuilding may take generations to achieve, if it can be done at all. Currently, our knowledge on these aspects is severely limited and requires funding of long-term, carefully focused research. Furthermore, one must consider the long-term costs and benefits of particular 'rebuilding' targets of this type. Some of these aspects have been highlighted to varying degrees by several authors (*e.g.*, Murawski *et al.*, 2001; Grift *et al.*, 2003; Ottersen, 2008; Murawski, submitted).

There is also variation among national jurisdictions in the use of the terms *recovery plans* and *rebuilding plans*. Within the United States, *recovery plans* are associated with the recovery of critically endangered species from the risk of population extinction, whereas *rebuilding plans* are associated with the recovery of depleted marine capture fisheries and rebuilding the stock to reach more productive levels of exploitation as mandated under federal law of the Magnuson-Stevens Fishery Conservation and Management Act. On the other hand, in Australia and the European Community for example, the generally applied term concerning depleted fish stocks/fisheries is *recovery plans*. Further details are provided in the UNCOVER-related study of Wakeford *et al.* (2007, 2009).

On the basis of the above-mentioned considerations, the UNCOVER project—in writing its Synthesis Reports—will generally use the term 'recovery' as outlined in the first paragraph of sub-section 2.1.4, unless one specifically means 'rebuilding'.

Numerous abbreviations and acronyms are used in this report. The first time these occur in the text they are spelt out in full. Annex 1 provides a list of these abbreviations and acronyms.

2 THE UNCOVER PROJECT's APPROACH, METHODOLOGY, DELIVERABLES AND PUBLICATIONS

2.1 The UNCOVER consortium, project management and governance

The UNCOVER project involved 17 partner and 10 subcontractor institutions representing primary centres of fisheries, environmental, oceanographic and ecological sciences from a total of 14 countries (12 EU, plus Norway and Russia) (Figure 2.1; Annex 2).

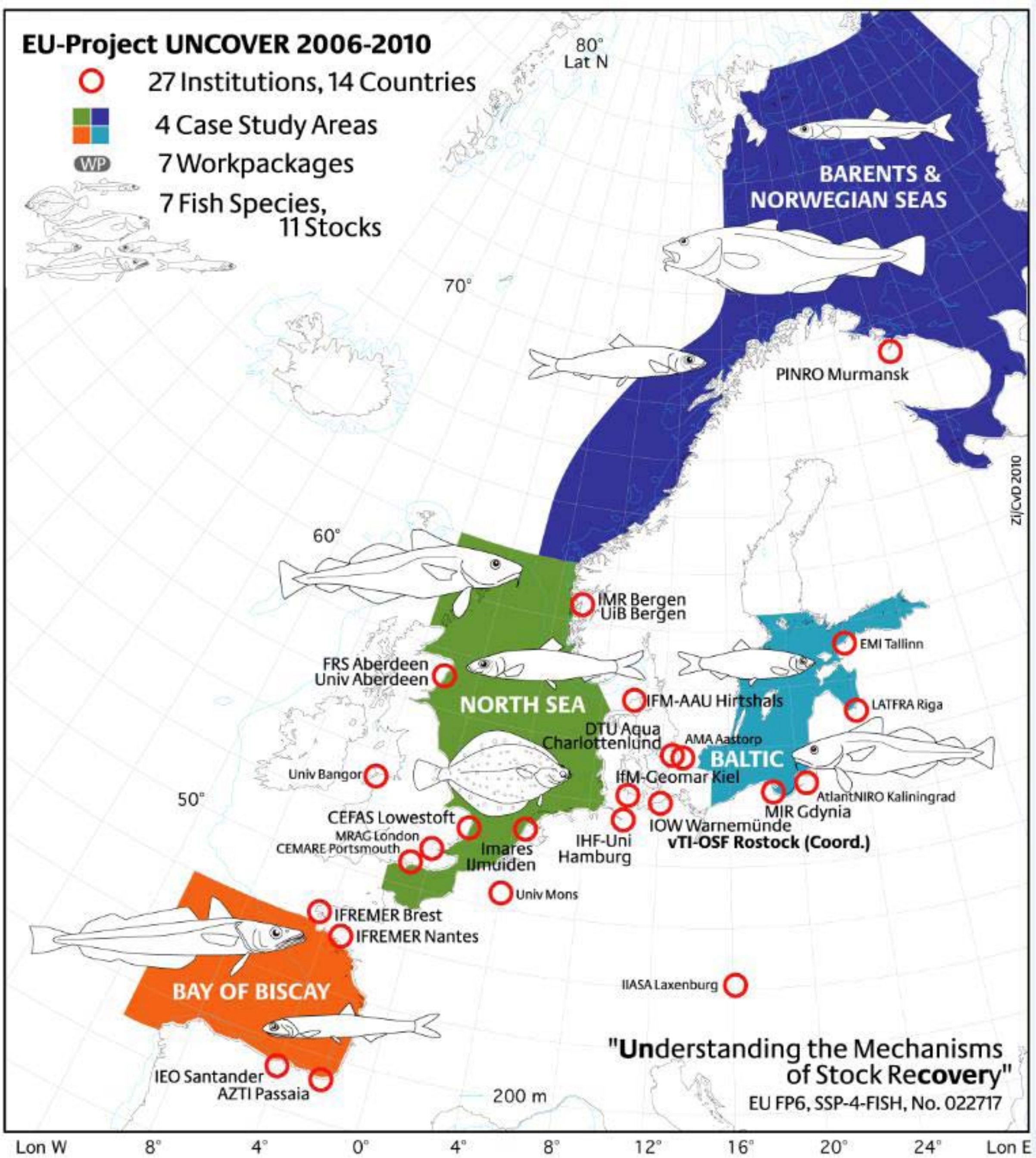

Figure 2.1. Map showing the geographical location of the four Case Study areas, the associated target fish stocks, and the participating institutions from 14 countries, involved in the UNCOVER project.

Many of the personnel from these institutions, including persons involved in the UNCOVER project, actively participate in key Study/Working Groups of the International Council for the Exploration of the Sea (ICES) which underpin the ICES Advisory Services for ecosystem-based fisheries and environmental management.

2.2 The UNCOVER approach

2.2.1 Organization via Workpackages and Case Study areas

UNCOVER was organized in seven WPs (Figure 2.2) focusing on the four Case Study areas (CSAs) (Figure 2.1). The leadership of the WPs and CSs is listed in Annex 3.

WP1, 2, and 3 addressed biological and ecological aspects of stock development, including environmental and fisheries influences. Their results fed into WP4 which build the model series to evaluate different recovery strategies that are sensitive to various stock, environmental and fisheries conditions. WP5 dealt with economic and social issues that are critical to the design and implementation of effective recovery plans. The task of WP6 was to coordinate the close collaboration between WPs1-5, and to synthesize and summarize the outcomes in a useful way for fisheries managers and decision-makers. As already mentioned, WP7 handled general project management, communicating results and making sure that activities within WPs and case study areas matched successfully. Further details of the tasks of WPs 1-6 are provided below.

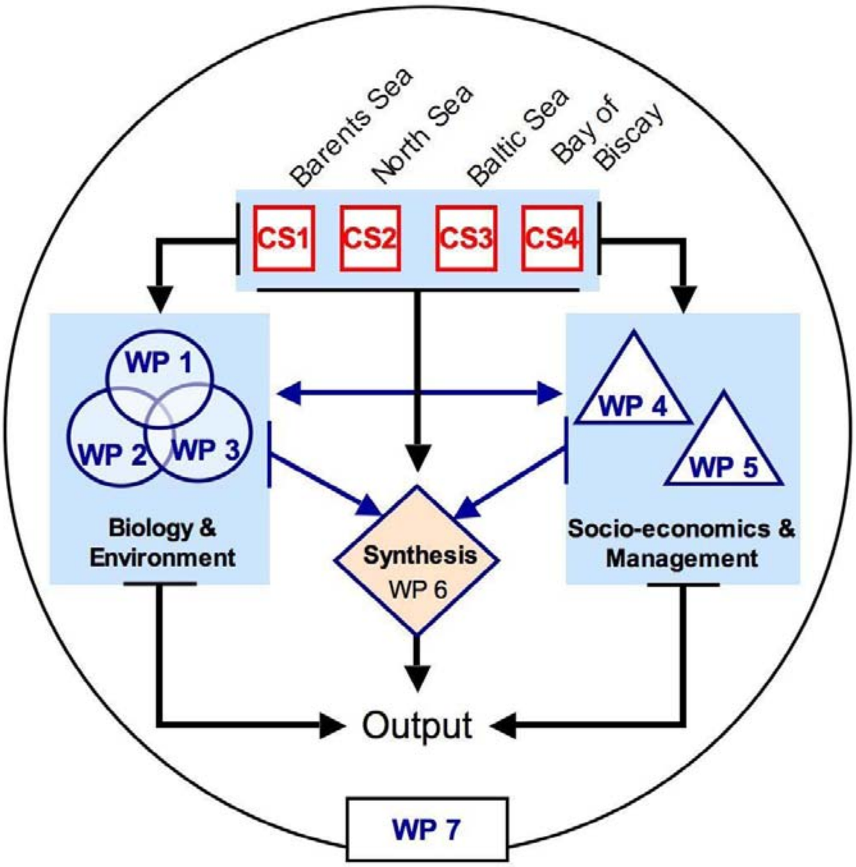

Figure 2.2. UNCOVER program structure; showing the interdependencies between Workpackages (WP) and Case Studies (CS).

WP1: Mechanisms of changes in stock structure and reproductive potential.

This WP was directed towards understanding traits and mechanisms of changes in stock distribution, biology, and reproductive potential, genetic structure and evolutionary effects of fishing. The approach provided an initial collation and review of all the available information on the target species for recovery, by CS area in order to establish time series of empirical data for application in process models and stock reproductive potential estimates to be used by other WPs. The specific objectives of the WP were to:

a) Develop process models to predict immature fish growth and maturation, and seasonal reproductive investment of adults considering abiotic and biotic factors that affect energy allocation, atresia and spawning omission.
b) Review and evaluate egg quality and viability of offspring under differing stock structures depending on maternal characteristics and environmental factors.
c) Establish models capturing variability in stock reproductive potential under varying stock size, demography and environmental conditions.
d) Review and model the available genetic information on natural changes in effective population sizes, selective changes in life history/morphology and physiology and changes in genetic isolation between populations caused by human intervention.
e) Evaluate and model fishery-induced evolution in the target fish stocks and the implications for recovering fish stocks.
f) Examine and model the known distribution and migration patterns of the target species under high and low stock sizes and evaluate the consequences of changes in environmental conditions during periods of stock recovery.

WP2: Impact of exogenous processes on recruitment dynamics.

This WP examined the biological and oceanographic basis for the survival and developmental success of eggs, larvae and early juveniles. Initially, available data and information on the target stocks was collated to produce historical time series of environmental proxies and variables affecting recruitment. This included ecosystem specific data on abiotic and biotic conditions affecting survival and development including, for example, temperature, prey and predator abundances (in cooperation with WP3), and ocean circulation. It also required spatially and temporally resolved time series of the realized egg production, information about the timing and location of spawning both derived from WP1 as well as data on the abundance and distribution of larvae and young-of-the-year juveniles. The specific objectives of the WP were to:

a) Increase understanding of processes affecting recruitment of target fish species.
b) Describe and quantify links between historical variations in recruitment, egg production, spawner demographics and environmental variability.
c) Evaluate using process knowledge the sensitivity of recruitment to variations in egg production, spawner demographics and environmental variability.

WP3: Trophodynamic control of stock dynamics.

This WP resolved the direct or indirect trophic control of stock recovery. Switches in magnitude and direction of trophic control of population dynamics and implications for stock recovery were investigated in combination with fishing and environmental forcing, as the combination of all three processes change the entire food-web structures and fluxes and thereby affect stock recovery potentials. The specific objectives of the WP were to:

a) To identify the physical and biological key processes that lead to historic changes in food-webs and to understand how they force the occurrence of slow and/or sudden changes, including regime shifts.
b) To quantify historical changes in food-web fluxes and trends in stock sizes by application of improved deterministic and stochastic multi-species models.
c) To estimate the impact of local high-intensity predation events on survival rates of early and juvenile life stages of recovery species, and develop and implement methods to parameterize these local processes in large scale multi-species models.
d) To enhance the predictive capabilities of deterministic and stochastic ecosystem and multi-species assessment models by implementing verified process sub models.
e) To predict the impact of trophic control, exerted by both direct and indirect predation under contrasting environmental and fishing regimes, on stock recovery paths.

WP 4: Evaluation of strategies for rebuilding.

This WP identified what we need to know and what are appropriate actions when developing recovery plans, *i.e.,* to determine the value of: 1) information, since some processes will be more important than others and we need to identify and give priority to these rather than just collate previous work; and 2) control, concerning what can we actually change through management action. The specific objectives of the WP were to:

a) Identification and specification of recovery strategies to be evaluated within the Framework for the Evaluation of Management Strategies (FEMS), including identification of strategic questions, information needs and control options.
b) Identification and synthesis of appropriate information (models and data) representing key processes affecting stock recovery into a form suitable for incorporation within FEMS (selected stocks only).
c) To evaluate alternative management strategies and produce a suite of management strategy options for generic aspects of stock recovery in these selected stocks.

WP5: Social, economic and governance influences on recovery plan effectiveness.

This WP provided WP6 with the information needed to place the results of WPs 1-4 into the broader context of overall fisheries systems in order to translate these results into recommendations for effective recovery strategies reflecting realistic economic, political and social circumstances. The specific objectives of the WP were to:

a) Provide a world-wide synthesis of existing recovery plans.
b) Identify and evaluate successful recovery plans based upon a synthesis of expert opinions regarding case studies from within and outside the European fishing community.
c) Evaluate the potential roles of stakeholders in the creation and implementation of recovery plans.
d) Use existing bio-economic modeling tools of fishery dynamics and social impact assessment (SIA) methods to describe the expected reactions of the interested public to the options available in recovery plans.

WP 6: Project synthesis.

This WP, via outputs from synthesis, provided biologically, ecologically, technically and socio-economically ‘realistic’ strategies for achieving stock recovery. In a first step, it focused on strategies for selected CS-specific stocks. In a second step, it provided specific guidelines for the generalized design, implementation and assessment of recovery plans based upon a synthesis of project products. The specific objectives of the WP were to:

a) Summarize and integrate the stock-specific key factors and processes emerging from WP1 (*i.e.*, factors affecting growth, maturation, fecundity, genetic composition, distribution and habitat utilization) and evaluate the implications of changes in these for stock recovery.
b) Identify changes in the ecosystem that affect recruitment (*e.g.*, hydrographic conditions, interactions between recruits) during periods of stock decline and recovery based on results from WP2
c) Implement stock and recruitment models that incorporate the dynamics of both stock demographics and critical environmental agents (bottom-up and top-down controls) identified for Case Study specific fish stocks currently outside safe biological limits.
d) Synthesize output from WP4 on the evaluation of strategies for rebuilding and the application of bio-economic modeling tools of fishery dynamics and social impact assessment methods conducted under WP5.

The recovery strategies developed in UNCOVER are specific to four particular CS areas (Barents and Norwegian Seas, North Sea, Baltic Sea, Bay of Biscay and Iberian Peninsula), each with its own ecosystem, important fish species, and ways of fishing (Table 2.1). These represent ecosystems that vary significantly in structure and productivity due to differences in climatic influences, physical properties, species composition and species interactions. They encompass a wide range of physiological and population limiting conditions and processes, and are subject to differing harvesting intensity and strategy and represent a broad array of socio-economic conditions.

Table 2.1. The four Case Study (CS) Areas, and the targeted stocks for recovery, focused on by UNCOVER.

CS Area 1: Barents and Norwegian Seas	
Targeted stocks	• Northeast Arctic (NEA) cod • Norwegian spring-spawning (NSS) herring • Barents Sea capelin
CS Area 2: North Sea	
Targeted stocks	• North Sea (NS) cod • Autumn-spawning (AS) herring • North Sea plaice
CS Area 3: Baltic Sea	
Targeted stocks	• Eastern Baltic (EB) cod (also known as Central Baltic Cod) • Baltic sprat
CS Area 4: Bay of Biscay and Iberian Peninsula	
Targeted stocks	• Northern hake • Southern hake • Anchovy

2.2.2 Working via the ICES advisory system and EU forums on developing management plans, recovery plans and harvest control rules

The International Council for the Exploration of the Sea (ICES), founded in 1902, coordinates and promotes marine research on oceanography, the marine environment, the marine ecosystem, and on living marine resources in the North Atlantic (Rozwadowski, 2002). Members of the ICES community now include all coastal States bordering the North Atlantic and the Baltic Sea, with affiliate members in the Mediterranean Sea and southern hemisphere. ICES is a network of more than 1 600 scientists from 200 institutes linked by an intergovernmental agreement (ICES Convention) to add value to national research efforts.

ICES is the prime source of independent, politically objective scientific advice on the marine ecosystem, including fishery management, to governments and international regulatory bodies concerned with the North Atlantic and adjacent seas. Each year ICES, through its Advisory Committee (ACOM), provides advice about the status and trends, including levels of TACs, of commercially important fish stocks/fisheries to its 20 member countries as well as to the European Commission and European Council of Ministers, and the regional fishery bodies (RFBs) constituted by these member countries.

ICES provides the scientific information and advice connected with fishery management in the four Case Study areas focused on by the UNCOVER project. As the majority of the UNCOVER project partner institutions often participate in the work of ICES, within its Study/Working Groups (SGs/WGs) and other forums, the project has actively contributed—via relevant groups and forums—to the development and evaluation of Long-term Management Plans (LTMPs), Harvest Control Rules (HCRs), and recovery plans within the ICES system.

The work of UNCOVER has been integrated purposefully with the ICES advisory system as well as with relevant EU groups like the Scientific, Technical and Economic Committee for Fisheries (STECF), so that in effect UNCOVER has contributed to the generation and/or evaluation of LTMPs, HCRs and recovery plans for fish stock/fisheries which, for the most part, have been critiqued and incorporated, in whole or in part, into the LTMPs, HCRs and recovery plans emerging from the ICES advisory system as well as expert groups organized by the EU. Thus, such LTMPs, HCRs and recovery plans have subsequently either already been adopted or are in the process of being adopted by the RFBs which depend on ICES for their scientific information and advice.

For the UNCOVER CS areas, besides the individual coastal States, the following regional fishery bodies (RFBs) either have been or currently are the recipients of ICES advice on developing and/or evaluating MPs/RPs/HCRs:

Barents and Norwegian Seas:	***Joint Norwegian – Russian Fisheries Commission***: NEA cod and capelin in the Barents Sea; ***Northeast Atlantic Fisheries Commission (NEAFC)***: NSS herring in the Norwegian Sea.
North Sea:	***EU Member States (via Council of Ministers) and Norway (i.e., Bilateral agreement between EU and Norway)***: Cod and Autumn spawning herring; ***EU Member States (via Council of Ministers):*** Plaice.
Baltic Sea:	***EU Member States (via Council of Ministers) and Russia (i.e., Bilateral agreement between EU and Russia)***[3]: Sprat; Eastern Baltic cod.
Bay of Biscay and Iberian Peninsula:	***EU Member States (via Council of Ministers):*** Northern hake, Southern hake, Anchovy.

[3] Formerly by the International Baltic Sea Fisheries Commission (IBSFC, the Convention on Fishing and Conservation of the Living Resources in the Baltic Sea and the Belts of 1973, the so-called Gdansk Convention) which ceased to exist on 1 January 2007.

The ICES advisory-related SGs/WGs and other forums which UNCOVER personnel/institutions have contributed to are listed below:

Acronym	Full name
AFWG	ICES Arctic Fisheries Working Group
AGCREMP	ICES *Ad Hoc* Group on Cod Recovery Management Plan
HAWG	ICES Herring Assessment Working Group for the Area South of 62¡ N
SGBRE-07-03	STECF Sub-Group meeting on Balance between Resources and their Exploitation
SGHERWAY	ICES Study Group on the Evaluation of Assessment and Management Strategies of the Western Herring Stocks
SGRST-08-02	STECF Subgroup on Stock Reviews
WGANC	ICES Working Group on Anchovy
WGBFAS	ICES Baltic Fisheries Assessment Working Group
WGHMM	ICES Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim
WGIAB	ICES Working Group on Integrated Assessment in the Baltic
WGMHSA	ICES Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy
WGPBI	Working Group on Modelling Physical-Biological Interactions
WGSAM	ICES Working Group on Multispecies Assessment Methods
WGWIDE	ICES Working group on Widely Distributed Stocks
WKAEH	ICES Workshop on Age Estimation of European Hake
WKMAMPEL	ICES Workshop on Multi-annual Management of Pelagic Fish Stocks in the Baltic
WKMAT	ICES Workshop on Sexual Maturity Sampling
WKOMSE	ICES-STECF Workshop on Fishery Management Plan Development and Evaluation
WKREFBAS	ICES Workshop on Reference Points in the Baltic Sea
WKSHORT	ICES Benchmark Workshop on Short-lived Species

2.3 Models used

Within UNCOVER, models were mainly used on three different levels:

1) ***Individual-Based Models*** (IBMs) were developed to investigate the ways in which variability in environmental (physical and biological) factors influence the rates of survival and growth of marine fish early life stages.

2) ***Multispecies models*** have been used to project future stock recovery potentials.

3) ***Fisheries management evaluation tools*** were applied and further developed to evaluate alternative management strategies.

In this section, the main models used within UNCOVER are presented briefly to give an overview about the different modeling approaches applied during the project. More details can be found either in this document, and other UNCOVER reports, such as the four Case Study reports.

2.3.1 Individual-Based Models (IBMs)

The development of recovery plans for depleted/collapsed stocks draws extensively on the 'traditional' practices of stock assessments and projections that tend to assume that the past reflects what will happen in the future. However, the dynamics of depleted/collapsed and healthy stocks can be expected to be different and climate-driven changes in the environment may influence the productivity of stocks and hence their ability to recover. Bio-physical, individual-based models (IBMs) have been developed during the UNCOVER project to investigate the ways in which variability in environmental (physical and biological) factors influence the rates of survival and growth of the early stages of marine fish. These models provide 3-D, spatially explicit estimates of the drift, growth and (often) survival of particles (eggs and larvae) by utilizing three, interlinked models (a 3-D hydrodynamic model, a particle tracking model and a biological feeding/growth model and/or otolith-based growth models). Furthermore, physical environmental variables were used to identify specific habitat suitability of larval and juvenile fish.

IBM's have been produced for five of the target species examined in the UNCOVER project: 1) Atlantic cod (*Gadus morhua*); 2) Atlantic herring (*Clupea harengus*); 3) European anchovy (*Engraulis encrasicolus*); 4) North Sea plaice (*Pleuronectes platessa*); and 5) Baltic sprat (*Sprattus sprattus*). Separate models have been constructed to examine the early life stages of Atlantic cod in each of three CS areas (Barents Sea, North Sea and Baltic Sea). Similarly, separate models are now available for herring in two CS areas (Barents Sea and North Sea). More details about the application of IBMs and results within UNCOVER are presented in the report 'Advanced versions of new process-based biological-physical IBMs for some species in CS regions': www.uncover.eu

2.3.2 Multispecies models

Multispecies models with proven hindcasting capabilities have been used to project future stock recovery potentials. Alternative, yet similarly plausible, scenarios of environmental and anthropogenic influences have been tested to provide a suite of alternative recovery paths. A synthesis of recovery paths has, in turn, provided uncertainty levels. The multispecies models have produced self-standing predictions on stock recovery paths since they are able to incorporate multi-fleet interactions (4M/SMS) as well as resolve spatial processes in the systems (GADGET, Simulation models).

Two models mainly used within UNCOVER are briefly introduced below. More details on these as well as other multispecies models used are presented in this document in section 4.4 'Multispecies interactions and trophic controls'.

GADGET

GADGET stands for Globally applicable Area-Disaggregated General Ecosystem Toolbox. GADGET (Begley and Howell, 2004) is a software tool developed to model marine ecosystems taking into account the impact of the trophic interactions and the impact of fishing on the species. GADGET allows the user to include a number of features of the ecosystem into the model: one or more species, each of which may be split into multiple components, multiple areas with migration between areas, predation between and within species, growth, maturation; reproduction and recruitment, multiple commercial and survey fleets taking catches from the populations. GADGET works by running an internal forward projection model based on many parameters describing the ecosystem, and then comparing the output from this model to observed measurements to get a likelihood score. The model ecosystem parameters can then be adjusted, and the model re-run, until an optimum is found, which corresponds to the model with the lowest likelihood score. This iterative, computationally intensive process is handled within GADGET, using a robust minimization algorithm.

SMS

SMS is a stochastic multispecies model describing stock dynamics of interacting stocks linked together by predation. It operates on annual or seasonal time steps. The model consists of sub-models of survival, fishing mortality, predation mortality, survey catchability and stock-recruitment. SMS uses maximum likelihood to estimate parameters and the total likelihood function consists of four terms related to observations of international catch at age, survey catch per unit effort (CPUE), stomach contents observation, and a stock-recruitment (penalty) function.

2.3.3 Fisheries management evaluation tools

Fisheries management evaluation tools were applied and further developed to evaluate alternative management strategies.

The ***FLR software framework*** (www.flr-project.org) was used as for evaluating management strategies within UNCOVER. This ensured that the methodology developed by UNCOVER could be readily used by ICES and other scientific projects, on the one hand, and that UNCOVER could take advantage of work being performed under other EU projects, on the other hand. To incorporate process information into management evaluation tools, simulation modules have been developed for each Case Study area, indicating the modeling framework, operating model (OM), conditioning of the OM, as well as the strategic question being addressed that will be used for the management evaluation. The technical details of each of the modules that are to be used in these management evaluation simulations, *e.g.,* the stock-recruitment relationships of the stocks, are described in the sections presenting their application in the different case study areas.

ISIS-Fish (MahŽvas and Pelletier, 2004; Pelletier and MahŽvas, 2005) is a fisheries dynamics model based on three sub-models: a population model, an exploitation model and a management model. Each sub-model is spatially explicit and operates on a monthly time-step. Further details are found in the relevant Case Study reports for the Baltic Sea and for the Bay of Biscay where the model was used.

2.4 Reiteration and synthesizing process

The WP6 team (comprised mainly of the WP6 Co-Leaders, the Coordinator, the WP5 Leader, the WP6-Consultant from AquaMarine Advisers, and the current/former Project Managers) was instrumental, in close cooperation with the leadership of the other WPs and CSs, in organizing and steering the overall reiteration and synthesis process. This included arranging a series of strategically scheduled and focused workshops, and planning and drafting the various sections of the final synthesis reporting.

The WP6 team also kept the planning process under review for the Joint ICES/PICES/UNCOVER Symposium (3-9 November 2009) on '*Rebuilding Depleted Fish Stocks - Biology, Ecology, Social Science and Management Strategies*'.

2.4.1 Periodic workshops for presenting and critiquing emerging results, and communal planning

Workshop 'Initial modules for each case-study specific or generic stock-recovery evaluation evaluated and feedback provided' (Tenerife, Spain, November 2007)

The workshop was the starting point to evaluate the state of work within the WPs and CS areas. All biological information (data and models) gathered and developed during the first 18 month of the project were exchanged among the different teams. The initial modules for each case-study specific (2nd level question) or generic (1st level question) hypotheses were evaluated. The output of existing process and coupled process models for potential incorporation into combined modeling approaches was reviewed, including a first priority ranking of processes for stock recovery.

An action plan was developed for further module development, testing and application. This involved evaluation of the importance of biological and environmental aspects for dynamics of target stocks and systems. The workshop formed a crucial and important milestone during the UNCOVER project to start the iteration process and to combine the results.

Workshop 'Further iteration process developed and defined' (Lake District, UK, June 2008)

At this workshop, the reiteration process to combine all results was continued. Available data and models from the different WPs were checked whether they are suitable to answer the questions on stock specific and generic levels (Deliverables 20 and 21) as well to support the evaluations of management plans. At this workshop, social and institutional aspects were included in the process and results presented by WP5. A special session specified the integration between WPs 4, 5 and 6.

Based on a selection and refinement of stock specific and generic strategic questions, the further iteration process was defined. Cooperation between WPs 1-4 within each of the four CS areas was specified, including decisions on approaches and data sets/models to be used. The approach to link the results from the more biologically orientated WPs 1-3 and the socio-economic WP5 for the evaluation in WP4, as well as synthesis in WP6, was refined.

Workshop 'Integration of findings' (Barcelona, March 2009)

At this workshop, all four CS areas presented their current status and all WPs presented a summary of their findings. WPs 1-3 were instructed to specify their specific outputs for transfer to WPs 4-6. The Case Studies were instructed to present envisaged management options according to the current understanding. All CS areas and all WPs presented abstracts (findings) for the upcoming ICES/PICES/UNCOVER Symposium. This included suggestions to WP leaders to deliver review papers across CS areas for the symposium. WP6 specified the necessary CS and WP inputs needed for the integration of findings and agreed on a coordinated approach.

2.4.2 'Writing Workshop' for production of Case Study area reports and Ad Hoc Group reports for final results synthesis

The final UNCOVER workshop was planed as the concluding iteration process of all CS areas and WPs, as well as a writing workshop drafting sections for the final UNCOVER project report. All CS areas presented their final drafts of the 'CS Area Reports', whereby the writing process had been initiated the end of 2009. In a first step, these presentations were utilized to identify gaps in the various thematic sections while agreeing on a common reporting format. In a second step, the application of WP findings in the various CSs was analyzed and discussed to achieve a balance between CS and WP findings in the final project reporting.

Breakout groups focused on the review of the individual CS Area reports while at the same time identifying key findings and recovery scenarios. The WPs were asked to provide feedback on whether key findings from the respective WPs had been incorporated into the individual CS Area reports and/or into contemporary fisheries research and the ICES advisory system.

Ad Hoc working groups, established at the workshop, focused on highlighting: 1) the main outcomes/conclusions and recommendations from UNCOVER; and 2) predicting sources of uncertainties; and 3) assessing the requirements for successful recovery plans.

Invited participants for this workshop were the WP and CS leaders and the entire WP6 team.

The 'products' of this workshop directly fed into the present UNCOVER synthesis report and into the public, synthesis deliverable D.32 from WP6 focusing on the evaluation of the final recovery scenarios and the principal components and constraints of recovery plans.

The workshop, structured into plenary and working group sessions, ensured the feedback of findings to the participants to reflect on the available information and decide if it was sufficient or if another process of iteration was necessary. Being focused and aware of these these reiteration steps not only led to quality assurance of the collected data, assumptions and recommendations, but also added to the integrity of the conceptual synthesis.

2.4.3 Joint ICES/PICES/UNCOVER Symposium (Warnemünde, Germany, November 2009).

UNCOVER joined ICES and the North Pacific Marine Science Organization (PICES) in co-sponsoring, arranging and implementing a Symposium on '*Rebuilding Depleted Fish Stocks - Biology, Ecology, Social Science and Management Strategies*', held in Warnemünde (Germany) from 3-9 November 2009. The symposium's objective was to bring together research scientists from diverse disciplines, managers, policy-makers, the fishing industry and other stakeholders to present and discuss knowledge about the recent status and strategies for the recovery of overexploited fish and shellfish stocks, and to review worldwide progress in recovering depleted stocks in the context of achieving sustainable fisheries. The symposium and its outcome is reported on in section 3.5.

The presentations and posters are available for download at: www.uncover.eu

2.4.4 Synthesizing process

As mentioned in section 2.2, UNCOVER was organized into a conceptual framework consisting of seven WPs and four CS areas. Thereby the WPs were delivering the project results, *i.e.*, peer-reviewed papers and deliverables. These results were then implemented and tested in the CSs to improve the understanding of the ecosystems and the key stocks in an attempt to develop sound recovery strategies. The testing of findings in the CSs followed an iterative approach and is reflected in the UNCOVER workshops. Through the application of findings in the different CSs the synthesizing process was initiated concentrating on those factors, which gave the best explanation of the natural resource system and its specific local conditions as well as to develop solutions for depleted stocks.

2.5 Approaches to social and economic issues

Social and economic research in UNCOVER has taken two basic approaches. The first was socio-economic research focused on understanding the impacts of existing recovery plans on fishing communities and fishing fleets. This researched used techniques from anthropology to investigate community impacts and from economics to investigate impacts on fleets. Then lessons from these two investigations were combined to try to understand the overall question of under what circumstances compliance with recovery plans can be expected from fishers. The second basic approach was sociological research on the relevant governance[4] institutions. It focused on how the main stakeholders in European fisheries saw recovery plans and how these plans fit in to the overall fisheries system.

Fishing communities were investigated through social impact assessments (SIAs) undertaken in 10 communities that had been affected by the Northern Hake, Baltic Cod and North Sea Cod recovery plans. An SIA is a methodical assessment of the quality of life of persons and communities whose social, cultural, and natural environment is affected by policy changes, such as through the fisheries management and recovery plans. Social impacts refer to changes to individuals and communities due to management actions that alter the day-to-day way in which people live, work, relate to one another, organize to meet their needs, and generally cope as members of a fisheries society. SIA provide an appraisal of possible social ramifications and proposals for management alternatives, often with possible mitigation measures.

Bioeconomic modeling was used to understand the implications of recovery plans for fishing fleets. A combination of fisheries was evaluated against different recovery strategies. This was done specifically in terms of fishers' decisions such as effort allocation, discards, as well as the resulting outcomes such as profit and fishing mortality. Analysis focused on decommissioning (capacity management), days at sea reduction, and mesh size restrictions. Economic compliance theory was used to evaluate to quantitatively measure expected fishers' response to alternative recovery plans. The bio-economic analysis focused on the following case studies: Cod, plaice and herring in the North Sea; and hake and anchovy in the Bay of Biscay.

In the next step, these SIAs and bio-economic analyses were qualitatively combined. The focus of this exercise was the question of compliance with management measures and how social, cultural and economic combine to influence fishers' behaviour.

[4] Social scientists are more and more commonly use the term 'governance' rather than government, governing or management. Under this trend lies an important idea: a lot of different institutions – many government agencies, markets, civil organisations – make decisions that have an impact on the environment. The term 'Governance' points to how all these things work together in decision-making processes.

The governance research was based on an analysis of stakeholder positions on recovery plans. It made use of several sociological field research activities. Twenty-four individual interviews and four focused group interviews were held with various fisheries experts, managers, RAC leaders, fishers, fisher representatives and members of conservation NGOs. In addition, 15 fisheries management-related meetings were observed and notes taken on positions and opinions expressed about recovery plans. Documents on stakeholder positions, particularly those of the RAC were also reviewed. Finally these documents, the transcripts of interviews, and observers' notes from meetings were entered into textual analysis software and cross-compared. Themes were identified by going through the material from paragraph by paragraph, and assigning to each any number of short codes naming a topic or specific argument. These codes were not created beforehand; instead they were generated by the reading, interpreting and comparing the paragraphs using a well established social science technique called 'grounded theory' (Glaser and Strauss, 1967). The resulting themes were used as the basis of the governance report.

2.6 Publications and outreach activities

UNCOVER has been committed to provide an open environment, promoting personal interactions with the public, stakeholders in the fisheries sector and the research community. The following outreach materials were used to improve UNCOVER's visibility and to disseminate results:

- The **UNCOVER website** has become a repository for project documentation and public deliverables. The web portal with an internal and external section has been continuously updated and will be maintained beyond the lifetime of the project, see also www.uncover.eu
- Several **flyers, posters and newsletters** have been produced and were widely disseminated introducing the project and promoting the UNCOVER symposium.
- Within WPs1-6 a total of 33 **deliverables** have been produced, of which 10 are available to the interested public. The UNCOVER webpage summarizes and provides access to those deliverables which are available to the public.
- More than 80 **peer reviewed scientific papers** have directly evolved out of UNCOVER and a substantial amount of papers are still pending publication. A complete list of papers can be found at the website.
- The **symposium proceedings** in the *ICES Journal of Marine Science* will act as an UNCOVER cooperate publication promoting the UNCOVER website and raising public awareness for the issue of fish stock recovery. The proceedings are scheduled for publication in October 2010.

A variety of outreach activities to disseminate information on UNCOVER activities on national, European and international scale have been supported, including:

- Throughout UNCOVER, scientists have actively **participated in relevant working groups** within the ICES advisory system as well as with EU groups like STECF (see section 2.2.2).

- **Participation at conferences** ensured the presentation of the project to stakeholders as well as dissemination of relevant research findings. Exemples were the distribution of the UNCOVER project flyer and the MRAG report from WP5 at the North Sea RAC and Western Waters RAC conference on Cod Recovery in Edinburgh (UK) in March 2007. For a complete list of attended conferences, please see www.uncover.eu.

- **Teaching activities** have played a significant role within UNCOVER and started with the first modeling workshop in October 2006. This involved the linking of already existing operating models to the management evaluation tools implemented in FLR. Emanating from work performed in UNCOVER, a public five-day training course was organized by ICES and ICCAT from 5-9 April 2010 in Vigo (Spain). The training course demonstrated how to conduct Management Strategy Evaluations (MSE) using FLR (www.flr-project.org) to develop LTMPs that are robust to uncertainty.

- **Working in partnership** has been important to develop the international symposium on rebuilding depleted fish stocks (section 2.4.3). The value of this type of funding partnership has been demonstrated through the active engagement of 10 sponsors of the symposium. This involved not only scientific organizations such as ICES, PICES, NAFO and DFO (Canada), but also the European intergovernmental network COST (European Cooperation in the field of Scientific and Technical Research) with its Action FRESH (Fish Reproduction and Fisheries) as well as the private sector through Stiftung Seeklar (Germany).

- The **international symposium and its panel discussion** with invited keynotes and stakeholders from around the world has been a milestone in the project and played a fundamental role in external communications (see section 2.4.3 and associated Annex).

2.7 Deliverables

Throughout the life of the UNCOVER project, many deliverables have been produced. These deliverables range from information requests through to draft and final reports, which reflect the working procedure of the individual WPs. They are also exemplary for the collaboration of partners in the pursuit of the project objectives. As such the deliverables have been chronologically timed to meet these goals. While some of the deliverables are confidential and restricted to project participants and the European Commission, others are public. The public deliverables can be accessed and downloaded from the UNCOVER web page: www.uncover.eu.

The complete list of deliverables can be found in Annex 4.

2.8 Self-assessment

Performing a critical self-assessment of the UNCOVER project revealed several implementation challenges. These ranged from the mere complexity and divergence of the studied ecosystems and stocks to the integration of scientific disciplines as well as changes in the fisheries policy and the entire ICES advisory system. Furthermore, the complexity did not reveal itself right from the start but became evident during the course of the project. This implied the need for constant iteration between performed work and evaluation, simulation modeling to address uncertainty and focusing on the CSs through developing recovery scenarios. In the majority of cases this led to the uptake or remodeling of data into the research process of UNCOVER. However, there have also been cases that were unsuccessful. An example was the failure to integrate IBMs, which enhanced our understanding of recruitment processes considerably, into FLR. But the project design enabled constructive discussions and encouraged participatory learning. In the end this was the key to conducting high quality research and being effective in producing meaningful research results.

In general, the UNCOVER project was only possible through collaboration with strong research partners and the motivation of the individual scientists who contributed to the success of UNCOVER.

3 UNCOVER ANALYSIS OF WORLD-WIDE RECOVERY OF FISH STOCKS/ FISHERIES: KEY FACTORS FOR SUCCESS

The EU FP6 UNCOVER project has elaborated a rational scientific basis for developing recovery strategies for 11 fish stocks that are located in some of the major European regional seas (see section 6.3 for the final recovery scenarios). The objectives of UNCOVER were to identify changes experienced during stock depletion and even collapse in some cases, to understand the prospects of their recovery, to enhance the scientific understanding of the mechanisms of fish stock recovery, and to formulate recommendations how best to implement stock recovery plans.

Based on the above-mentioned objectives, the UNCOVER project took a multidisciplinary approach to: a) Synthesize and integrate relevant information from previous and ongoing research programmes; and b) Evaluate and develop recovery strategies that incorporate biological, environmental, and technical and socio-economic factors. Furthermore, UNCOVER has also actively taken steps to inform itself, and integrate relevant knowledge, into the project from around the world. Two of the major initiatives conducted in this direction by UNCOVER were:

1) A review, close to the start of the project, of the institutional arrangements and evaluation of factors associated with successful recovery plans from various key regions of the world;
2) Co-sponsoring, planning and implementing an international symposium, close to the end of the project, regarding lessons learnt and best practices from across the world, on recovering depleted stocks, based on biological, ecological, social science and management considerations.

3.1 The Wakeford *et al.* (2007, 2009) approach

As part of UNCOVER, at the project's start, Wakeford *et al.* (2007, 2009) produced a review of the development and success of fish stock/fishery recovery plans in Australia, Europe, New Zealand and the United States, based on case studies of a range of factors that have been associated with successful stock recovery[5] for 33 fish stocks/fisheries. The case studies represented 9 successful, 23 unsuccessful, and one undetermined, recovery situations, as judged

[5] Wakeford *et al.* (2009) in their table 7 used the term 'Rebuilt' for when a recovery plan had been successful. In accord with use in the UNCOVER project as a whole, the term 'Recovered' has been substituted in this document for 'Rebuilt'.

by Wakeford *et al.* (2007, 2009) on information available in 2005-2006, including different stock characteristics and recovery processes.

The relative importance of each of 13 *performance criteria* (i-xiii), arranged under *five categories*, to the overall success or lack of recovery was assessed and subjectively scored, based on the best available information, by Wakeford *et al.* (2007, 2009) between 0 and 5 (low/very poor to high/very good) for the various case studies (Table 3.1). Some factors are more likely to be associated with successful recovery plans than others. Wakeford *et al.* (2007, 2009) calculated the average ranked score for each performance associated with recovered and non-recovered fish stocks/fisheries, and used the difference between each average to identify which factors are more closely associated with successful recovery plans, *i.e.*, the larger the difference between the average scores of 'recovered' and 'non-recovered' fish stocks/fisheries for a particular criterion the more important the criterion.

Table 3.1. The 13 *performance criteria* used by Wakeford *et al.* (2007, 2009) to evaluate the recovery plans arranged under five *categories*.

Category	Performance criteria	
Institutional arrangements and management strategies	(i)	Defining the recovery process
	(ii)	Management performance criteria
	(iii)	Property rights
	(iv)	Legal aspects
	(v)	Monitoring, control and surveillance
	(vi)	Complexity of fishery system
	(vii)	Rapid reduction in fishing mortality
Environmental	(viii)	Environmental conditions during recovery time period
Biological	(ix)	Life history characteristics
	(x)	Status of the stock
Economic	(xi)	Economic efficiency
Social	(xii)	Social impact and compensation mechanisms
	(xiii)	Stakeholder participation

Based on comparing the difference (but without using quantitative statistics to examine the level of significance) between the average scores of the 9 stocks/fisheries judged as recovered and the 23 stocks judged as not-recovered, Wakeford *et al.* (2009) concluded that '*a combination of factors is needed to enable fish stocks to recover*'. They emphasized that:

- Rapid and often large reductions in catches at the start of the recovery process, and biological characteristics, such as the life-history strategies of species and the demographic composition of the stock, played a key role in the ability of populations to recover;
- Recovery is more effective when the recovery plan is part of a legal mandate, which is automatically triggered on reaching pre-defined limit reference points. Of the four regions studied, the United States was the only country to have a legal framework (via the Magnuson-Stevens Fishery Conservation and Management Act) within which clear, prescriptive guidelines are given to establish a recovery process within a pre-defined time period;
- Furthermore, recovery is also more likely when a) fishing effort reductions are created through regulating days at sea, decommissioning or harvest control rule schemes, and b)

there are positive recruitment events during the recovery period, either stimulated by or coincident with reductions in effort.

Building further on Wakeford *et al.* (2007, 2009), Hammer *et al.* (in submission) have conducted, within the UNCOVER project, a further examination of the Wakeford (*op. cit.*) data with a view to determining the importance of the various performance criteria, singly and in combination, using a range of statistical techniques including multivariate modeling approaches. These findings are reported on in section 3.3.

3.2 Institutions and progress on recovery plan in four global regions

Wakeford *et al.* (2007, 2009) reviewed recovery plans in four global regions. This section summarizes their findings about the institutional arrangement for recovery plans and their overall progress. It is emphasized that the data presented for sections 3.2.1 to 3.2.4 are only valid for the specific period focused on (*i.e.*, 2005-2006) by Wakeford *et al.* (*op. cit.*).

3.2.1 United States of America

The National Oceanographic and Atmospheric Administration (NOAA Fisheries), operating through the National Marine Fisheries Service (NMFS), is responsible for the management, conservation and protection of living marine resources within the exclusive economic zone (EEZ) in Federal waters (3-200 miles). Within three miles, fisheries management is the responsibility of the several states. In 1996, amendments to the Magnuson-Stevens Act, known as the Sustainable Fisheries Act (SFA) created a legal mandate to end overfishing and rebuild depleted fish stocks. Within a Fisheries Management Plan (FMP) a definition of overfishing must be specified both in terms of the maximum fishing mortality threshold (MFMT) and the minimum stock size threshold (MSST).

Within the United States, *recovery plans* are associated with the recovery of critically endangered species from the risk of population extinction whereas *rebuilding plans* are associated with the recovery of depleted marine capture fisheries and rebuilding the stock to reach more productive levels of exploitation. Recovery plans are mandated under the ESA and MMPA whereas rebuilding plans are under federal law of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

It is the responsibility of NMFS to notify the relevant regional fishery management council when fisheries are overfished or approaching an overfished condition. Rebuilding plans are normally associated with an amendment to an existing FMP. Within an FMP, a definition of overfishing must be specified both in terms of the maximum fishing mortality threshold and the minimum stock size threshold (MSST). Within a rebuilding plan, the target year must be specified based on the time required for the stock to reach the optimal yield. This target is bounded by a lower limit defined as the time needed for rebuilding in the absence of fishing. The MSFCMA states that the rebuilding time period shall be as short as possible, and usually may not exceed 10 years unless there are mitigating factors such as the biology of the stock or social considerations that require a longer time frame. If a stock falls below the MSST, the regional fishery management council has one year to develop and implement a stock rebuilding plan. If a rebuilding plan is not submitted within the specified time period, it is then the responsibility of NMFS to develop and implement a plan within nine months. A newer innovation is a Federal requirement that fishery management plans specify annual catch limits to ensure that that overfishing does not occur in the fishery. Such limits are to be implemented in 2010 for fisheries subject to overfishing and in 2011 for all other fisheries. For rebuilding stocks, the ‘acceptable biological catch’ (ABC) and ‘annual catch limit’ (ACL) should be set at lower levels during some or all stages of rebuilding than when a stock is rebuilt.

3.2.2 Australia

A range of Government authorities are responsible for the management of Commonwealth (3-200 nm), State (0-3) and Territory fisheries. The Australian Fisheries Management Authority (AFMA) has managed the Commonwealth fisheries within the exclusive economic zone since 1992. The Offshore Constitutional Settlement (OCS) provides the basis for the different responsible authorities to agree on management of particular fisheries under a single law, the *Fisheries Administration Act* 1991, and the *Fisheries Management Act*, 1991. Australian Government fisheries management policy is based on the principle of community ownership of the resource.. A longstanding government policy of managing Commonwealth fisheries using output controls in the form of individual transferable quotas (ITQs) exists. However, at the present time a range of output and input based management controls are applied to Commonwealth fisheries in Australia. The primary management objectives are to ensure ecologically sustainable development and economic efficiency. At both the State and Commonwealth level, management is highly participatory and often includes community and indigenous stakeholders. Furthermore, the policy of cost-recovery requires that the users of the resource pay for the full cost of supporting management, compliance for example.

AFMA has put *recovery strategies* in place for at least 11 depleted fish stocks through new [fishery] *management plan* arrangements. *Recovery Plans* exist for a number of marine resources (*e.g.* grey nurse shark) but these are prepared by the Australian Government Department for Environment and Heritage to stop the decline of threatened species or threatened ecological communities listed in the *Environment Protection and Biodiversity Conservation Act* 1999. For the overfished stocks amongst the AFMA managed fisheries, no formal recovery plans have been defined. Fishery management measures have been intended to bring about recovery of most overfished stocks, but the response has been variable. Two tiger prawn species from the Northern Prawn fishery are the only success story to date.

AFMA has moved towards a US-type system, where *overfishing* is defined as the point at which the current level of fishing mortality is greater than a specified threshold level above which leads to further stock depletion, and *overfished* is defined when the current level of biomass is below a specified threshold level that puts the stock in danger of collapse. A recovery plan would then rebuild the stock to an optimal level, although unlike the US, this may not currently reflect the maximum sustainable yield.

3.2.3 New Zealand

Management of fisheries is controlled by the central government through administration of the *Fisheries Act*, 1996, by the Ministry of Fisheries. The Quota Management System (QMS) is the most common method of managing commercial fish stocks in New Zealand’s waters, and presently includes 95 species representing 90% of the commercial harvest. This system, which allocates perpetually owned quota shares to fishers is aimed at providing property rights to fish stocks and thereby creating institutional arrangements for stakeholder-led management in consultation with all relevant parties (government; commercial, customary Maori and recreational fishers; and environmental groups and interests).

Management plans take two forms. Stock strategies developed by the Ministry which define management objectives, instruments, research, compliance and administration services; and, Fisheries Plans which can be developed with and implemented by relevant stakeholders. Fishery Plans are being developed for all major fisheries. In addition to management of national fisheries, like Australia, New Zealand participates in management of straddling stocks with Australia and internationally managed stocks such as Southern bluefin tuna.

Administratively, New Zealand's waters are divided into Fisheries Management areas, but a stock is the basic management unit. Each stock has a TAC which is set with reference to the MSY, except for certain exceptions (where biological characteristics make estimation of MSY not possible, stocks with a national allocation under an international agreement; stocks managed on a rotational or enhanced basis; highly migratory stocks; or, where a proposal for an alternative to MSY is made by quota share owners). The TAC is made up of all sources of fishing including Maori customary fishing, recreational fishing and a Total Allowable Commercial Catch (TACC).

For any fish stock, the TAC may be set such that the stock is fished down to sizes that support MSY, or that enables a stock to recover to a size that supports MSY. Thus for commercial fisheries the management strategy allows for fish stock recovery, and separate *recovery plans* are not developed. Fishery assessment working groups generate advice for each status category: stock above a level that can produce MSY; stock at a level that can produce MSY; or, stock below a level that can produce MSY. The terms of reference for stocks below MSY, and that therefore require recovery are to:

– Determine if recent total removals and the current TAC and/or TACC are at levels which will allow the stock to rebuild to a level that can produce the MSY or to some appropriate larger stock level;
– Identify any factors relating to the interdependence of stocks of fish that would determine whether a stock level above that which can produce the MSY is appropriate; and,
– Determine any biological characteristics of the stock or environmental conditions that would influence the rate of rebuild.

It is noteworthy that the New Zealand system explicitly includes consideration of the multispecies nature of fish stocks (interdependence) and biological and environmental factors that may contribute to recovery.

Stock assessments relate to the status of the stock with respect to MSY: 'Above', 'At', or 'Below' the biomass that will generate MSY. Yield reference points relate to Maximum Constant Yield (MCY) and Current Annual Yield (CAY), which derive from a static and a dynamic interpretation of MSY. MCY implies a constant yield (catch) every year. CAY recognizes that fish population biomass will fluctuate in size from year to year, so the catch taken should also vary from year to year. However, the industry's need for stability would limit changing catches too frequently. New Zealand uses an objective of MCY, but many factors are taken into consideration in setting the TAC or TACC in addition to MCY, and the system also allows changes if the level is too high or too low.

3.2.4 European Union

This section has been updated with respect to Wakeford *et al.* (2007, 2009) in order to explain the changing evolution of the European Union's (EU) management and recovery plans in the current context.

The International Council for the Exploration of the Sea (ICES) provides scientific advice to the European Commission on the status of commercially important fish stocks and the management of the associated fisheries. The Commission has created its own Scientific and Technical and Economic Committee on Fisheries (STECF) to provide input from scientific experts to help the Commission implement the Common Fisheries Policy (CFP). Following a significant decline in the status of many European fisheries, and after a lengthy period of consultation with stakeholders, the CFP was reformed in 2002 to include concepts of long-term sustainability and the development of multiannual fisheries management plans. The revision of the CFP also established a more uniform system of monitoring, control and surveillance, and provided a mechanism to incorporate stakeholders within the decision making process through Regional Advisory Councils (RACs). Each year, annual fishing quotas and total allowable catches (TAC) are set by the European Fisheries Council in December. These are not, however, determined solely on the basis of scientific information, but are influenced by social, economic and political issues.

If there is sufficient evidence of a serious threat to the conservation of a marine resource or marine ecosystem resulting from fishing activities, Article 6 of Council Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy, enables the European Commission to take immediate action on a set of emergency measures, which shall last not more than six months duration. This might include a reduction in fishing effort for stocks in danger of collapse.

The first set of EU recovery plans aimed to recover the stock to safe biological limits (SBL) within a 10-year period. When the stock has recovered, defined as when the quantity of mature fish has been greater than that decided upon by managers as being within safe biological limits for a period of *two consecutive years*, the 'Council shall *then* decide on a proposal from the Commission to remove the stock from the recovery plan and to establish a management plan for that stock in accordance with Article 6 of Regulation (EC) No 2371/2002' [emphasis added].

In 2002, a distinction was made between a 'recovery plan' and a 'management plan'. The former applies to a stock whose biomass falls below biologically safe limits or for which catches are so high that the stock cannot replenish itself. This means that there are no longer enough fish that are mature, or survive long enough before capture, to ensure the stock's future through reproduction. The aim of the recovery plan, therefore, is to bring adult biomass to a safe level under the precautionary approach. A management plan, on the other hand, applies to a stock that is not vulnerable but for which long-term sustainable yield is guaranteed by setting a catch rate that guarantees this objective. To sum up, a recovery plan applies to a vulnerable stock whereas a management plan applies to a non-vulnerable stock and aims to make its exploitation sustainable over the longer term.

Today, however, the EU has dropped this distinction between recovery and management plans and refers only to 'long-term' or 'multiannual plans'. Whatever the situation of the stock, the goal is ultimately to reach maximum sustainable yield (MSY) by setting an appropriate exploitation rate. Multiannual plans are not restricted to vulnerable stocks alone. At the 2002 Sustainable Development Summit (Johannesburg, South Africa), the EU Member States pledged to exploit all their stocks at MSY by 2015. Thus, long-term planning is essential.

ICES has developed a limit reference point to indicate the biomass level below which recruitment may be impaired. Taking into account the uncertainty inherent in any stock assessment, ICES further defines a higher precautionary reference point, B_{pa} such that when assessments indicate the spawning stock to be at B_{pa} there is a high probability that the true biomass is above B_{lim}. At the time the Wakefield *et al.* (2007, 2009) study was conducted (*i.e.*, 2005-2006) the EU, unlike the USA, had not yet identified target reference points and the relationship between B_{pa} and B_{msy} is unknown for most stocks. However, the situation in Europe is changing fast as documented in section 6.3.

The European Commission in 2009 recognized that: a) 88% of European Community (EC) stocks are being fished beyond MSY, and that they could increase and generate more economic output if submitted to less fishing pressure for only a few years; b) 30% of these stocks are outside safe biological limits, and thus may not be able to replenish; and c) most of Europe's fishing fleets are either running losses or returning low profits (EC, 2009)

At the time of the Wakeford *et al.* (*op. cit.*) analysis (*i.e.* 2005-2006), recovery plans existed for only three species in European waters: for cod (4 stocks; Council Regulation 423/2004), northern hake (Council Regulation 811/2004), southern hake and Norway lobster (Council Regulation 2166/2005). A series of emergency measures have been adopted for anchovy and closed fishing areas to protect and rebuild sandeel stocks. As of 2007, no stock had yet formally recovered from an EU recovery plan.

3.3 Multivariate extension of the Wakeford *et al.* (2007, 2009) study: Approach and outcomes

The Wakeford *et al.* (2007, 2009) studies did not apply statistical tests to determine the level of relative importance of the 13 studied performance criteria, and multivariate analyses were not conducted to examine the relationship of the performance criteria and their possible combined effect. Thus, as an additional contribution from UNCOVER, Hammer *et al.* (submitted) extended the analysis of Wakeford *et al.* (2007, 2009) using the same scoring and classification data as collected for the 33 stocks/fisheries. Rather than using average score-values, as done by Wakeford *et al.* (2009), as the basis for conclusions on the importance of the 13 performance criteria, Hammer *et al.* (*op. cit.*) applied non-parametric statistics and multivariate statistics to determine *inter alia* the significance of the various performance criteria for recovery of the various stocks/fisheries and their relative and absolute contributions singly and in combination, including developing a stepwise, additive model of the key criteria providing a high level of discrimination between 'Recovered' and 'Non-recovered' stocks/fisheries.

Hammer *et al.* (*op. cit.*) first found [applying the non-parametric Mann-Whitney (Wilcoxon) W (M-W W) test] that significant differences between the 'Recovered' and 'Non-recovered' fish stocks/fisheries existed for 9 performance criteria: (i) Defining the recovery process; (ii) Management performance criteria; (iv) Legal aspects; (vii) Rapid reduction in fishing mortality; (viii) Environmental conditions during the recovery period; (ix) Life history characteristics (of the target fish stocks); (x) Status of the stock; (xi) Economic efficiency; and (xii) Stakeholder participation. However, from this alone it was not possible to quantify which of these criteria are most important, singly or combined, in determining whether fish stocks/fisheries are 'Recovered' or 'Non-recovered'.

Figure 3.1. CCA biplot showing the positioning of 13 performance criteria (i-xiii) with respect to fish stocks/fisheries being 'Recovered' and 'Non-Recovered' (arrowed vectors) based on scoring data from Wakeford *et al.* (2007, 2009) collected from 32 fish stocks/fisheries in Australia, Europe, New Zealand and the United States. The criteria most associated with 'Recovered' and 'Non-recovered' stocks/ fisheries are those, which are found towards, and beyond, the arrow-tips of the respective vectors.

By further applying Canonical Correspondence Analysis (CCA) (Figure 3.1), the new variables established by Hammer *et al.* (submitted) as 'Recovered' (constructed with positive response value 1 and negative response value 1) and 'Non-Recovered' (constructed with values opposite to 'Recovered') demonstrated that the performance criteria most positively associated with successful fish stock/fishery recovery were—based on the data collection and its scoring at the time (*ca.* 2005-2006) of the Wakeford *et al.* (*op. cit.*) study—in order of their importance: (vii) Rapid reduction in fishing mortality; (ix) Life history characteristics of the target fish species; (xi) Economic efficiency; (ii) Management performance; (viii) Environmental conditions during the recovery period; and (i) Defining a recovery process. Obviously, the other performance criteria aligned around the end of the 'Non-recovered' area of the CCA biplot are not positively associated with successful stock/fishery recovery. It is noteworthy—and probably contentious to do so—that some criteria (xii: Impact analysis/compensation; iii: Property rights) were particularly associated with 'Non-recovered' stocks, as further seen from their highest scores tending to weight in this direction (Table 12.1 in Annex 5 shows the original scores). However, one would prudently interpret this as more probably indicating that high scores of criteria (xii) and (iii) are not sufficient, in isolation, to ensure recovery of a fish stock/fishery.

A Discriminant Analysis (DA) was conducted by Hammer *et al.* (*op. cit.*), following the CCA, by developing a set of discriminating functions which help predict the stocks/fisheries recovery status (termed 'Recovery status': 1 = Yes, 'Recovered'; 2 = No, 'Non-recovered') using the performance criteria scores (Table 12.1 in Annex 5) were used to develop a model to discriminate between the two levels of 'Recovery status'. Using a forward stepwise selection algorithm, involving inputting in the first instance the 9 most notable performance criteria as identified from the M-W W test and examined further in the CCA, four criteria were eventually selected as providing the most significant predictors of 'Recovery status'. These criteria, in the order they were selected for the model, are: (vii) Rapid reduction in fishing mortality; (viii) Environmental conditions during the recovery period; (ix) Life history characteristics; and (ii) Management performance. The four variables (*i.e.*, performance criteria) each added very significantly ($P<0.001$) to the model fit as they were entered. In contrast to its apparent prominence in the CCA, criterion (xi) (Economic efficiency) was not selected for inclusion in the 'best' DA model.

For the Wakeford *et al.* (2009) classification, the DA model 'correctly' predicted the 'recovery status' of 31 out of 32 stocks/fisheries (96.88%), of which all 9 (100%) of the 'Recovered' stocks/fisheries and 22 out of 23 (95.65%) 'Non-recovered' fish stocks/fisheries were 'correctly' classified (Table 12.1 in Annex 5). The only discrepancy between the DA and the Wakeford *et al.* (2009) classifications was that for hoki, which the DA classified as 'Recovered'. The hoki, which actually comprises two stocks and not one, has since been considered as recovered by the New Zealand authorities (NZMF, 2009).

Application of CCA and DA has given us further insights about the data collected and analyzed by Wakeford *et al.* (2007, 2009) regarding performance criteria for evaluating the stock/fishery recovery of 33 case studies. The CCA provides a framework for assessing how the relative influence of particular criteria at a *specific time* (the situation about 2006) affects the stocks/fisheries in general. The position of the 13 performance criteria (criteria) aligned in the direction of the 'Recovered' vector indicates that, in particular, 'Rapid reduction in fishing mortality' (vii), 'Life history characteristics' (ix) and 'Management performance' criteria (ii) are most closely associated with successful recovery.

There is also potential to use the CCA in future to examine changes over time by plotting in updated data for the scores for various factors and identifying the direction of the change (*e.g.* getting better or worse). Thus, it is important to recognize that in reality the trajectory of specific stocks/fisheries between rebuilt and non-rebuilt will represent a form of continuum over time between the simple binary classification. Additionally, however, the DA demonstrates the advantages of being able to independently and objectively test the binary classification of recovery status (*i.e.* 'Recovered', 'Non-recovered'), based on the stepwise model incorporating the main predictors. Without knowing the status of the stocks/fisheries, only that there are alternative binary levels, the DA model has predicted 'correctly' (*i.e.* in accord with the original Wakeford study classification) in all but one (hoki) of 32 stocks. Furthermore, our DA table hazards a classification of 'Non-recovered', with supporting probability, for the Gummy shark stock/fishery which Wakeford *et al.* (2009) did not specifically classify (*i.e.* denoted as n/a). This is an example of the potential use of DA to classify 'new' observations in the binary group context. For independent cross-checking the classifications arrived at by DA and the original classifications of Wakeford *et al.* (2009), Hammer *et al.* (submitted) also used two other statistical classification techniques (section 12.3 in Annex 5) which provided inde3pendent¾y close corroboration of their findings.

It is notable that the four main predictors (*i.e.*, performance criteria) incorporated into the final DA model are closely in agreement with the outcome of the CCA analysis. Thus, the results of two independent and robust statistical analyses support one another. The only difference between the DA model and the CCA is that the latter also suggests the likely importance of criterion (xi) (Economic efficiency) which the DA model did not select for inclusion in the stepwise, *final 'best' quantitative combination* classification model. The four best, additive predictors of successful recovery resulting from the DA model are **(vii) 'Rapid reduction in fishing mortality**', **(viii) 'Environmental conditions during recovery time period'**, **(ix) 'Life history characteristics' of the target stock**, and **(ii) 'Management performance'.** We contend that these performance criteria are in intuitive accord with the fundamental factors affecting fish stocks and fisheries (*c.f.* Beverton and Holt, 1957; Cushing, 1975). These factors are discussed below.

3.3.1 Performance criterion: 'Management performance'

Clearly effective fishery management plays a vital role in successful fish stock/fishery recovery. Case studies with management plans and/or HCRs having clear performance criteria are more closely associated with successful recovery (Wakeford *et al.*, 2009). For example, such plans/HCRs benefit from rigorous, scientific testing with a view to evaluating their likely performance (Kell *et al.*, 2006; Kelly, 2006). Management plans and HCRs must be specific, clearly defined and understood by all involved parties, time-bound and complied with until recovery conditions have been achieved. Although there may be a politically motivated desire to place a limit on annual TAC changes to maintain stability for the industry, flexibility and adaptability in modifying TAC bounds should not be excluded, as rigid limitations can affect the ability to meet management targets as seen from evaluations of several earlier EU MPs/HCRS for roundfish (Kell *et al.*, 2006; Kelly *et al.*, 2006).

3.3.2 Performance criterion: 'Rapid reduction in fishing mortality'

A substantial and rapid reduction in fishing mortality is a key factor contributing to the overall success of a recovery plan, whereas 'too little, too late' catch reductions delay the onset of recovery or prevent recovery at all (Caddy and Agnew, 2004; Horwood *et al.*, 2006; Rosenberg *et al.*, 2006; Shelton *et al.*, 2006; Wakeford *et al.*, 2009). The key is indeed the speed of initial reduction in fishing mortality. This is because the effect of small reductions may easily be subservient to the uncertainty of the assessments. As a result of small reductions there will probably be a sequence of years in which recovery responses are not evident, whereas the public debate on further reduction of TAC and quota will be continued year after year, as a process undermining the credibility of the scientific advice if the effect of previous reductions cannot be shown.

Protection of a sizeable SSB, and thereby the generation of new recruits is essential (Beverton and Holt, 1957). Hence, it is vital to ensure that rapid reduction in fishing mortality prevents the SSB falling below sub-optimal threshold levels where there may be uncertainty about the nature of the stock-recruitment relationship, due to lack of experience and appropriate data, and the potential inability of a heavily depleted SSB to generate sufficient recruits for effective rebuilding (ICES, 2004). Effective limitations on the fishery in time and space are essential to achieve the necessary reduction in fishing mortality, including strategic location and use of marine protected areas (MPAs) that are aimed, for example, at securing recruitment by conserving adults in spawning congregations which are prone to high CPUE or conserving juveniles in nursery areas from bycatches (Hoffmann and PŽrez-Ruzafa, 2008.). The prime example of rapid and effective reductions in fishing mortality on recovery of fish stocks was evident in the marked resurgence of catches of several important fish stocks in the North Sea following World Wars I and II, and in the Barents Sea following World War II, during which periods military activities, including areal closures due to minefields, severely limited fishing effort (Borley, 1923; Margetts and Holt, 1947; Nakken, 1998).

3.3.3 Performance criterion: 'Environmental conditions during the recovery time period'

The stock biomass and production dynamics depend on particular environmental conditions at various stages of the life cycle for optimal growth and recruitment, such as temperature, salinity, oxygen, food type and availability, ocean currents, and limitations on pollution or other forms of human encroachment that degrade habitats (Beverton and Holt, 1957; Cushing, 1975; Laevastu and Favorite, 1988; Bakun, 1996; McFarlane *et al.*, 2000). The 'ocean climate' and its variability forces many of the above-mentioned variables and so plays a major role in determining the productivity of the stock, be it directly or indirectly. Accordingly, favourable environmental conditions are closely associated with successful stock recovery (Wakeford *et al.*, 2009), which is as trivial as it is true and remains an outstanding factor in recovery.

There is concern that the spawning stocks, of demersal fish in particular, in losing the buffering demographic presence of older age-groups of fish as a result of intensive fishing mortality, have increased their susceptibility to the combined effects of high fishing mortality and climate change (Daan 1994; Heino and God¿ 2002; Perry *et al.*, 2010; Planque *et al.*, 2010). Brander (2005) has emphasized with respect to cod (but it may equally well apply to many other species) that increased mortality (by fishing or other causes) reduces SSB, life expectancy, and the number of older, larger fish that make a greater contribution to reproductive output, and that resultant spawning population, with a lower mean age of spawners, and fewer age classes, has a shorter spawning season and a smaller range in specific gravity of eggs. Accordingly, both effects reduce the distribution of early life stages in space and time, and may make them more vulnerable to variability in the environment.

3.3.4 Performance criterion: 'Life history characteristics'

It is inherent that these traits for target fish species are key determinants for population responses to climate change and human-induced pressures such as high fishing intensity (Kawasaki, 1983; Caddy and Gulland, 1983; ESA, 1998; King and McFarlane, 2003). Included in life history parameters are size-at-maturity, maximum size and longevity, growth rate, fecundity and egg size. Typically, long-lived, slow-growing species, with low fecundity (K-strategists) are more likely to decline under high fishing pressure, and so are also less likely or less quickly to recover, compared with short-lived, early-maturing, high-fecundity species (r-strategists) (Winemiller and Rose, 1992; Spencer and Collie, 1997; Hutchings and Reynolds, 2004). It has been demonstrated that, for example when faced with providing advice on exploited fish species in data poor situations, conceptual knowledge of life history characteristics can be used to classify the species (*e.g.*, into strategist groupings), with accompanying fisheries management options (Caddy, 1998; King and McFarlane, 2003). Thus, it is likely that fish stock recovery will be weakened when scientific advice and management fails to recognize the implications of life history traits and associated demographic dynamics (King and McFarlane, 2003; Hutchings and Reynolds, 2004).

The above emphasis on the selected performance criteria does not disregard other potentially influential criteria such as 'Stakeholder participation'; 'Property rights'; 'Monitoring, control, and surveillance', and 'Economic efficiency', that increasingly are being focused on in future evolution of Rights-based Management. We recognize that such institutional criteria are relatively difficult to measure/score, given the difficulties of both creating comparative definitions and collating comparable data. These institutional factors may very well be critically important for particular recovery challenges. Nevertheless, the current DA output emphasizes that the four most significant model predictors *additively* provide the *essential foundation* for effective recovery of most fish stocks/fisheries, before the other considered performance criteria may provide leverage. Furthermore, the Wakeford *et al.* (2009) tabulation provides a snapshot in time (ca. 2006) of the recovery or depletion status of the stocks/fisheries, and this may change quite quickly for some stocks given the right circumstances. Thus, it may be informative to monitor how situations change over time within this framework, and add more stocks into the database, in order to improve our understanding. To do this one needs an objective and robust classification methodology, which may benefit from better documentation regarding the actual process of scoring, inter-calibration, *etc*. However, the results of the Hammer *et al.* (submitted) analyses using CCA, DA, as well as independent corroboration by other statistical classification techniques, of the Wakeford *et al.* (2009) classification system provide substantial grounds for believing that the procedure is basically reliable.

3.4 The importance of governance for European recovery plans

The four performance criteria identified here as most effective for fish stock/fishery recovery are the result of a very bio-centric evaluation. Even though one performance criterion itself is of economic and two criteria are of a social nature, there is more to economic and social impact concerning effective recovery of stocks than can be qualified under the headings of 'Economic Efficiency', 'Social Impact and Compensatory Mechanisms' and Stakeholder Participation'. Therefore, recovery and the factors leading to success need to be discussed in the context of governance.

Recovery plans in Europe have not simply been clusters of management measures designed to bring about the recovery of particular species. UNCOVER's research on governance found that they have acted as focal points for collective action around reforming fisheries management at various scale levels. They have help set the stage for the institutional aspects that need to be incorporated in the current reform of the Common Fisheries Policy (CFP). While the plans have included many specific measures the 'recovery plans' themselves have not been rigidly defined and this has allowed a general stakeholder consensus. This consensus has been that these species need recovery, that recovery efforts should lead to long term management plans (LTMPs), and that somewhat greater emphasis should be placed on limiting fishing mortality and discards than on the setting of biomass targets.

A critical conjoining of reform efforts emerged because the recovery plans came just before the other critical part of the 2002 reform of the CFP began to take shape. These were the Regional Advisory Councils (RACs), which have become the main conduit for stakeholder participation in creating fisheries policy. The initial round of pre-RAC recovery plans was not an effective process. As one RAC staff member told us "*this idea of recovery plans ... was kind of sprung upon the fishing industry, which had no real warning about it*". One result was an intensification of the industry's initial reluctance. However, the recovery plans quickly became a major focus of the RACs and this led to the articulation of the general consensus of support for the plans.

The most important result has been the *active* support of recovery plans: a significant number of cooperative activities addressing improved stock assessment and data collection, increased compliance with measures, the avoidance of catching recovery species, and the reduction of discards. All of these actions have required support from both science and government – and how to structure this support has emerged as the key institutional challenge within recovery plans. Recovery plans are science-policy 'boundary objects' that require both input and mutual accountability from scientists, government, NGOs and the fishing industry.

The major challenges to the legitimacy of recovery plans have stemmed from their focus on single species. The conservation NGOs in particular raise questions about how the recovery plans should fit into an ecosystem approach to management. For the fishing industry and managers the worst problems arise in mixed-fisheries. Initial recovery plans were accused of 'ignoring' mixed-fisheries. The advantages of effort management in mixed-fishery recovery plans have led to hybrid effort and quota management schemes with greatly increased bureaucracy. The general consensus comes apart when mixed-fishery stocks begin to recover. Fishermen associate a depleted stock with a lack of fish, while other stakeholders are looking for a recovered age structure. When the stock begins to recover, fishermen see many young fish that, under strict recovery regulations, are interfering with their fishing for other fish. This leads to regulatory discards: the idea that managers are '*making fishermen throw good fish back dead*'.

Fishing communities play a critical role in active support. UNCOVER did an in-depth analysis of ten fishing communities and performed economic analyses on fishing fleets in three of the case studies. Both the economic and social analysis found that those communities and fleets that could not diversify their fishing suffered the most. The social analysis also revealed that a combination of the ability to diversity and an active fisheries-oriented civil society showed the highest potential for innovative engagement in fisheries management. What was less important was the degree of overall dependency on fishing for employment. Even communities with extensive civil society activities, which were for reasons of economics or ecology unable to diversify their fishing, displayed less active support.

The importance of civil society, expressed in active social networks, for fisheries management is very clear from the recovery plan experience. Fishing communities that did not have active fisheries-oriented networks did not contribute actively to the plans. Engagement was most directly expressed at the regional level and involved fishermen's organizations. At the shared-seas level these organizations began to work with conservation NGOs and other stakeholders. Governments at all levels facilitated these efforts. A central example was the work of the North Sea Commission, a network of regional governments that was critical in the formation of the North Sea RAC (Degnbol and Wilson, 2008). Member States were able to work with fishers and scientists to use distribution of fisheries resources in ways that improved resource use, as in the Scottish Conservation Credit Scheme where fishing effort was used as an incentive for intensified conservation practices. At the EU level, the European Commission played the central role of facilitating and legitimating the RACs.

Turning to the next reform of the CFP, we need to consider that policy choices will have an impact on our ability to generate *active* support for recovery plans and eventually LTMPs. What needs to be promoted is a network for elaborating recovery plans and long-term management plans as science-policy boundary objects. The basic network is in place in the form of the RACs and ICES. This network can be linked to more local levels, where appropriate, by involving Member State and sub-national governments. Funds need to be made available for concrete collaborative research and dissemination, and these activities need to be seen as inherent parts of recovery plans; recovery plans are much more than harvest control rules (HCRs), they are cooperative efforts to restore both stocks and profitable fishing. Much of this can be done through existing mechanisms of research contracts and framework projects but we must also find ways to ease the participation of industry and civil society in these mechanisms that are currently set up with only scientific institutes in mind. The EU and its Member State governments have multiple roles in recovery plans. They need to set directions. While broad stakeholder input in defining the scope of the problem, directions, targets and requirements, have to be set to avoid endless discussions. Once this is done the main role of government is to facilitate the multi-scale, multi-stakeholder and multi-disciplinary networks that actually change fishing practices to enable recovery.

3.5 International Symposium on 'Rebuilding Depleted Stocks – Biology, Ecology, Social Science and Management Strategies'

UNCOVER joined the International Council for the Exploration of the Sea (ICES) and the North Pacific Marine Science Organization (PICES) in co-sponsoring, arranging and implementing a Symposium on '*Rebuilding Depleted Fish Stocks - Biology, Ecology, Social Science and Management Strategies*', held in Warnemünde (Germany) from 3-9 November 2009. The symposium was convened by Cornelius Hammer (Germany), Olav Sigurd Kjesbu (Norway), Gordon H. Kruse (USA) and Peter Shelton (Canada).

The symposium's objective was to bring together research scientists from diverse disciplines, managers, policy-makers, the fishing industry and other stakeholders to present and discuss knowledge about the recent status and strategies for the recovery of overexploited fish and shellfish stocks, and to review worldwide progress in recovering depleted stocks in the context of achieving sustainable fisheries. Biological, ecological, modeling as well as socio-economic and management aspects were covered with respect to depletion and recovery/rebuilding of stocks. A total of 120 participants from 21 countries attended the symposium, and a total of 53 presentations were produced in five sessions, accompanied by 28 posters.

On the final day, a Panel Discussion, involving senior scientists, managers, and representatives from the fishing industry and NGOs, reviewed the outcomes of the symposium and responded to questions from the floor. The panel concluded that:

1) There is currently available a rich knowledge of stock rebuilding experiences to draw upon.
2) Now is a critical time in the recovery debate, but more information is needed about socioeconomic considerations/impacts, and more interactions are needed with stakeholders. There is a need to clearly describe downside losses and upside benefits of recovery programs.
3) Stock recovery plans represent the most widespread wildlife planning experiments available anywhere. As such, it is imperative that these plans be documented, archived, and the experiences with these plans communicated to all.
4) It is essential to think carefully about stock recovery as the end points may not be well known. Hence, an adaptive approach may be appropriate.
5) Significant investments will be required in fishery science in the future. The current models to assess stocks were developed when fishing mortality rates were generally between F= 0.3-0.8. However, new assessment tools will be needed when stocks are managed at much lower rates (*e.g.*, F=M). Clearly, fishery science will need to be more integrated in the future and explicitly incorporate habitat, environmental, and ecosystem aspects.
6) The human and economic costs of stock recovery to society need to be documented and communicated. Recognition of the considerable costs and resources involved in recovery efforts should help management to vigorously avoid stock collapses in the future.
7) Stock recovery invariably implies fewer fishers in the future and significant transition costs. It is also important that any resultant replacement activities of fisheries (*e.g.*, tourism; waterfront housing development) should not interrupt or impede stock recovery efforts by their resultant impact,
8) While stock recovery may be possible, stock rebuilding may not. If fisheries-induced evolutionary changes have occurred, or if ecosystem and climate changes have significantly altered the productivity, demography or dynamics of depleted fish stocks, restored stocks may differ markedly (*i.e.*, genetically, physiologically, and ecologically) from their status prior to depletion. In some cases, recovery to former biomass levels may not be possible.
9) Uncertainties will always exist with respect to the stock recovery/rebuilding process. These uncertainties should not undermine the development and implementation of recovery plans. A precautionary and adaptive approach may be required to avoid delays in taking effective

action, not only for stocks already in dire straits, but to keep those that are beginning to show signs of reduction from becoming depleted.

10) The current evidence suggests that management can be effective in recovering and rebuilding of fish stocks/fisheries and restoring the economic and social benefits derived from sustainable fisheries.

Further information on the symposium is provided in Annex 6.

4 POTENTIAL 'SCIENTIFIC' CONSTRAINTS IMPOSED ON RECOVERY STRATEGIES

4.1 Introduction

This section examines the factors which may place 'scientific' constraints on the recovery of fish stocks/fisheries. Such factors can be considered in the general context of drivers of population dynamics which affect the stock size (abundance/biomass), either beneficially or detrimentally (Figure 4.1):

a) *The two population regulatory aspects that* ***potentially*** *may cause the fish stock size to increase*. These are '**recruitment**' (*i.e.*, the number of young fish resulting from spawning, hatching and survival until they join at a given age the fishable stock) and '**growth**' (*i.e.*, change in body size/weight of fish in the fishable stock). In reality, both recruitment and growth may vary considerably from 'good' to 'poor' dependent upon environmental conditions influencing survival and feeding success, as well as stock structure and intra- and inter-species interactions.

b) *The two population regulatory aspects that* ***potentially*** *may cause the fish stock size to decrease*. These are '**fishing mortality**' (*i.e.*, the number of fish that are killed due to fishing activities) and '**natural mortality**' (*i.e.*, the number of fish that are killed from natural causes, mainly regarded as predation and pathogens/diseases). In reality, both fishing mortality and natural mortality may vary considerably from 'low' to 'high' levels.

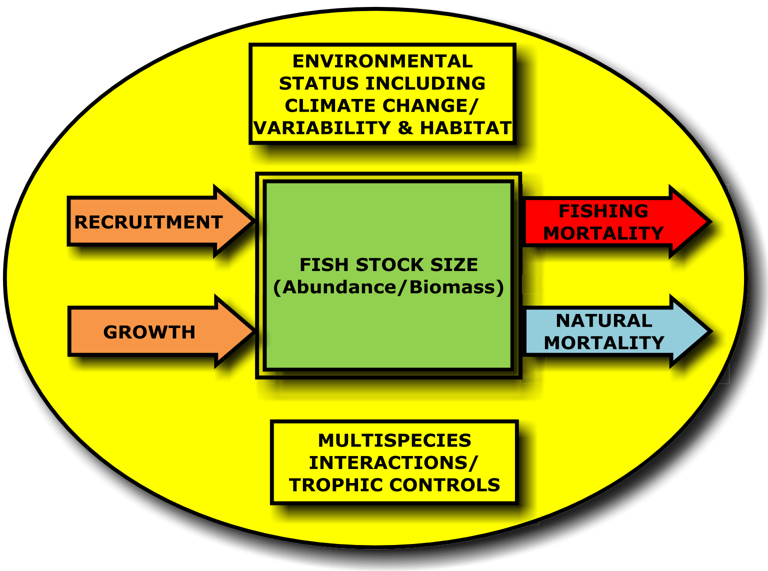

Figure 4.1. The main factors affecting changes in size of a fish stock.

It is, however, the ***balance*** between a) and b) above, taken over a particular period of time, which determines whether the stock size increases or decreases.

Intuitively, it is clear that it is through varying the *actual* (*i.e.*, real and operative) fishing mortality (via regulating fishing effort/capacity) that humans can most *directly* and effectively manage fisheries in terms of the ecosystem approach to fisheries management (EAFM). Nevertheless, appropriate management of the undesirable impacts of other human activities, resulting from various forms of pollution including the introduction of invasive alien species, and other forms of human encroachment, are required to conserve, and where appropriate restore, 'good environmental status' as required by the MSFD. Taking note of this preamble, the following parts of section 4 examine the potential 'scientific' constraints that can affect recovery strategies.

4.2 Unaccounted fishing mortality (UFM): IUU fishing and discards

4.2.1 Preamble

Fishing mortality (F) is a vitally important variable in fisheries science and regulating its intensity is the key to the effective management of a fishery. With respect to fish stock assessments, and prognoses concerning the recovery of depleted stocks, uncertainty concerning F (*i.e.,* the uncertainty whether the 'removals' during evaluation/assessment simulations correspond to the intended F-value) must be taken into account. The undependable nature of fisheries catch statistics are potentially the most important sources of risk and uncertainty which can adversely affect the success of LTMPs, HCRs and recovery plans for fish stocks/fisheries, as they lead to a poor assessment/evaluation process which may drive predictions far away from reality.

The scientific advice and management of many international fish stocks, included several of those forming the focus of the UNCOVER project, are being undermined by increasing levels of illegal, unreported and unregulated (IUU) fishing which contributes to 'unaccounted' fishing mortality (UFM).

In 2007, the European Court of Auditors (ECA) published a highly critical report on the control, inspection and sanction systems of the CFP (ECA, 2007), which constitute factors of relevance to the occurrence of UFM. The long list of failings included: 1) Catch data are neither complete nor reliable, and the real level of catches is therefore unknown; 2) Inspection systems do not ensure that infringements of fisheries rules are effectively prevented; and 3) The overcapacity of the EU's fishing fleet is an incitement to illegal fishing. This is further elaborated later in this section.

The estimation of F is imprecise because, in addition to the frequently undependable 'nominal' catch, there are other 'unaccounted' sources of fishing mortality. Incorporating estimates of UFM into stock assessment models is important in order to improve the reliability of assessment results and predictions of future stock trajectories under different management scenarios.

The importance of UFM was recognized by ICES as a significant source of error in fish stock assessments when it established the Study Group on Unaccounted Fishing Mortality which focused on the two major sources of concern (ICES, 2005): a) IUU fishing; and b) Discarding, which may or may not be illegal depending on the jurisdiction.

Various methods for estimating IUU fishing and discards are identified in Pitcher *et al.* (2002), Agnew and Kirkwood (2005), ICES (2005) and Hopkins and Lassen (2008).

4.2.2 Definition of the IUU and discards problems, and their consequences

The FAO/International Plan of Action to Prevent, Deter, and Eliminate Illegal, Unreported and Unregulated Fishing (IPOA-IUU) provides a complex definition of IUU fishing (FAO, 2001). However, IUU fishing applies to '*Catches taken within an EEZ which are both illegal (contravene rules and regulations) and retained, and which are usually unreported, and all unreported catches taken in high seas waters subject to a Regional Fisheries Management Organization's (RFMO) jurisdiction*' (Agnew *et al.*, 2009). In the European Regional Seas these are specified in the 2008 EC Council Regulation (No. 1005/2008) on IUU.

Discards are the portion of the catch which is not retained on board during commercial fishing operations and is returned overboard, often dead or dying reflecting the low survival rate of discards, to the sea before returning to harbour. Substantial unaccounted discarding is an unintended consequence of TAC management. Within the EU discarding is legal: so rather having a TAC regime *sensu stricto*, a total allowable landings system exists (TAL) and the discarded component of the catch is unregulated and unrecorded. One of the most serious forms of discarding is known as 'high-grading', which is the practice of discarding low-value small fish in order to fill the quota allotted with higher-value big fish. Fish which are discarded are often catches of species which fishers are not allowed to land, for instance due to quota restrictions, or unmarketable species, *e.g.,* individuals which are below minimum landing sizes. Discards form part of the bycatch of a fishing operation, although bycatch includes marketable species caught unintentionally. There is a need for more and better data on the amount and species composition of bycatches and discards (ICES, 2009). The problem of discarding differs greatly between different maritime areas, as a result of different fishing practices, diverse species composition, and different jurisdictions. Generally the discard problem is greater in so-called mixed-fisheries, *e.g.,* North Sea demersal trawling fisheries.

It is clear that IUU fishing and discarding have been periodically extensive for most of the commercial fish stocks and fisheries at the focus of the UNCOVER project (Nakken, 1998; Bray, 2000; Dings¿r, 2001; Rejwan *et al.*, 2001; Valdemarsen 2003; Kelleher, 2005; MRAG, 2005; ORCA-EU, 2007; ICES, 2008, 2009; Nakken, 2008; WWF, 2008). These are specifically documented in greater detail later in this section with respect to the UNCOVER target recovery-stocks/fisheries.

Both IUU and discarding have detrimental impacts in conservation, economic and scientific terms. Criticism of IUU and discarding is widespread, in the fisheries sector as well as outside of it, among consumers, citizens groups and in political forums. These UFM-related practices undermine the proper scientific assessment of stocks because the full catch mortality of the fishery, as removal of fish from a stock relative to quotas, is not accurately registered. Resultant incorrect fish stock assessments due to poor data quality and model outputs, lead to risks and uncertainty concerning the credibility of scientific advice, and the dependent management and political decision-making systems regarding setting TAC levels. For MPs/RPs, one of the ultimate consequences of excessive UFM is the risk of depletion of the spawning stock one aims to conserve in order to secure vital recruitment.

UFM underpins the claim that 'Quotas don't work' and proposals for the use of alternatives such as regulating fishing effort, *e.g.,* days at sea, implementation of closed areas. In the case of IUU, it distorts economics, markets, livelihoods, *etc.*, and acts against those who legitimately 'follow the rules'. Bycatch and discarding of unwanted fish, besides affecting the accuracy of stock assessments, reduces the numbers of juveniles before they have matured to the spawning stock, and may reduce the fish that are available to feed larger, piscivorous fish such as cod and hake. In the 2009 Green Paper on the reform of the CFP (EC, 2009), it is noted that '*discarding has prevented several stocks from recovering in spite of low quotas.*'

Great concern is often expressed by ICES over the poor quality of the catch and effort data from most of the important fisheries in the ICES area (ICES, 2008, 2009). As a matter of general policy, ICES attempts to correct for shortcomings in the data (*c.f.* ICES, 2005 for examples of methodology), but by their nature such corrections are uncertain and difficult to document, and open to debate. In some years it has not been possible for ICES to carry out stock assessments, and therefore provide advice, for a number of the key stocks because of the poor quality of the catch data. The responsibility for providing information on discards and non-reporting, and the uncertainty on their extent lies foremost with the national authorities and the industry.

IUU and discarding potentially augment the problems of 'decision overfishing' (*i.e.,* politically agreed regulatory overfishing) when negotiated TACs are set in excess of sustainable levels of exploitation. For example, EU fisheries ministers agreed TACs in 2006 on average 45% higher than the catches recommended by ICES scientific advice: science-based advice has often formed the basis for 'talking-up quotas' (Aps *et al.*, 2007). On top of this, addition of IUU fishing levels—which may be substantial—intensifies the problem. Until recently in the Baltic Sea, for example, management measures have been insufficient to reduce the fishing mortality as required and rebuilding of stocks was therefore not achieved (Aps and Lassen, submitted).

4.2.3 Steps to eliminate discards in the EU and elsewhere

The Statement of Conclusions arising from the 1997 North Sea Intermediate Ministerial Meeting on the Integration of Fisheries and Environmental Issues (IMM, 1997) recognized *inter alia* that efforts should be made '*As a matter of urgency, searching for all possible effective means, including the possibility of a ban, to minimize discards.*'

In 2002 the European Commission launched an Action Plan (EC, 2002) to tackle the main causes of discarding unwanted fish overboard and eliminate discards in European fisheries. Several times since then the Commission has reiterated its goal of solving the discards issue including proposing: a) reducing fishing effort, in order to decrease discards, as well as keeping permitted catches within agreed limits; b) using technical measures such as the structure and selectivity of nets, minimum landing sizes, catch composition in relation to defined mesh size, closed area and real-time areal closure; c) considering a discard ban; d) obligations to leaving fishing grounds where/when high quantities of young/undersized fish occur or are caught; e) making better use of potentially discarded, low-value fish for direct or indirect human consumption; and f) other measures, such as establishing pilot projects for testing discard bans in commercial fisheries, and examining the possibility of reducing discards due to exhausted quotas by, among other things, establishing bycatch quotas or setting multispecies TACs. In May 2009, the Commission emphasized that many measures can be taken already in the framework of the current CFP legislation, *e.g.,* bans on high-grading, use of selective fishing gear, real-time closure of fishing areas and a reduction in fishing effort. In bilateral management agreements with Norway, the EU has put a high-grading ban in place in the North Sea and Skagerrak since 1 January 2009 for all TAC-regulated species, and it is anticipated that this high-grading ban will be extended to cover all other EU waters as of 2010. Furthermore, in the Green Paper consultation on the periodic reform of the CFP produced by the European Commission, it is proposed that discarding should be eliminated by 2012, and it is reiterated that reducing overall fishing effort will also decrease discards, as well as keeping permitted catches within agreed limits (EC, 2009).

In Norway, Iceland, and the Faroe Islands, for example, under-sized individuals of commercial species are not allowed to be discarded and must be retained for information on these to be included in fish stock assessment databases. Based on the data, fisheries can be closed very rapidly if an area is associated with large bycatches of young fish and/or when a certain percentage of the catch is undersized. The banning of discards is a fast increasing moment in various parts of the world including in RFMOs. It is notable that NEAFC adopted in November 2009 a ban on discards in NEAFC high seas fisheries.

4.2.4 Occurrence, costs and drivers of IUU fishing

IUU fishing is a global problem as it occurs in most regions, not only in EEZs of the developing world and high-seas areas, but also in the EEZs of major developed countries including those of the EU and the EEA. The total value IUU losses worldwide are ca. 11 – 26 million t (Pauly *et al.*, 2003; MRAG 2005, Agnew *et al.* 2009). In a study of selected EU fisheries, it is estimated (EFTEC, 2008) that lost catches from 2008 to 2020 will amount to EUR 10.7 billion, equivalent to an annual average of about 30% of fishery value in the investigated fisheries. This equates to >27,800 lost job opportunities in fishing and processing industries or around 13% of total fisheries employment. In terms of lost stocks, costs of almost EUR 9 billion are suggested.

The main drivers of IUU fishing mortality have been identified (Agnew *et al.* 2009) and include: a) Ineffective management including unregulated fisheries; b) Fleet overcapacity and restrictive management measures (*e.g.,* TACs, effort limitation, gear types / configuration); c) Poor enforcement / controls at sea and on land; d) Tax benefits, subsidies and investment incentives from ‘Flag of Convenience’ States; e) Extraordinary economic pressures (*e.g.,* increasing fuel costs); and f) De-stigmatized perception of IUU activities by society due to under-estimation of environmental and social impacts.

The European Court of Auditors (ECA) has severely criticized the ineffective fisheries control within EU waters (ECA, 2007). The ECA noted that lower catches and overexploitation of fishery resources have been observed for many years and represent the failure of the CFP. Yet, since its inception in 1983, the objective of the CFP has been the sustainable exploitation of living aquatic resources. Setting TACs and national quotas in order to limit catch volumes is the cornerstone of this policy. The ECA’s audit led to the conclusion *inter alia* that: a) As catch data are neither complete nor reliable and the real level of catches is thus unknown, this prevents proper application of the TAC and quota systems; b) Inspection systems do not provide assurance that infringements are effectively prevented and detected - the absence of general control standards is an impediment to adequate control pressure and optimization of inspection activities; c) The procedures for dealing with reported infringements do not support the assertion that every infringement is followed up and still less attracts penalties; d) Overcapacity reduces the profitability of the fishing industry and, in a context of decreasing authorized catches, is an incitement to non-compliance with these restrictions. It also affects the quality of the data forwarded; the Community's current approach, which is based on reducing the fishing effort, is unlikely to resolve the problem of overcapacity; e) If this situation continues, it will bring grave consequences not only for the natural resource, but also for the future of the fishing industry and the areas associated with it; and, f) If the political authorities want the CFP to achieve its objective of sustainable exploitation of fisheries resources, the present control, inspection and sanction systems must be strengthened considerably.

4.2.5 Specific actions to tackle IUU

The following proposals for effective actions to prevent IUU have been summarized by Hopkins and Lassen (2008) in a presentation to the European Supreme Auditing Institutions Working Group on Environmental Auditing:

- Adoption of mandatory systems for Port State control and trans-shipment inspections, and establishing common databases in countries in RFMOs;
- Improved control of vessel licensing /permits and control at sea for compliance. Inspection for undersized fish, bycatch/discards, fishing gears, catch on-deck and in holds, vessel tracking devices (VMS, VDS), catch log-book, *etc*;
- Better control at landings for compliance including landings declarations/sales notes;
- Traceability of fish standards: harvested from a legitimate source /manner, through 'chain of custody' to consumer;
- Open, objective and verifiable certification schemes rewarding fishers and fisheries with good standards;
- Include fisher and environmental organizations with market-representatives in strategies for tackling IUU; and
- Extended international cooperation between national authorities (*e.g.,* tax, customs, police and prosecutors). Link these closely with scientists and managers.

In accord with many of the above-mention factors, the recent Commission Regulation (EC) No. 1010/2009 of 22 October 2009 lays down detailed rules, and a handbook of guidelines, for the implementation of Council Regulation (EC) No 1005/2008 establishing a Community system to prevent, deter and eliminate IUU fishing.

4.2.6 The incidence of UFM in the UNCOVER target stocks

The more recent and/or current extent of these UFM-related uncertainties, for the stocks forming the primary focus of the UNCOVER project in the following four Case Study areas, are noted by ICES (2008, 2009), and other cited sources, as summarized below:

Norwegian and Barents Seas
<u>NEA cod</u>: There has been a significant amount of unreported catches, although there are indications that these are decreasing: unreported landings are thought to have constituted 3% of estimated catches in 2008, down from 26% in 2005. Actual catches exceeded the TAC by 25% in 2004, 32% in 2005 and around 14% in 2006 and 2007, having declined to 8% in 2008. Discarding is thought to be significant in some periods although discarding is illegal in Norway and Russia. Nakken (1998) also notes that the TACS as advised by ICES quite frequently were too high due to overestimation of stock size in the annual assessments, thereby contributing to higher fishing mortality. The TAC for 2009 was set above the catch corresponding to the agreed management plan, so that ICES no longer views the management plan as precautionary.

Norwegian spring-spawning herring: After the re-opening of the fishery, following its collapse, when recovery was evident in the 1980s and 1990s, the set TACs quite often exceeded the advised TACs, but since 2007 the TAC has been set in line with the advised TAC level, indicating that compliance is quite high. Discarding is thought to be low but slippage has not been quantified and could not be considered in the current assessments. Under-reporting is probably occurring, but the magnitude of the extra removals could not be estimated and their relative importance is probably low under the present high catches scenario.
Barents Sea capelin: The management compliance of advice is strong: catches have been very close to advised limits every year since 1987. The bycatch of other species is negligible in this directed fishery.
Baltic Sea
Eastern Baltic cod: The quality of the assessment and efficiency of the management measures for the Eastern Baltic has suffered because of inaccurate input catch-data due to IUU fishing. ICES has included estimates of mis- and non-reported landings in the assessment but asserts that the estimate of 2007's fishing mortality is highly uncertain due to the likely underestimation of 2007's total landings. Total catches have periodically exceeded the set TAC with estimates varying from 32% to 45%. The estimate for 2008, suggests that unreported landings have declined to only 6% due to better enforcement of fishing controls, although the size of the reduction raises doubts about its validity. Discarding and highgrading are expected to increase in the fishery in 2010 due to juveniles become more abundant as a result of relatively good recruitment in recent years. Baltic sprat: Catches have never exceeded the set TACs, indicating good compliance. However, the main problem is the catch data because, in many of the mixed-fisheries for herring and sprat, the separation of herring and sprat catches is imprecise. The uncertainties could influence the estimates of absolute stock size and fishing mortality. Better sampling of industrial fisheries has improved the quality of the data input to the assessment. Discards from sprat fishing are probably small because undersized and lower quality fish can be used for production of fishmeal and feeding in animal farms. In fisheries directed for human consumption, however, young fish (0 and 1 age-groups) are discarded with higher rates in years when strong year-classes recruit to the fishery. The amount of discarding of these age-groups is unknown. However, the collection of sprat discards data is underway.
North Sea
Cod: Due to information on landings and effort being highly unreliable, commercial indices were not used in the assessment; instead, the assessment uses only survey data for calibration. Many countries with substantial cod landings have not supplied discarding estimates and so added to uncertainty in the assessment, despite their obligation under EU data collection regulations. Quantities of additional unallocated removals were estimated by the assessment model on the basis of the total mortality indicated by the survey. Unallocated removals estimates could potentially include components due to increased natural mortality and discarding as well as unreported landings. However, it is assumed that these removals do originate in fishing activities. Official landings consistently comply with the set TACs, but discards have accounted since 2006 for a contribution to fishing mortality that is equivalent to the landings. Strong indications exist of unaccounted removals due to other sources, presumably fishing-related, and are considered to be increasing and to have accounted in 2008 for removals comparable to summed landings and counted discards. These deficiencies highlight the need for urgent improvements in implementation and enforcement. Autumn spawning herring: Historically, actual total catches in ICES areas IV and VIId have consistently exceeded set catch limits. For the past decade the overshoots have been primarily a result of overfishing by fleet A (Subareas IV and VIId directed fisheries and bycatch in Norwegian industrial fisheries), but to an increasing extent over fishing consisted of catches taken in IVa West misreported as catches taken by the C-fleet in Division IIIa. In the last year this has decreased due to a new Danish national control and enforcement in 2009 only allowing fishing within one management area during a single fishing trip. The total catch in 2007 as well

as 2008 for areas IV and VIId were above the agreed TACs whereas in 2009 the total TAC was not taken in the North Sea. When available, information on discards is included in the assessment. Measures to reduce misreporting include a ban on landing bycatch in ports without sampling schemes. EU bycatch limits are set for the B-fleet and bycatches are deducted from quotas and the fisheries must be closed as soon as the bycatch ceiling is reached.

Bay of Biscay and Iberian Peninsula

Northern hake: Compliance with the set TACS was historically strong in the fishery until 2001 when the TAC was reduced by almost 50%. Compliance with the TAC in 2006 and after coincided with increases in the set TACs. Discarding of juvenile hake can be substantial in some areas and fleets. Incomplete discard sampling over all fleets is a significant issue, as is the tendency for the assessments to overestimate the size of the spawning stock and problems with commercial CPUE series.

Limiting mortality of juvenile fish through technical measures that reduce bycatch/discards and shift the selection pattern towards older fish would substantially increase the spawning biomass and long-term yields. The *Nephrops* fishery also contributes via bycatch/discards to hake mortality, levels of which are uncertain; this source of UFM can be ameliorated by the use of a squared mesh panel to reduce discarding of undersized hake, as enforced since 2006 in the French *Nephrops* fishery.

Southern hake: Discarding is not considered in the assessment, although it constitutes around 20% of landings, mainly of juvenile fish. Compliance with the set TAC was strong in the fishery up to 2004, but IUU fishing has been extensive since then as the TAC has been increasingly overshot, with landings having reached more than twice the agreed TAC. A discrepancy between the minimum landing size and allowed mesh sizes means that fish just below the minimum landing size are frequently retained and suffer a high discarding rate.

Regarding the demersal stocks in the Bay of Biscay, among which hake is included, ICES (2009) underlines that the information on the observed mix of species caught in fisheries in this area is not complete. An evaluation of the effects of any combination of fleet effort on *depleted stocks* (italics inserted by UNCOVER) would require that the catch data on which such estimates were based included discard information for all relevant fleets. Such data are not available to ICES. ICES is therefore not in a position to present scenarios of the effects of various combinations of fleet effort. If data including discards were available, it might be possible to present a forecast based on major groupings of fleets/fisheries.

Anchovy: The fishery has been stopped since 2005 due to the collapse of the stock. In the past, a TAC was set independently of the state of the stock (ca. 30 000 t to 33 000 t), and this had limited impact in regulating catches in the fishery. The December 2009 EU Fisheries Council meeting decided that '*in the light of the scientific surveys carried out last autumn, the anchovy fisheries will be temporary re-opened as from 1 January 2010 in the Bay of Biscay. It will be subject to a later adjustment in accordance with a new scientific advice to be provided in spring 2010.*'

4.3 Climate change and variability, environmental controls, key habitats and system constraints

4.3.1 Preamble

Climate forcing has been identified as a major driver of environmental, ecosystem and fish stock dynamics (Cushing, 1975, ICES, 1994; Ottersen *et al.*, 2010). In particular, the stock biomass and production dynamics, and fluctuations thereof, often depend on particular environmental (abiotic) conditions (*e.g.,* gradients in temperature, salinity, stratification/density, oxygen, and the forcing of these by ocean currents), at various stages of the life cycle for optimizing recruitment and survival (manifested in abundance), distributions and migrations in space and time, and body growth and reproduction (Rijnsdorp *et al.*, 2009). Especially in temperate, boreal and arctic- boreal ecosystems, environmental factors—including 'ocean climate' as an amalgam—are increasingly being recognized as strongly influencing the carrying capacity of fish stocks (Drinkwater, 2005; Batcheldor and Kim, 2008; Rijnsdorp *et al.*, 2009). Thus, favourable climatic conditions facilitate successful stock recovery, and unfavourable climatic conditions will constrain recovery (Hammer *et al.,* submitted) (c.f., section 3.3.3). This is particularly important in stocks, such as European stocks of cod, where environmental effects act as a multiplier, independent of the size of spawning-stock biomass (SSB), in the stock-recruit (S/R) relationship (Brander and Mohn, 2004; Brander, 2005).

In European cod stocks it has been shown that the environment, as represented by the climate-related North Atlantic Oscillation (NAO) index, affects recruitment more strongly when their SSB is low, so that when low SSB occurs then recovery is very dependent on favourable environmental conditions (Brander, 2005). Currently, it is believed that the reasons for this increased sensitivity to climate forcing is connected with the effect of a truncated age/size structure on recruitment, whereby the reduction in the number of age/size groups leads to a decline in spawning intensity/efficiency, duration and spatial extent; features which decrease the stock's resilience to climate change/variability (Marteinsdottir and Thararinsson, 1998; Begg and Marteinsdottir, 2002; Ottersen *et al.*, 2006; Perry *et al.*, 2010). All this is a powerful justification for avoiding low stock biomass caused by overfishing.

To complicate matters, human exploitive pressures, such as fishing and pollution (eutrophication and toxic substances) may interact with climate to cause complex effects on marine populations (Ottersen *et al.*, 2010). Climate effects in concert with fishing, in particular, can magnify or diminish the abundance and structure of populations and the state and functioning of marine ecosystems (Cushing, 1982; Hall, 1999; Perry *et al.*, 2010). They are considered to be the major causes of recruitment variability of fish stocks, and so largely govern their decline and recovery (Rothschild, 2000; Brander, 2005; Jennings and Brander, 2010; Planque *et al.*, 2010; Ottersen *et al.*, 2010).

As humans cannot directly manage climate but can manage fisheries directly, the level of fishing mortality/effort directed at a stock should be adapted to reflect the changing environment. It has belatedly been recognized that scientific advice and management must operate in a potentially rapidly fluctuating environment in that biological reference points (BRPs) for stocks need altering to reflect significant changes in the environment, especially where regime shifts have occurred (Brander, 2005, 2005; Kell *et al.*, 2005; Kšster *et al.*, 2009). Thus, to achieve sustainable fisheries, apparent changes in stock productivity need to be considered when defining HCRs, and their associated BRPs, by identifying ecological regimes of similar productive states, either by separating time-series into shorter periods of similar environment, or by direct inclusion in environmentally sensitive stock-recruitment relationships (ICES, 2007; Kšster *et al.*, 2009). At present no clear methodology exists for determining limit and target reference points under shifting environmental conditions.

There is an extensive range of ways that environmental change affects the assessment and their projection, as well as management of fisheries. ICES Workshop on the Integration of Environmental Information into Fisheries Management Strategies and Advice (WKEFA) (ICES, 2007) has provided an overview of several of the pertinent issues, and their possible interactions, under four main topics:

1) Entries and exits from populations (recruitment, natural mortality and migration);

2) Internal population processes encompassing, a range of aspects associated with growth maturation and reproduction;
3) Location and habitat, including aspects such as vertical and horizontal movement; and
4) Multispecies interactions;
5) Composite (ecosystem) issues in advice.

WKEFA underlined that many of these factors act together and, as the result of complex linkages, physical drivers may affect food supply or reproductive habitat, resulting in changes in location, growth, maturation and reproductive potential. This leads to changes in recruitment followed by changes in natural mortality due to different species interactions. Variability is observed at a wide range of scales of space and time, and impose concepts of stochastic stability and regime shift that are useful for consideration of problems we face rather than a perception that there are a number of stable states that can be defined and that we may move between in either predictable or unpredictable ways.

WKEFA viewed regimes as being quasi-stable states around which we observe variability, such states are useful concepts for management, but did not consider the formal methodology of identification of regime shifts in the sense of linear and nonlinear processes. Stocks have been considered by WKEFA on the basis of carrying capacity[6], productivity[7] and depensation[8]. Annex 7 provides a summary of the findings from the WKEFA deliberations extracted from their report (ICES, 2007).

4.3.2 The impact of climate change and variability on populations, communities and ecosystems

Climate Change vs Variability

The difference between climate variability and change is clarified by Perry *et al.* (2010):

- *Climate variability* occurs on a wide range of time scales from seasonal periods to 1-3 year oscillating but erratic periods (*e.g.*; ENSO: El Ni–o-Southern Oscillation), to decadal aperiodic variability at 5-50 years, to centennial and longer periods. For the purpose of fish-related considerations these are variability at periods equal to or less than several generations of fish, for example <100 years.
- *Climate change* (trend) is the secular change which at present, in the case of temperature, appears to be increasing, and largely human-driven, and whose rate is small compared with that of the variability of smaller time scales. Climate change may also affect climate variability.

Several studies (Ottersen *et al.*, 2004; 2010; Rijnsdorp *et al.*, 2009; Drinkwater *et al.*, 2010) have reviewed and identified the means by which climate, with or without forcing from fishing and other human pressures, may influence fish and their ecosystems on a process-by-process basis considering spawning and reproduction, abundance and recruitment, growth, distribution and migration, natural mortality, and catchability and availability for fisheries. Additionally, the abiotic environment affects feeding rates and competition by favouring some species and not others, as well as the abundance, quality, size, timing, spatial distribution, and concentration of

[6] Carrying capacity relates to the mean level a stock might reach and within the framework of an S/R relationship is the recruitment that is expected when it is independent of stock size.
[7] Productivity expresses the rate of recovery from a depleted state or the rate of decline under heavy fishing pressure and relates to the slope of the S/R relationship near the origin.
[8] Depensation is the reduction in reproduction that results from stock size related effects.

food. Multispecies interactions and trophic controls are affected by climatic influences on the abundance and distribution of predators and prey (see below with regard to CS areas and section 4.4 for details of multispecies interactions and trophic controls).

Climate change, in the form of marked climate warming, will increasingly impact, over the coming decades, upon the biological, economic and social aspects of fisheries. As climate change impacts may vary between detrimental and beneficial depending on the regional environment, it will pose challenges and provide opportunities at the scientific, management and socioeconomic levels. 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 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.

It is important to address the impacts, both detrimental and beneficial, of climate forcing on ecosystems sustaining fisheries. Some ecosystems and their biota may suffer and some may benefit. It is important to understand 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.,* seabirds and marine mammals) which play important roles in fisheries systems.

Over the last several decades, we have seen an intensifying view arguing for fisheries science and management to understand and take account of the interactions between climate and fishing, rather than a basically uninformative attempt to disentangle their effects and address each separately (Perry *et al.*, 2010; Planque *et al.*, 2010). The justification is that it is the interactions between climate and fishing which drive important changes in exploited living marine resources and their ecosystems. Perry *et al.* (2010) have made a comprehensive review of the sensitivity of marine ecosystems to climate and the intensity of fishing, and concluded that:

- The effects of fishing on exploited marine populations converge towards a reduction in the diversity of demographic, spatial and population characteristics. This is manifested in a loss of older age-groups, spatial contraction in distributions, loss of sub-units, and alteration of life history traits in populations. These effects may make populations more strongly connected to climate variability at inter-annual to inter-decadal scales.
- Fishing reduces the mean size of individuals and the mean trophic level of communities, decreasing their turn-over time, and leading them to track environmental variability more closely.
- Ecosystems under intense exploitation evolve towards stronger bottom-up control and greater sensitivity to climate forcing.
- Because climate change occurs relatively slowly and incrementally, its effects are unlikely to have immediate impacts on marine systems, but will be manifest as the accumulation of the interactions between fishing and climate variability, unless threshold values are exceeded.

Habitat Controls

'Habitat for fish is a place—or for migratory fishes, a set of places—in which a fish, a fish population or a fish assemblage can find the physical and chemical features needed for life, such as suitable water quality, migration routes, spawning grounds, feeding sites, resting sites, and shelter from enemies and adverse weather. Although food, predators, and competitors *are not* habitat, proper places in which to seek food, escape predators, and contend with competitors *are* part of habitat, and a suitable ecosystem for fish includes habitat for these other organisms, as well' (Orth and White, 1993). There is a need to improve our capacity to recognize change and loss of habitats, and their associated biodiversity, and identify and quantify the natural and human induced drivers of such change and loss, with a view to understanding the causative processes and ultimate consequences for biodiversity. Conservation of habitats is vital for protecting the species that rely on the habitats for their viability, including sustaining the ecological goods and services upon which the living marine resources and the fisheries depend. Impairment of habitat quality and quantity threatens the biodiversity and integrity of marine ecosystems, the sustainability of fisheries, and ultimately, the well-being of the coastal communities who rely on fishing. Accordingly, in tackling the issue of recovery of fish stocks/fisheries it is essential to recognize that fisheries potentially affect the ecosystem and the fish stocks are affected by the ecosystems.

Substantial degradation, fragmentation and eventual loss of habitats—together with associated threats to their characteristic faunal and floral communities—have become increasingly evident over the past centuries due to various encroaching human activities and changes in climate (GESAMP, 1997). Thus, the conservation of habitats is a rapidly growing need with regard to the protection of biodiversity as an essential factor in ensuring the sustainability of ecological goods and services. Particularly since the industrial revolution, and conspicuously so today, human populations and their activities have not only benefited from but also increasingly exerted pressures on the marine ecosystem. These human activities affecting the marine environment and its living marine resources include: Oil and gas exploration and production including platforms and pipelines; power generation including wind farms; shipping and maritime transport: dredging and dumping of wastes and litter; mining and mineral and aggregate extraction; fisheries and aquaculture; coastal engineering and land reclamation; human settlements and coastal industries (*e.g.,* pulp and paper, iron and steel, chemicals and petrochemicals, and food processing operations); and recreation and tourism. The pressures resulting from these human activities have caused the intensive and unsustainable exploitation of many fish stocks and other resources, pollution from harmful and hazardous substances (*e.g.,* heavy metals, persistent organic pollutants, radioactivity, and oil spills), excessive inputs of nutrients and organic material leading to the effects of eutrophication, introductions of alien organisms, and other diverse forms of ecological disturbances. This has resulted in serious depletion of vulnerable species and the degradation of sensitive habitats, some of which are in danger of local extinction, as well as causing changes in environmental quality, and the structure, function and integrity of particular ecosystems.

Contaminants, such as persistent organic pollutants (*e.g.,* DDT, PCBs, and dioxins) and heavy metals tend to accumulate via the food-web causing health problems in several biota (*e.g.,* benthos, birds and marine mammals), and levels of some pollutants in seafood (*e.g.,* fatty fish and shellfish) constitute a health risk in some areas, such as parts of the Baltic Sea. Such degradations of ecosystem health have resulted in associated detrimental human socioeconomic impacts. Furthermore, the impacts of this human induced global change, including climate warming, on marine ecosystems are of major concern and are anticipated to have substantial impacts on human communities in coastal and offshore areas.

Marine habitats provide fish stocks with the key necessities of life: food, shelter, and breeding grounds. Recognizing the importance of habitat quality and quantity to the health of fish species and the coastal communities and commercial fisheries that rely on them, the USA's Magnuson-Stevens Act was amended to ensure the designation and protection of 'essential fish habitat' (EFH). The Magnuson-Stevens Act describes EFH as '*those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.*'

Critical for understanding the future structure of marine food-webs and their services such as production of fish stocks is the ability to project the future occurrence of habitats critical for key species and groups. This is a major challenge, which is acknowledged by the science. An approach to linking habitat and population dynamics is to use quantitative process models to substantiate the current ecosystem situations. However, this approach neglects the adaptive nature of marine species (*e.g.*, Pšrtner *et al.*, 2006). Statistical models relate present day geographical distribution of species and communities to their environmental conditions (Guisan and Zimmermann, 2000). Habitat models have successfully been used in terrestrial ecology for conservation and management issues and are currently being introduced into marine research (*e.g.*, Loukos *et al.*, 2003; Zarauz *et al.*, 2008; Cheung *et al.*, 2010). When properly developed these models have the potential to produce short-term predictions of the distribution, abundances and changes of key players on non-adaptive time scales for marine habitats (*e.g.*, Planque *et al.,* 2007; Fernandes *et al.*, in press). These predictive habitat models employ different approaches dependent upon the type of data (*e.g.*, Generalized additive models, Bayesian networks, ENFA; see Guisan and Zimmermann, 2000). A second approach employs agent-based models within which individual-based interactions and adaptive strategies are played out under prescribed physical settings, is a promising way forward (*e.g.*, Huse, 2005). To this end, UNCOVER WP 2 has furthered our understanding of the impacts of environmental controls on fish recruitment. Such models have been demonstrated as leading to emergent properties from complex systems, reflecting trade-offs between survival, reproduction and competition with the potential to determine coexistence or exclusion of similar (genetic or functional) zooplankton species (*e.g.*, Huse, 2005).

The identification of key habitats during ontogeny is the core for management strategies based on Marine Protected Areas (MPAs). MPAs focus on the protection of 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.

There is a need for improved understanding of 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.

System Dynamics: Interactions and Regime Shifts

A number of other issues inherent in marine ecosystems limit our ability to predict future states. First, the ocean's vast size, large spatial and temporal variability, and the numerous difficulties in making observations ensure that the system is grossly under-sampled. As a result, it is difficult to detect interactions among organisms or changes within marine ecosystems as a result of changes in abiotic and biotic forcings. Our ability to develop predictive understanding is further compromised by the interconnected (Link, 2002) and adaptive nature of marine ecosystems. These characteristics define marine ecosystems as complex adaptive systems (CAS) where system properties, such as diversity-productivity relationships, trophic structure and patterns of energy and material flow, emerge from interactions among individuals, creating critical feedback loops which influence the dynamics of these interactions (Levin, 1998). Following CAS theory, interactions occur between species ranging from weak to strong in nature, determine the emergent properties of the system.

CAS exist in a balance between stability and chaos with systems dominated by few strong links being potentially more susceptible to chaotic behaviour than those dominated by weak linkages (Pascual and Dunne, 2006). CAS are stable enough to have persistent patterns and fluid enough to transmit information between components. They are always changing and are assumed to exhibit self-organized criticality (*e.g.*, exhibiting power law behaviour). Deterministic prediction of future states is not possible for CAS and hence for marine ecosystems. However, we can predict the likelihood of certain events (Waldrop, 1992).

Furthermore, in addition to rapid changes between stability and chaos, complex systems also can exhibit abrupt or discontinuous transitions between stable states or regimes as a result of changes in trophic interactions and abiotic forcing. These regime shifts/transitions tend not to be reversible along, for example, the same path, but to be characterized by 'bifurcations', *i.e.*, the abrupt transition of the ecosystem from say a 'cool' regime to a 'warm' regime takes place at a higher temperature than the reverse transition from a 'warm' back to a 'cool' regime. Evidence of these abrupt transitions is accumulating for a variety of terrestrial and marine ecosystems (Scheffer *et al.*, 2001), including the fisheries ecosystem in the subarctic North Pacific (Francis *et al.*, 1998). Our ability to predict the occurrence of regime shifts, which are an emergent property of marine ecosystems and a feature of CAS is not possible. We can, however, potentially predict the probability of occurrence of a shift based on the characteristics of the ecosystem, the critical rates and limits of the key species, and its external forcing (*e.g.*, Carpenter *et al.* 2008).

4.3.3 Prudent strategies for fisheries mitigation and adaptation to climate change

It is vital to understand how the fisheries sectors will be affected by climate change and to develop prudent strategies for mitigation and adaptation. Knowledge is required concerning how these sectors may optimally respond to climate affects on the (re)distributions and productivity of both 'old' and 'new' biological resources. Fisheries management plans and policies should better incorporate the effects of climate change and variability in establishing rational harvesting levels, rules and practices, and developing prudent adaptive strategies and mitigatory measures. Marine resource managers need to develop approaches, which maintain the resilience of individuals, populations and communities and ecosystems to the combined and interacting effects of climate and fishing (Perry *et al.*, 2010).

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 levels of many living marine resources: a less heavily fished marine system is likely to provide more stable catches with climate variability and change than would a heavily fished system (Perry *et al.*, 2010). In addition to increasing the resilience of stocks 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 (Brander, 2008).

The traditional emphasis of fisheries science, advice and management on preserving young fish, to ensure reproduction and maximize yield per recruit, has tended to obscure the important 'buffering' role of larger/older fish in stocks (Planque *et al.*, 2010). In most assessments, the state of the adult stock is represented by the SSB, which basically ignores the stock's demography despite age/size structure forming a basis of its calculation. However, the MSFD (EC, 2008) has the laudable aspiration of conserving not only stocks within safe biological limits, but '*exhibiting a population age and size distribution that is indicative of a healthy stock.* Clearly, aiming to maintain fishing mortality (F) levels at $F\leq_{FMSY}$ will help to conserve the proportion of large/old fish, and so SSB diversity, and thus counteract the effects of climate change and variability. Empirically, one can estimate the relative age distribution of a stock with respect to varying F, while making informed assumptions on natural mortality (M) and growth rates of the stock (see Baltic Sea Case Study report). It is important, however, to avoid the classic response in managing a depleted stock of raising the size limit (through larger mesh sizes or other means), as this results in the quota coming from the declining proportion of old, large fish still surviving, with potential dire consequences for optimizing stock recruitment in the face of climate change and variability (Ottersen, *et al.*, 2006).

4.3.4 Greater knowledge about climate change on spread of non-indigenous and invasive organisms

It is important to improve our knowledge concerning how non-indigenous and invasive organisms may be introduced/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 unintentional 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. New knowledge is needed on assessing and predicting the benefits and risks from non-indigenous and/or invasive organisms, devising techniques and models for impact assessments/risk analyses, early-warning systems and more combating measures. Better understanding 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. Further information on the topic of invasive alien species is found in section 4.6.

4.3.5 The effects of climate on the target fish stocks in the four Case Study areas

In marine systems climate change is evidenced by rapid warming trends in sea surface temperature (SST) with subsequent changes in stratification, transport and cascading to a warming of the deep ocean. These trends have been observed, in the period 1982 – 2006, in so-called 'fast and superfast' Large Marine Ecosystem (LME) clusters found in land-locked or semi-enclosed seas, such as the European seas (Belkin, 2009). In these LMEs, surface warming has occurred 2-4 times faster than the globally averaged rates of SST warming reported by the IPCC-2007 (Belkin, 2009; Sherman *et al.*, 2009). Three of the four UNCOVER Case Study areas figured among the combined fast and super-fast LME clusters from the total of 64 LMEs studied (Sherman *et al.*, 2009), with the ranking of warming (highest to lowest, 1982 – 2006, for the 64 LMEs) of the UNCOVER-relevant LMES in the period being: 1) the Baltic Sea (1.35°C, ranked 1 of all 64 LMEs); 2) the North Sea (1.31°C, ranked 2); 3) the Norwegian Sea (0.85°C, ranked 99); 4) the Celtic-Biscay Shelf (0.72°C, ranked 14), and 5) the Barents Sea[9] (0.12°C). Only one of the UNCOVER areas is included among the slow-warming LMEs. In essence, Sherman *et al.* (2009) suggest that the trends for increases or decreases in the fisheries biomass yields in the last 25 years in the fastest warming LMEs reflect the manner in which: a) warming promotes or worsens the phytoplankton and zooplankton productivity of the specific LMEs for supporting (*e.g.,* via growth and recruitment) the production of the main commercially important fish stocks resident in these LMEs; and b) the extent to which the intensity of harvesting (*e.g.,* underexploited, fully exploited, overexploited) of the fish resources is commensurate with the changing productivity of the particular LMEs. Thus, changes in temperature can be associated with major changes in their ecosystems and the productivity and yields of fish communities. Accordingly, the UNCOVER project emphasizes that climate change is a major factor to be taken into account in the management of fish stocks. Critically in these systems the magnitude and direction of the environmental change moves beyond levels of previous scientific and management experience. Hence, given the importance of climate change on ecosystem dynamics there are increased levels of uncertainty and risk influencing our predictive capacity and thus our goal of achieving sustainable fisheries. Risk and uncertainty needs to be balanced with appropriate application of the precautionary approach.

In the following, sections the focus is primarily placed on specific aspects related to climate forcing affecting the target fish stocks for recovery.

Norwegian and Barents Seas

<u>Preamble</u>

Environmental changes such as changes in temperature and inflow may affect several population processes, most notably spatio-temporal distributions, and recruitment and growth. Such effects should be taken into account both in long-term simulations investigating recovery strategies as well as in short-term predictions of stock development. We first outline our process knowledge, then we discuss how this is/can be implemented in models used in UNCOVER as well as in stock assessment models. It is important to integrate abiotic and biotic factors in such models, so this section needs to be viewed together with sections 3.3.3, 3.3.4 and section 4.4.

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[9] The low temperature increase noted for the Barents Sea LME by Belkin (2009) and Sherman *et al.* (2009) is due to the temperature integration algorithm covering <u>both</u> Arctic and Atlantic water masses (Igor Belkin, *pers. comm.*). Thus, the inclusion of the cold Arctic water masses, north of the Polar Front, in the temperature calculations has substantially reduced the overall temperature rise. Restricting the calculations to Atlantic waters, where most commercial fish catches occur, is likely to provide a ranking similar to the Norwegian Sea.

<u>Process knowledge</u>

Recruitment

Norwegian spring-spawning herring and Northeast Arctic cod and haddock all spawn along the northwestern coast of Norway bordering the Norwegian Sea (see Nakken 2008 and references therein). In all cases, the larvae drift northwestward to the main nursery areas of the Barents Sea. The pre-recruits spend up to four years in these nursery areas before recruiting to the Norwegian Sea in the case of herring or shifting to adult feeding areas in the Barents Sea in the case of cod and haddock. Historically, the key environmental drivers on the recruitment of some of the main fish stocks in the Barents Sea (*i.e.*, cod, herring, haddock) are connected with variations in inflow of warm Atlantic water from the Norwegian Sea. Inflow variability alters the extent of the Atlantic domain in the Barents Sea in which the commercially important fish stocks thrive and advect important planktonic biomass such as *Calanus finmarchicus* which forms a crucial diet component in particular phases of fish ontogeny. A high inflow/temperature flux has been positively correlated with recruitment of cod, herring and haddock stocks, in particular, which frequently showed a concerted recruitment response. Numerous studies have reported the linkages between environmental factors and recruitment for Barents Sea/Norwegian Sea fish stocks (*e.g.*, Dragesund, 1971; Ponomarenko, 1973, 1984; S¾tersdal and Loeng, 1987; Ellertsen *et al.*, 1989; Sundby, 1994; Ottersen *et al.*, 1994; Ottersen and Sundby, 1995; Ottersen and Loeng, 2000; Sundby, 2000; Toresen and ¯stvedt, 2000; Ottersen and Stenseth, 2001; Ciannelli *et al.*, 2007; Dings¿r *et al.*, 2007).

The correlation between good recruitment of cod, herring and haddock and elevated temperature seen from the 1950s to the 1990s does not, however, show up in the 2000s (*c.f.*, Case Study report for Norwegian and Barents Seas), although it still seems to be correct that strong year-classes of these stocks are not produced in cold years. It should be noted that the herring SSB was very low in the 1970s, following stock collapse, so good herring year-classes could not be produced then anyway.

This apparent change has so far not been discussed in any refereed paper. However, we propose three explanations, none of which can alone explain the change:

- The SSB of all stocks has been fairly high in the 2000s, and the climate effect on recruitment is strongest at low SSBs (Brander *et al.*, 2005; Nakken, 2008).
- Inflow and temperature may affect the recruitment in different ways, and this may also differ between species. While the volume flux into the Barents Sea has a strong variation on inter-annual time scales (Ingvaldsen *et al.*, 2004), the inflowing temperature shows long-term trends and has increased by more than a degree since the late 1970s (Skagseth *et al.*, 2008).
- The factors affecting the year-class abundance between the 0-group stage and age 3 may have changed. The mechanism here is not clear, but the revised indices of 0-group abundance calculated by Eriksen *et al.* (2009) indicate that the year-class strength may change considerably between the 0-group stage and age 3. The CS report on the Norwegian and Barents Seas shows that the recruitment pattern is quite different at those two stages, particularly for cod.

<u>System dynamics and regime shifts</u>

The capelin, a small fatty fish, feeds on lipid-rich calanoid copepods (*e.g.*, *Calanus finmarchicus*), and to a lesser extent krill as well as amphipods, with small capelin feeding on the former while the two latter are selected, if available, by larger capelin (Gj¿s¾ter, 1998; Orlova *et al.,* 2002). The capelin acts as the key intermediary between herbivorous zooplankton and the upper trophic levels in the Barents Sea (Prokhorov, 1965; Gj¿s¾ter, 1998; Dolgov, 2002). This short, 'fatty food chain', in which capelin forages on lipid-rich herbivorous zooplankton, is an essential feature maintaining the productivity of cod, and many seabirds and marine mammals in the high latitude ecosystem (Falk-Petersen *et al.,* 1990; Nilssen *et al.*, 1994; Sakshaug *et al.,* 1994; Rose and O'Driscoll, 2002; Gjøsæter *et al.* 2009). As expected for a fish with a short 'r' strategist life-cycle, targeted both by many predators and a fishery, the capelin stock is prone to major fluctuations (Hopkins and Nilssen, 1991; Ushakov and Prozorkevich, 2002).

Barents Sea capelin were heavily fished in the 1970s and the first half of the 1980s when there were few Norwegian spring-spawning herring due to the herring stock's collapse (>95% biomass decline) in the early 1960s from excessive overfishing (Gj¿s¾ter, 1998; Toresen and ¯stvedt, 2000). In the mid-1980s, the capelin stock collapsed and has since varied greatly. Since recovery of the herring stock in the early 1980s, juvenile herring can appear in great abundance in the Barents Sea due to strong year-classes, and are the most important predator on capelin larvae and the primary cause of poor capelin recruitment (Hamre, 1994; Gj¿s¾ter and Bogstad, 1998; Huse and Toresen, 2000; Pedersen *et al.*, 2009). Capelin recruitment failure is most prevalent when the distribution of capelin larvae and strong year-classes of young herring overlap in space and time in the Barents Sea (Gj¿s¾ter and Bogstad, 1998; Pedersen *et al.*, 2009).

Periodic stock collapses (>95% biomass declines) of capelin (1985-1989, 1993-1997, and 2003-2006), caused major impacts both downwards (*e.g.*, increased zooplankton biomass) and upwards (*e.g.*, decreased growth, delayed maturation and increased cannibalism in cod; increased mortality rates and recruitment failures of various seabirds; food limitation, altered migrations and reduced reproductive success of harp seals) in the food-web (Gj¿s¾ter *et al.* 2009).

The distributions of cod and herring in the Barents Sea change substantially over time (seasonal, annual and decadal) depending on their abundance and climate-related forcing. Thus, climate has a strong indirect, delayed effect on capelin dynamics as a result of warmer climate being generally associated with the production of strong year-classes of herring and cod which exert an elevated predation mortality on larval and juvenile capelin, respectively (Toresen and ¯stvedt, 2000; Ottersen and Loeng, 2000; Ottersen and Stenseth, 2001; Hjermann *et al.*, 2004a, b, c). The capelin fishery is managed according to a target 'escapement' strategy, with a HCR allowing (with 95% probability) the spawning stock biomass to be above the proposed B_{lim}, (200 000 t) taking predation by cod into account.

The use of simple correlates as proxies for recruitment does not include an understanding of the processes and it is apparent that a number of ecosystem parameters vary with, for example, temperature. By way of example, in the Barents Sea there is a temperature effect on the distribution of young fish but there is also the influence of population size; both the new year-class and older individuals affecting survival through, for example, cannibalism (Ciannelli *et al.*, 2007). In the case of herring, temperature regimes can affect spawning times and hence survival rates through a mismatch with predation of larvae by saithe (Huseb¿ *et al.*, 2009), but there is also an effect caused by the stock structure, *i.e.*, the proportion of repeat versus recruit spawners. Overall, whilst there is an effect of environmental conditions on recruitment, there is also an effect of bottom-up and top-down control on survival which that is not necessarily coupled to environmental conditions. An obvious example is the substantial impact resulting from predation of strong year-classes of juvenile herring on larval capelin and hence capelin recruitment (c.f., CS report on the Norwegian and Barents Seas, and section 4.4).

North Sea

Preamble

Environmental events affect the status of the North Sea ecosystem, including its fishery and the considerable variation in SSB of demersal stocks, including plaice and cod. However, the combined impacts of fishing and environmental drivers are hard to separate (ICES, 2008b). In 2007, ICES concluded that no environmental signals were identified to be specifically considered in assessment or management (ICES, 2008b). However, recruitment of some commercially important gadoids is at a low level and this has led to speculation that the ecosystem may be changing in an irreversible direction.

One of the most important examples of how environmental drivers can affect stock dynamics is the ‘gadoid outburst’ during the late 1960s up to the early 1980s, which were characterized by a sudden increase in the abundance of large, commercially important gadoid species. During this period cod, haddock, whiting, and saithe all produced a series of strong year-classes. The most likely explanation for the gadoid outburst is climate forcing (Cushing, 1984). Following the outburst there was a decline in stock levels. As the high fishing pressure, which had already reduced the spawning potential of cod, did not decline fast enough in line with the environmentally induced decline in recruitment, the stock collapsed (Caddy and Agnew, 2004). Haddock and saithe have since recovered but the decline of cod has continued largely due to fishing pressure which was so high in the 1990s that the stock was predicted to collapse (Cook *et al.*, 1997). However, the warm climate and low zooplankton abundance, particularly of *C. finmarchicus*, have also been implicated in the decline, and lack of recovery, of cod (Planque and Fredou, 1999; Beaugrand *et al.*, 2003; Drinkwater, 2005; Rindorf and Lewy, 2006).

System dynamics and regime shifts

Current recovery plans generally assume that there has not been a significant underlying change in environmental conditions, and hence that the ‘carrying-capacity’, and the structure of the food-web of the North Sea ecosystem has not changed. It is now widely appreciated that this might not be the case as the North Sea ecosystem has undergone a regime shift in the 1980s, centered on two periods of rapid changes (1982-1985 and 1987-1988). The changes in large-scale hydro-meteorological forcing, affecting also local hydrographic variability, have caused drastic changes in plankton communities, which have gone on to have impacts across the ecosystem. For example, fish recruitment success has decreased in gadoids and initially increased in flatfish recruitment followed by a more variable phase after the second centre period (Beaugrand *et al.*, 2003; Reid *et al.*, 2003).

Year-class strength in Autumn-spawning herring appears to be determined by processes acting during the early larval period (<30 mm SL) when early larvae (10-11 mm SL) drifting across the North Sea during the winter (Nash and Dickey-Collas, 2005). Mechanisms acting during this ‘overwintering’ period also appear responsible for the most recent (2002-2008) poor year-classes (Payne *et al.*, 2009).

Generally, the period after the regime established the new state in 1988 is characterized by warmer temperature, low abundance of northern fish and zooplankton species (Beaugrand *et al.*, 2002), and increasing abundance and diversity of southern plankton (Reid *et al.*, 2003) and fish (Beare *et al.*, 2004a) species. These changes purportedly have had a negative impact on North Sea cod recruitment as *C. finmarchicus* is a major prey for cod larvae due to it being the right size and occurs at the right time of year. Consequently, it has been suggested that the loss of this vital prey species could impact the ability of cod to recover because of anticipated failures in future cod recruitment (Beaugrand *et al.*, 2003). It has been pointed out recently that regime shifts have profound implications and should be incorporated into management strategies: an idea consistent with furthering ecosystem-based management (Rothschild and Shannon, 2004).

'Non-stationarity' of natural ecosystems influences the apparent success/ failure of closed areas in the North Atlantic including the southern North Sea 'Plaice box' (van Keeken *et al.*, 2007). Juvenile North Sea plaice are typically concentrated in shallow inshore waters and move gradually offshore as they become larger. But, Wadden Sea surveys indicate that 1-group plaice is now almost absent from places where it once was highly abundant. This is probably linked not only to changes in the productivity of the region but also the marked warming of the southern North Sea in recent years. The 'Plaice Box' is now much less effective as a management measure compared with 10-15 years ago.

Sandeels are an essential component of the diet of most piscivorous fish species (Daan, 1989; Hislop *et al.*, 1997) as well as birds (Wanless *et al.*, 1998) and marine mammals (Santos *et al.*, 2004). The spawning biomass of sandeel has declined since a 1998 peak and recruitment has been low since 2002. Their reduced abundance is likely to have severe repercussions for the whole North Sea ecosystem (ICES, 2008b).

Baltic Sea

<u>Preamble</u>

Climate change has already manifested itself on the Baltic Sea environment and is predicted to continue during this century (HELCOM, 2007; MacKenzie and Schiedek, 2007). The Baltic Sea's temperature rose about six times faster than the global ocean average over the past 25 years, exhibiting one of the highest increase rates of any large marine ecosystem (EEA, 2008; Belkin, 2009). Thus, the Baltic Sea ecosystem and fisheries management should be viewed in the context of a rapidly changing environment with mean annual sea surface temperature predicted to rise by ca. 2°C to 4°C by the end of the 21st century, and anticipated increased freshwater input and reduced levels of marine inflows leading to reduced salinity, stronger stratification and reduced oxygenation of the deeper waters (HELCOM, 2007). Marine tolerant species will be relatively disadvantaged and their distributions will partially contract as the marine domain of the Baltic Sea shrinks (MacKenzie *et al.*, 2007).

Cod and sprat spawn in the deep Baltic basins, with overlapping spawning times, but climate affects the recruitment of cod and sprat differently, with a high North Atlantic Oscillation (NAO) index being negatively associated with recruitment of the former and positively associated with recruitment of the latter (Köster *et al.*, 2003a). The physical conditions in the Baltic Sea respond to climate change through (i) direct air-sea interaction, ii) the magnitude of freshwater run-off, and iii) interactions with the ocean at the open boundary (Stigebrandt and Gustafsson, 2003). Surface temperatures are determined by the dominance of either westerly winds with mild ‘Atlantic air, (*i.e.*, high NAO) or easterly winds with cold ‘continental air’ resulting in low temperatures and extensive ice cover (*i.e.,* low NAO). River run-off affects salinity by directly freshening surface waters. Renewal of the bottom water of the deep Baltic basins by inflows of saline and oxygenated water from the North Sea, via the Kattegat and Belt Sea, is indirectly prevented because increased zonal atmospheric circulation increases the freshwater input (MatthŠus and Schinke, 1999). The period of high NAO index since the late 1980s resulted in an increase in average water temperatures (Fonselius and Valderrama, 2003). The dominance of ‘westerly weather’ increased further the amount of run-off, thereby drastically decreasing salinities (HŠnninen *et al.*, 2000).

Important processes affecting recruitment of cod and sprat in the Baltic are the: i) spatial distribution of egg production is dependent on ambient hydrographic conditions (cod: MacKenzie *et al.*, 2000; sprat: Parmanne *et al.*, 1994); ii) quantity of egg production in relation to food availability (cod: Kraus *et al.*, 2002; sprat: Alekseeva *et al.*, 1997); iii) egg developmental success in relation to oxygen concentration for cod (Nissling *et al.*, 1994; Wieland *et al.*, 1994) and temperature for sprat (Nissling, 2004) at depths of incubation; iv) egg predation by clupeids dependent on predator-prey overlap (cod: Kšster and Mšllmann, 2000a; sprat: Kšster and Mšllmann, 2000b); v) larval development in relation to hydrographic conditions (cod: Nissling *et al.*, 1994, sprat: Baumann *et al.*, 2006) and food availability (cod: Hinrichsen *et al.*, 2002; sprat: Voss *et al.*, 2009 this vol.); and vi) predation on juveniles (cod: Sparholt, 1994; sprat: Kšster *et al.*, 2003a). All the above processes are driven by hydrographic and climatic conditions negatively affecting the cod population (Kšster et. al., 2003a), while the sprat stock benefited from them (Kšster *et al.*, 2003b; Voss *et al.* 2009) despite a developing industrial fishery targeted at the latter.

For example, successful spawning, fertilization and egg development in cod only occurs in deep-water layers with oxygen concentrations >2ml l^{-1} and a salinity of >11 psu, with the volume of water where this is fulfilled known as the cod ‘reproductive volume’ (RV) (MacKenzie *et al.*, 2000). Processes affecting the RV are: i) the magnitude of inflows of saline oxygenated water from the western Baltic (MacKenzie *et al.*, 2000); ii) temperature regimes in the western Baltic during winter, which affect the oxygen solubility prior to advection (Hinrichsen *et al.*, 2002b); iii) river run-off (Hinrichsen *et al.*, 2002b); and iv) oxygen consumption by biological processes (Hansson and Rudstam, 1990). Climate induced reduction in the inflow of North Sea water since the 1980s has substantially shrunk the available cod reproductive volume thus resulting in high cod egg mortality, especially in the more eastern Gdansk Deep and Gotland Basin compared with the Bornholm Deep (MacKenzie *et al.*, 2000).

The predation intensity by sprat on cod eggs increases in stagnation periods, contributing to the low reproductive success of cod in the last three decades. Sprat eggs float at a shallower depth than cod eggs, due to a different specific gravity, and their survival is less affected by poor oxygen conditions then by temperature. Weak year-classes of sprat tend to arise after cold winters, which generate low temperatures (<4¡C) in the intermediate water layer during spawning in spring. Accordingly, the trend for warmer winters, and associated favorable hydrographic conditions for egg survival, contributes to the high reproductive success of sprat (MacKenzie *et al.*, 2008).

Zooplankton availability as food may also affect both cod and clupeid larval survival. In the Baltic Proper, comparatively high cod and herring SSB and recruitment is associated with increased abundance and biomass of the copepod *Pseudocalanus acuspes* during cooler, higher salinity/oxygen conditions connected with good inflow, while sprat recruitment is favoured by increased abundances of the copepods *Acartia* spp. and *Temora longicornis* and warm spring temperatures connected with a strong NAO index (Mšllmann *et al.*, 2000, 2003; Alheit *et al.*, 2005; Mšllmann *et al.*, 2005).

Also fluctuations in herring and sprat growth are influenced by climate (Mšllmann *et al.*, 2005), with a substantial reduction in herring weight at age resulting in a continuous decline of the total biomass since the early 1980s (Kšster *et al.*, 2003a). Growth of cod has been described as density dependent and affected largely by the relative availability of clupeid prey (Baranova and Uzars, 1986; Baranova, 1992). Thus, concurrent with the decline in stock size an increase in weight-at-age is observed (Kšster *et al.*, 2005b). The increase continued until the beginning of the 1990s, followed by a decline in age-specific weight, potentially related to the cod spawning time changing from spring to summer months (ICES, 2006).

<u>System dynamics and regime shifts</u>

Reduced inflows from the North Sea and warm temperatures combined with heavy fishing pressure on cod during the past three decades has caused a shift in the fish community from cod to clupeids (herring and sprat) by first weakening cod recruitment (Jarre-Teichmann *et al.*, 2000; Kšster *et al.*, 2005a), thereby releasing sprat from predation pressure by cod (Kšster *et al.*, 2003a) and subsequently generating favourable recruitment conditions for sprat, thereby causing increased clupeid predation on cod early life stages (Kšster and Mšllmann, 2000a) and essential prey for cod larvae (Mšllmann *et al.*, 2003). Such changes are major features of a comprehensive regime shift experienced by the Baltic Proper ecosystem, moving from a cod to a sprat dominated system (Mšllmann *et al.*, 2008, 2009).

<u>Prognosis</u>

The future for the Eastern Baltic cod stock appears bleak based on the above climatic changes and predictions regarding the environmental conditions that are essential for egg development and production of good cod year-classes (MacKenzie *et al.*, 2007). Thus, it is prudent to balance the fishing mortality exerted on cod, sprat and herring to the carrying capacity of the environment, as well as analyzing alternative biological reference points, fishing strategies and management plans with respect to rebuilding the cod while not increasing the risks on the sprat and herring stocks.

Bay of Biscay and Iberian Peninsula

<u>Preamble</u>

Bay of Biscay

The Bay of Biscay lies in the inter-gyre region that separates the major oceanic gyres of the North Atlantic: the sub-polar, extending approximately between 45¡- 65¡N and driven by the Icelandic low pressure system; and the sub-tropical, between 10¡- 40¡N and forced by the anticyclonic atmospheric circulation around the Azores high pressure cell (Pollard *et al.*,1996). The properties and origin of Eastern North Atlantic Central Water (ENAC, 100 to 600m) and Mediterranean Water (MW, 600 to 1500m) interact with other physical features affecting the dynamics in the area (Koutsikopoulus and Le Cann, 1996).

The general circulation is dominated by the mesoscale activity (Friocourt *et al.*, 2008a); the oceanic domain of the Bay of Biscay presents a weak anticyclonic circulation (1-2 cm s^{-1}) at the levels of ENACW and MW (Figure 4.2). Over the continental slope a stronger poleward current is observed, the Iberian Poleward Current (IPC), named also ‘Navidad’ (Christmas) current (Pingree and Le Cann, 1990, 1992) or Portugal Coastal Counter Current (PCCC) (ç lvarez-Salgado *et al.*, 2003). Recent observational and modeling studies have confirmed previous interpretations of the IPC, but stressed its permanent, seasonally varying character, the role of large-scale meridional thermal gradients as primary driving mechanisms and of regional wind pattern as modulator of its intensity, position relative to shelf break and depth, and the strong eddy shedding activity (‘swoddies’ –slope water oceanic eddies) associated with the current (Peliz *et al.*, 2005; Gil, 2008). Observations have accumulated too on the IPC’s possible effect on the distribution of various ecosystem components, from plankton (Fern‡ndez *et al.*, 1991; Calvo-D’az *et al.*, 2004; Bode *et al.*, 2006; Cabal *et al.*, 2008) to fish larvae (Santos *et al.*, 2004), and processes such as primary production (ç lvarez-Salgado *et al.*, 2003), bacterial production (Mor‡n *et al.*, 2007) or fish recruitment (S‡nchez and Gil, 2000).

Over the shelf, residual currents are mainly governed by the wind, tides and water density. Over the Armorican shelf the residual current is weak and northwestward oriented (Pingree and Le Cann, 1989), while on the Aquitaine shelf it shows a strong seasonality, being towards the northwest from autumn to winter (Lazure *et al.*, 2008) and to the southeast the rest of the year (Le Cann, 1990). The situation is more variable in the southeastern corner of the Bay of Biscay (Cape Breton) and in the Cantabrian shelf due to the interaction between the complex topography (*i.e.*, coastline orientation, steeper shelf) and a more variable wind pattern (OSPAR, 2000). Wind-driven coastal upwelling is relatively frequent in summer along the Spanish and French shelves driven by easterly (Botas *et al.*, 1990; Lav’n *et al.*, 1998) and northerly winds (Jegou and Lazure, 1995) respectively. In the vicinity of estuaries, mainly Loire and Gironde, and river mouths, such those from the Adour and the small Cantabrian rivers, the presence of plumes of variable intensity, extent and persistence induce significant buoyancy currents which promote substantial mesoscale variability (Lazure and Jegou, 1998). In addition to eddies and river plumes, upwelling events and lower-salinity lenses also occur over the shelf (Puillat *et al.*, 2006).

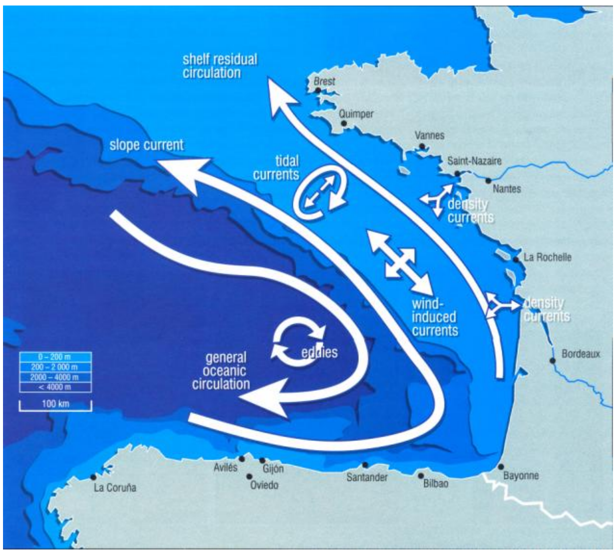


Figure 4.2. Scheme of the main oceanographic processes in the Bay of Biscay (OSPAR, 2000, from Koutsikopoulus and Le Cann, 1996)

All these hydrodynamic processes have a strongly varying character over the seasonal and medium-term. In fact, there is not a single major driver of the system in the Bay of Biscay, but rather a complex interplay between several drivers influencing the distribution and variability of the ecosystem components among them fish, from mesoscale to regional scale.

Within the fish community, European hake (*Merluccius merluccius)*, anchovy (*Engraulis encrasicolus*) and tunas (*Thunnus alalunga* and *T. Thynnus*) currently are the most important commercial fish species in the Bay of Biscay. Whilst tunas are large-scale migratory species, European hake and anchovy can be considered as the main fisheries, restricted to the Bay of Biscay ecosystem in terms of exploitation by human communities.

Iberian Peninsula

Three different areas are distinguishable in the Iberian Peninsula: (i) The Cantabrian Sea, with a diminishing Atlantic influence towards the interior of the Bay of Biscay, (ii) Galician and Portuguese coasts with high Atlantic influence driven by the Gulf current and important upwelling phenomena in the northern part; and (iii) The Gulf of Cadiz area which is a border between the Atlantic and the Mediterranean and also between the Iberian Peninsula and the African Coast. Within these zones the topographic diversity and the wide range of substrates result in many different types of coastal habitat.

The main pelagic species are sardine, anchovy, mackerel, horse mackerel and blue whiting. To the south, chub mackerel (*Scomber japonicus*), Mediterranean horse mackerel (*Trachurus. mediterraneus*) and blue jack mackerel (*T. picturatus*) are common too. Seasonally, albacore (*Thunnus alalunga*) occur along the shelf break. The main commercial demersal fish species caught by the trawl fleets are hake, megrims and anglerfishes.

The circulation of the west coast of the Iberian Peninsula is characterized by a complex current system subject to strong seasonality and mesoscale variability, showing reversing patterns between summer and winter in the upper layers of the slope and outer shelf. Another important feature of the upper layer is the Western Iberia Buoyant Plume (WIBP) which is a low salinity surface-water body fed by winter-intensified runoff from several rivers from the northwest coast of Portugal and fjord-like lagoons (Galician Rias). The intermediate layers are mainly occupied by a poleward flow of MW, which tends to contour the southwestern slope of Iberia, generating mesoscale features called Meddies, which can transport salty and warm MW over great distances in the North Atlantic (ICES, 2004c).

Along the Portuguese and Galician coast, during the spring and the summer, the surface currents generally flow towards the south following the coastline. These currents, together with the persistent equator-wards winds, produce an important upwelling, mainly on the Portuguese coast from the NazarŽ Canyon to the northwest corner of the Iberian Peninsula, where the coastline is more regular and there are no important capes and northern wind stress is more constant (Cunha, 2001). The upwelling phenomena provides nutrients and affects the thermal stratification leading to important biological production and substantial concentrations of zooplankton feeders at the shelf break, including snipefish, blue whiting (specially younger stages) and boarfish. In the Cantabrian Sea, the surface currents generally flow eastwards during winter - spring and change westwards in the summer. These changes in current direction produce seasonal coastal upwellings and high biological production, with variable importance depending on the strength of the currents.

European hake

European hake is distributed widely throughout the Northeast Atlantic, from Norway in the north to the Gulf of Guinea in the south, and in the Mediterranean and Black Seas. However hake is more abundant from the British Isles to the south of Spain (Casey and Pereiro, 1995). The population is divided by ICES into two stocks: the northern (ICES Subareas II, III, IV, VI, VII and Div. VIIIa,b,d) and the southern stock (ICES Div. VIIIc and IXa). The boundary between these stocks, Cap Breton Canyon, was defined mainly based on management considerations.

The hake is a demersal and benthopelagic species, found mainly between 70-370 m depth. However, it occurs also from inshore waters (30 m), to depths of 1000 m. European hake lives close to the bottom during daytime but during the night, moves up and down in the water column (Cohen *et al.*, 1990). The juvenile and small European hake live usually on muddy beds on the continental shelf, whereas large adults are found on the shelf/slope, where the bottom is rough and is associated with canyons and cliffs. Various studies have indicated that this species spawns several times within the reproductive season, *i.e.*, it is a batch-spawner, or a fractional spawner, species (Andreu, 1955; PŽrez and Pereiro, 1985; Sarano, 1986). The transportation of early life stages, from spawning grounds to coastward juvenile recruitment areas, can be foreseen in relation to the general water mass circulation, as postulated by Koutsikopoulos and Le Cann (1996). In fact, ç lvarez *et al.* (2004) inferred a north and northeast dispersion of eggs and larvae due to the main pattern of oceanographic processes such as wind induced currents and geostrophic flow.

Hake recruitment indices have been related to environmental factors. High recruitment occurs during intermediate oceanographic scenarios and decreasing recruitment is observed in extreme situations. In Galicia and the Cantabrian Sea, generally moderate environmental factors—such as weak Poleward Currents, moderate upwelling and good mesoscale activity close to the shelf—lead to strong recruitment. Hake recruitment leads to well-defined patches of juveniles in localized areas of the continental shelf. These concentrations vary in density according to the strength of the year-class, although they remain generally stable in size and spatial location. In Portuguese continental waters, the abundance of small individuals is higher between autumn and early spring. In the southwest, the main concentrations occur at 200-300 m depth, while in the south they are mainly distributed in coastal waters. In northern Portugal, recruits are more abundant between 100-200 m depth. These different depth-area associations may be related with the feeding habits of the recruits, since the zooplankton biomass is relatively higher there.

Anchovy

The main pelagic species in the Bay of Biscay are sardine and anchovy (small pelagics) and mackerel and horse mackerel (middle-size pelagics). These species form the basis of important fisheries that represent an essential source of income for local economies.

The distribution of anchovy in Atlantic European waters is nowadays mainly concentrated in two well-defined areas, the Bay of Biscay and the Gulf of C‡diz (Uriarte *et al.*, 1996; ICES, 2008a). Some residual coastal populations exist also along the Iberian coast, English Channel, Celtic Sea and North Sea (Beare *et al.*, 2004b; ICES, 2007b).

Anchovy in the Bay of Biscay may grow to >20 cm and their life span rarely exceeds three years. It forms large schools located between 5 - 15 meters above the bottom during the day

(MassŽ, 1996), although changes in the schooling pattern of anchovy have been described since about the year 2000 (ICES, 2008a). It is a serial spawner (several spawns per year) and reproduces in spring. The spawning area is located southward of 47¡ N and eastward of 5¡ W. Most spawning takes place over the continental shelf in areas influenced by the river plumes of the Gironde, Adour and Cantabrian rivers (Motos *et al.*, 1996). Recent studies have suggested that Bay of Biscay anchovy may recruit partially offshore (Irigoien *et al.*, 2007). But it is not clear to what extent individuals recruited off the shelf contribute to the total population (Irigoien *et al.*, 2008), partly because modeling studies have suggested that off-shelf waters do not fulfill the conditions for larvae survival (Allain *et al.*, 2007a,b). As spring and summer progresses, anchovy migrate from the interior of the Bay of Biscay towards the north along the French coast and towards the east along the Cantabrian Sea, where it spends the autumn. In winter it migrates in the opposite direction towards the east and southeast of the Bay of Biscay (Prouzet *et al.*, 1994). It has a high and very variable natural mortality. Mesoscale processes in relation to the vertical structure of the water column (stratification, upwelling and river plume extent) appear to have a great influence on the survival of larvae (Allain *et al.*, 2001). However they may only act as limiting factors (Planque and Buffaz, 2008), and the mechanisms through which these physical processes impact biological oceanography and recruitment are still to be better understood.

The anchovy stock, like all short-lived species, is very dependent on recruitment, and thus recruitment failures lead to low biomass levels observed in recent years. A reduction of the distribution of anchovy in the Bay of Biscay has been observed both in the acoustic and egg production survey (ICES, 2007b) and changes in the school composition have also been described (MassŽ and Gerlotto, 2003). In the past century, the anchovy population has almost disappeared from the Spanish coast and spawning grounds have been lost (ICES, 2004a). Based on circulation models, larval drift reveals that the larvae born in the French spawning grounds move towards Spanish coasts but fail to re-colonize there (Vaz and Petitgas, 2002). Although research surveys for anchovy juveniles show that early juveniles are found alone, separated from the adults, in the oceanic area and along Spanish coasts (Uriarte *et al.*, 2001; ICES, 2008a), juveniles are afterwards found together with the adults along the French coasts (Petitgas *et al.*, 2004, ICES, 2008a).

According to previous studies (Motos *et al.*, 1996; Uriarte *et al.*, 1996), anchovy populations appear to have density-dependent strategies of spawning area selection. Different hypotheses have been suggested to explain inter-annual and long-term variations in anchovy abundance, which are often attributed to important variability in recruitment levels, and are ultimately linked to variations in ocean processes. Changes in global and local environmental indexes have also been described for the Bay of Biscay, such as the North Atlantic Oscillation (NAO) index and Polar Eurasia and East Atlantic patterns (ICES, 2007c; Borja *et al.*, 2008) and upwelling and stratification index (Borja *et al.*, 1998; Alain *et al.*, 2001; Huret and Petitgas, 2007).

4.3.6 Conclusions from UNCOVER WPs 1-3 and Case Studies

- Climatic/environmental drivers influence the carrying capacity for fish stocks via changes in vital rates, production at the base of the food-web and transport processes. Our ability to predict the dynamics of stocks in relation to changes in climatic forcing is limited due to the complex relationship between abiotic processes and food-web interactions. In order to assess the trajectory of a stock, indicators of key stock and ecosystem status need to be identified based on historic relationships linked to stock dynamics and potential physiological constraints on stock viability. The MSFD outlines a number of such indicators, which can, if elaborated appropriately and employed, contribute to an understanding of the potential future dynamics of exploited fish stocks. The dynamics of these indicators have the potential to provide an early warning system helping to ensure achieving the MSY of the stocks.

- Over their ontogeny, exploited species utilize specific habitats defined by abiotic and biotic characteristics for spawning, larval and juvenile nursery areas. As a result, multispecies spatially-specific management strategies are necessary in order to avoid bycatch (*e.g.*, juvenile stages of commercially important fish) or to preserve key components of the stock (*e.g.*, spawning biomass) as a buffer to detrimental environmental conditions. Identification of these key habitats and processes influencing the recruitment, stock dynamics and recovery is critical for the implementation of environmentally sensitive management strategies.
- In recognition of the first bullet-point above, population models should be developed and applied that include biological variation and environmental drivers, based on existing statistical relationships and status indicators, recognizing that these relationships provide a short-term indicator of potential stock dynamics.
- Given the dynamic nature of ecosystems and fish stocks in a changing environment, HCRs are required where a precautionary fishing level is appropriately adjusted to ensure that yield improves and catch variability is low. When the environmental carrying capacity is poor for a stock, the use of environmentally related HCRs will buttress our ability to ensure the sustainable management of stocks. Such environmentally related HCRs provide improved information for stock conservation compared with simple stock-only based HCRs having no implicit consideration of the environment.
- Socio-economic and behavioural aspects of fisheries need to be monitored in the face of climate change, as these will have strong management and assessment implications for exploited stocks.
- The need to address the combination of climate change and fishing as forcing factors in fisheries reinforces the necessity for adopting a broad-based precautionary approach to management decision-making, and for modifying management systems so as to be more robust and adaptive.

4.4 Multispecies interactions and trophic controls

4.4.1 Preamble

Estimating the natural mortality (M) affecting the abundance of a fish stock is one of the most difficult and critical elements of a stock assessment. Multispecies predator-prey interactions and trophic controls are the primary factors determining the effective level of M on a fish stock (Stefansson, 2003), and so they may appreciably affect the recovery of depleted, target fish stocks by:

a) Predation acting on survival/mortality of all life stages, *i.e.*, egg, larva, juvenile and adult stages;

b) Food availability in terms of quantity and quality, including competition;

c) The dynamics of predator – prey overlap in space and time, regulating the above with respect to feeding success, survival/mortality rates, growth rates, body condition, maturation and reproductive output.

Climate and exploitation by fisheries are factors that tend to substantially influence the structure of populations, and the state and functioning of marine ecosystems (Cushing, 1982; Hall, 1999; Jennings and Brander, 2010). Thus, it follows that both these factors, singly or in combination, can magnify or diminish the force of multispecies predator-prey interactions and trophic controls that are important for fish population dynamics (Pitcher and Hart, 1983; Bakun, 1996; Planque *et al.*, 2010), and hence for the potential recovery of depleted stocks. This highlights the complexity of the interconnected relationships and thereby the potential for 'scientific' uncertainty, especially under conditions of rapid and/or unforeseen change and variability.

The dominant predator-prey interactions and trophic controls of relevance to fish stocks are generally inter-specific (*i.e.,* between different species), but intra-specific (*i.e.,* between the same species) ones may also be pertinent. The latter are mainly due to cannibalism and competition for food, particularly when food availability is a limiting factor.

4.4.2 General outcomes from UNCOVER

In the UNCOVER project, primarily through WP3, there has been clear evidence that multispecies interactions and trophic controls have a strong influence on stock recovery potential, and that their magnitudes of impact often depend on the prevailing environmental conditions. Thus, knowledge of multispecies interactions and trophic controls, particularly when incorporated into multispecies and ecosystem models, enable '*What if?*' situations to be explored, and predictions made, concerning fish stock recovery trajectories.

When trophic conditions, including predator-prey interactions, are beneficial for the targeted stock, the speed and magnitude of stock recovery will be more effective compared with unfavourable conditions. These trophic aspects are influenced by climate variability/change, for example, regulating the strength of recruitment and consequent abundance of key species at various tropic levels in the ecosystem, and by modifying environmental gradients and ocean currents which affect the productivity and distribution of predator and prey organisms. Additionally, the level of fishing mortality exerted on fish stocks has both direct and indirect effects on multispecies interactions and trophic controls in the ecosystem. Our knowledge of multispecies interactions affecting commercially important fish stocks has traditionally been better advanced concerning the middle and upper trophic levels, affecting juvenile and adult fish relative to lower trophic levels affecting egg and larval stages.

Research in UNCOVER based on previous research projects (*e.g.*, the EU projects LIFECO, STORE, CORE, STEREO, dst2, and BECAUSE) has demonstrated that, in most European marine ecosystems, predation is a key biological process determining the population dynamics of commercially important fish species. Predation is a key process determining the survival rates of pre-recruits and hence determines recruitment and stock recovery. Field sampling programs as well as analytical investigations have shown that the predominant fraction of fish prey observed in the stomachs of predatory fish generally consists of early and juvenile life stages. UNCOVER has shown that the predation mortality of pre-recruiting fish is determined by the spatio-temporal dynamics of predator - prey overlap in the 3D aquatic environment and the diet selection behaviour of the predators. Both processes depend on the hydrographic conditions as well as the sizes and structures of predator and prey stocks, as also highlighted previously by other EU projects (*c.f.*, LIFECO, STORE, CORE).

In UNCOVER, existing multispecies models have been more thoroughly developed by implementing validated and enhanced process models, as well as by taking into account additional relevant information on stock biology and drivers of recruitment dynamics (from WP1 and 2). Deterministic and stochastic multispecies models of different complexity (4M, SMS, ECOSIM, GADGET, STOCOBAR) have been applied to reconstruct the historical stock dynamics encompassing also periods of regime shifts. Thus, the ability of models to reconstruct the timing and rate of stock changes has been tested. Multispecies models with proven hindcast capabilities have been used to project future stock recovery potentials. Alternative, yet similarly plausible, environmental and anthropogenic scenarios have been tested to provide a suite of alternative recovery paths. A synthesis of recovery paths has, in turn, provided uncertainty levels. The multispecies models have delivered input into data for fisheries management evaluation tools (WP4), but produced also self-standing predictions on stock recovery paths.

UNCOVER has also drawn attention to the system-wide structuring force of small-scale predation hot spots, and further points to the importance of a more realistic implementation of local high-intensity predation events in food-web models (*e.g.*, Temming *et al.*, 2007). For example, concentrations of piscivorous fish on prey aggregations can result in immense predation impacts: In the North Sea, an aggregation of > 50 million juvenile cod was entirely wiped out in five days by predatory whiting, concentrating on these juveniles in an area of about 18 km^2. The consumption of only 32 hot spots of similar magnitude adds up to the average size of an incoming North Sea cod year-class. These findings support the hypothesis of predation as the major mortality source in young-of-the-year demersal fish species.

UNCOVER has shown, using size- and trait-based single species and community models, that the recovery plan of a target fish species/stock has direct effects on the recovered species/stock, as well as indirect effects on the predators consuming the recovered species/stock and the prey species which the recovered species itself consumes (Andersen and Rice, in submission). The indirect effects of a recovery plan are expected to be substantially smaller than the increase in the recovered species, *i.e.*, the effect on neighbouring trophic levels, immediately above and below the recovered species, is expected to be much smaller than the increase in the recovered species. The reduction in abundance of smaller asymptotic size-classes is due to increased predation pressure from the adults of the target species. The asymptotic size-classes which are larger than the target species are also affected by the increased predation pressure while they are in their juvenile stages. Furthermore, when the juveniles are in the same size range as the adults of the target species, they experience increased competition with the adults of the target species, which lowers their growth rate somewhat. Taken together the increased predation pressure on small juveniles and increased competition for food of the larger juveniles, lead to an even larger reduction of the *SSB* of the large asymptotic size-classes. Fish species which are much larger than the recovered species are likely to benefit from the increased food availability provided by the recovered species. Based on these considerations, recovery plans that reduce fishing effort overall will have more predictable community effects than recovery plans that only redirect fishing effort to increase fishing mortality (F) on other species.

The UNCOVER project, with respect to multispecies interactions and trophic controls relevant to the targeted stocks for recovery in the four Case Study areas, has particularly highlighted:

1) *Direct predatory effects on the recovery species*:

    a) Other species prey on early life stages and juveniles of the targeted recovery species, thereby either leading to depletion of the targeted stock or to reducing the potential for recovery of the targeted stock. Some examples: In the Barents Sea, juvenile herring prey on capelin (targeted stock) larvae and decimate recruitment; In the North Sea, adult mackerel and grey gurnard are able to exert substantial predation mortality on cod (targeted stock) juveniles; In the Baltic Sea, cod is the primary predator on sprat and herring (targeted stocks) with predation effects being particularly marked when the cod stock is large and the clupeid stocks are low.

    b) Cannibalism, as a self-directed predation mechanism. This is particularly notable for cod in the Barents Sea, North Sea, and Baltic Sea, and for hake in the Bay of Biscay. Also egg cannibalism occurs in sprat in the Baltic Sea.

2) *Indirect predatory effects on the recovery species*:

    a) Predators compete with the targeted recovery species for common prey. Some examples: In the Barents Sea, juvenile herring prey on capelin larvae, thereby depleting the abundance of older capelin as the preferred prey for larger cod (targeted stock); In the North Sea, predation by herring and mackerel on pelagic sandeels may adversely affect the recruitment of the latter which represent an important prey for cod (targeted species); In the Baltic Sea, sprat prey on the copepod *Pseudocalanus* which is an important prey for larval cod (targeted species).

    b) Predators affect a prey species which is a predator on the recovery species, and thereby partly diminishes predation exerted on the recovery species. Some examples: In the North Sea, gurnard prey on whiting which preys on cod (target species); In the Baltic Sea, adult cod prey on sprat which preys on cod eggs (target species).

    c) Depletion of prey species of the targeted recovery species, so increasing the predation (inter-specific and/or intra-specific) on the latter. Some examples: In the Barents Sea, a low capelin biomass leads to reduced food availability for cod (targeted species) which thus increases the prevalence of cannibalism in cod (target species); In the North Sea, a low biomass of forage fish (*e.g.,* sandeels, herring) may potentially lead to a switch in predation pressure by fish and seabirds away from these more normal forage species to pursue juvenile cod; In the Bay of Biscay, low levels of forage species (*e.g.,* anchovy, sardine) may increase the prevalence of cannibalism in hake.

Especially in 2 a) and 2 c) above, lack of prey for the targeted recovery species may additionally cause reduction in individual body condition and growth rates which, if sufficiently severe, may even lead to lowered age-at-maturity, and potentially decreased recruitment. This has been especially evident for NEA cod during stock collapses of capelin, the cod's preferred prey, in the Barents Sea.

It is pertinent to note with respect to cod recovery, as pointed out by Lilly *et al.* (2008) that the arcto-boreal Barents Sea has historically been dominated by one piscivorous fish species (cod) and one forage species (capelin) (Livingston and Tjelmeland, 2000), while in contrast ecosystems toward the southern limit of the cod's distribution, such as the boreo-temperate North Sea, have a broader array of piscivores and potential prey. The Baltic Sea marine fish fauna is species-poor compared to the adjacent North Sea—mainly due to its low salinity— and has historically been dominated by cod and two species of clupeids (sprat and herring) serving as forage fish. The Bay of Biscay, covering subtropical/boreal transition zones (OSPAR, 2000), has the gadoid hake as one of several piscivorous top predators (*e.g.,* albacore, blue fin tuna and swordfish) in a species-rich system of potential forage species and competitors. Accordingly, we emphasize that key trophic influences are likely to be more easily discerned, and exert more evident controls, in ecosystems such as the Barents Sea and the Baltic Sea that have relatively few key multispecies predation interactions. Thus, in such regions, the recovery pathways based on food-web dynamics for the targeted species are often easier to model and predict with respect to multispecies predatory interactions and trophic controls.

In the following, we detail the dynamics of some key inter-specific and intra-specific multispecies predatory interactions and trophic controls of relevance to recovery of the target fish stocks in the four UNCOVER Case Study areas.

Norwegian Sea and Barents Sea

Structural changes in pelagic (plankton, nekton) communities of the Barents Sea and the interactions of the main commercial fish species caused different states of the Barents Sea ecosystem in terms of structure and functioning. From time to time, the fishery had a significant contribution to the trophodynamics, on the background of climatic variations, with catastrophic consequences. It is exemplified by the disappearance of the Atlanto-Scandian herring, falling out of the ecosystem and cod diet for a long period (late 1960s-early 1980s).

In UNCOVER, the STOCOBAR model was used for evaluation of the capelin impact on cod stock dynamics in the Barents Sea. The cod stock dynamic in the model is described through representation of the main biological processes in the cod population such as: growth, feeding, condition, maturation recruitment, cannibalism, fishing mortality and survival. The model outputs demonstrated that low capelin stock biomass triggers mechanisms, which lead to a decline in the cod stock. The cumulative effect of capelin acts through the capelin-related rates of growth, maturation and survival of fish. The rate of cod stock recovery from low stock sizes is largely dependent on the capelin stock size.

In UNCOVER, furthermore, an age-length structured multispecies GADGET model has been developed for the Barents Sea incorporating minke whales, cod, herring, and capelin. The model allowed forecast runs that capture realistic stock fluctuations, and do not produce a steady state stock. A multispecies operating model has been set up, with GADGET acting as the operating model and FLR running realistic assessments. Modeled annual fishing quotas are based on the assessment and the currently agreed management rules. This cycle allows for errors on the data used for assessment and on the implementation of the management advice, producing a tool that can be used for assessing a wide variety of sources of uncertainties. The link to FLR allows for errors on the data used for assessment and on the implementation of the management advice for all stocks.

The results presented suggest that the currently agreed management rules function in keeping the stocks above biological limit points. Different scenarios have also been presented, illustrating the utility of the tool that can analyze the full range of sources of uncertainty in the fisheries system. The examples presented here indicate the importance of interactions within stocks, between stocks, and between the fish stocks and the fisheries, each with important associated uncertainties. In attempting to understand the whole system it is important that all of these be considered. The GADGET-FLR model has the utility to investigate the impact of different uncertainties and forcing factors in the Barents Sea fisheries, taking into account multispecies interactions, facilitating multispecies evaluations of the management rules and their robustness to different environmental conditions.

North Sea

Studies in UNCOVER revealed that trophic control of stock recovery can be manifested through a variety of direct and indirect processes (see above). Therefore, (fisheries) multispecies food-web models are a necessary component of any effort which aims to assess and predict the effects of naturally changing vectors in marine ecosystems under anthropogenic (*i.e.*, fishing) pressure. The main insights from these modeling attempts were:

1) Spatial predator prey overlap is the key process driving trophic interactions in the upper level of the North Sea food-web. It depends on the hydrographic conditions as well as the sizes and structures of the stocks;
2) Predation on pre-recruiting fish has a high influence on recruitment success and hence recovery potential. Small scale hot spots of predation on juvenile fish can reach magnitudes of ecosystem-, and population-wide impacts;
3) A confirmation of the reversal of the single species conclusion on the effects of effort reductions and mesh size increases: reducing effort on predators leads to lower yields in many fisheries than projected if species interactions are taken into account. This also implies that growth overfishing is far less important than previously thought;
4) A reduction of F remains the key management task, but may not be sufficient if the 'multispecies environment' does not provide favourable conditions;
5) A recovery of a predator stock has demonstrated consequences on the trajectories of other stocks interacting with this predator, either directly via predation or indirectly (competition).

The currently available data are poor for several key species and processes, which severely hampers the reduction of uncertainties in multispecies model predictions. Specifically, our knowledge on 0-group predation is extremely limited, leading to uncertain results. Another clear limitation is that the current model set-up ignores fish larvae due to a lack of sufficient data. This means that an important life stage is not modeled and has never been analyzed on a large scale, making it also extremely difficult to judge on the impact of predation on reduced herring larval survival in most recent years.

The scientific evaluation of the North Sea cod management plan was an important part in the process of its creation (ICES, 2008e). However, the evaluations were carried out with pure single species approaches. According to UNCOVER results, single species forecasts overestimate the recovery potential of North Sea cod considerably, as density dependent processes are ignored. In addition, changes in recruitment success and changes in large-scale spatial predator- prey overlap can play an important role in determining the recovery potential of North Sea cod. The year-to-year variation in spatial predator- prey overlap was found to be high especially for the interactions between cod and its main predators. The spatial overlap was found to increase with increasing temperature indicating that food-web processes will potentially reduce recovery potential, especially in warm periods. However, more information on processes responsible for distribution changes of predator and prey populations are needed to enable more accurate forecasts of the population dynamics of predator and prey populations.

The potential of the existence of a predator pit for North Sea cod demonstrated the need to take trophic multispecies interactions into account when evaluating stock recovery strategies. A growing cod population first has to outgrow the abundance range with rapidly increasing predation mortalities before it is able to expand its stock size towards such high abundance values, where SSB can be seen as having a positive effect on year-class strength.

For the first time, a comparison between SMS and the ecosystem model EwE was carried out in UNCOVER. Estimated SSB trajectories from the 2008 North Sea SMS version were compared to SSB trajectories estimated by the EwE model for the North Sea, parameterized. The EwE model was tuned to results of 4M, the deterministic version of SMS. Therefore, the historical SSB trajectories showed large similarities in the general abundance trends between both models. The absolute estimates of the SSB values, however, were sometimes quite distinct, *e.g.*, for cod and haddock. Next to historic SSB trajectories, also the predictive capabilities of both models were compared. Predictions from 2006 to 2030 were carried out with both models assuming a constant fishing mortality on precautionary level (F_{pa}) for all stocks. SMS and EwE came to different results in SSB predictions especially in short- to mid-term forecasts. In contrast, the long-term equilibria estimated for the different stocks were quite similar. Only for herring, both models came to substantially different results for future stock development. In general, EwE dynamics tended to be more dampened and tended to reach equilibria faster. This may be caused by the higher number of trophic links in the EwE model.

Baltic Sea

Multispecies simulations conducted with SMS suggest that fishing Eastern Baltic cod at F_{pa} = 0.6 may not rebuild the stock when applying a hockey stick stock-recruitment relationship based on data covering a period of low reproductive success. Including cannibalism in the simulations makes a difference only for stock recovery to B_{pa}; for recovery to B_{lim} it is of very limited importance, because of the relatively low adult predator stock size. The present F_{pa} may be sustainable in a high productivity system as indicated by single species simulations, but including cannibalism results in somewhat less optimistic trajectories. At higher F, the risk of SSB being below B_{pa} is increasing faster with increasing F in singles species simulations, *i.e.*, the compensatory mechanism of cannibalism gives more stability against high F, but it requires lower F to reduce the risk of being below B_{pa}. Simulated SSB and yield at equilibrium depend mostly on the time span used to fit the recruitment model. Choosing different stomach content data, representing periods of high and low cannibalism has only limited impact on the simulation results. The simulation results furthermore indicate that the present target F = 0.3 is precautionary also in periods of low recruitment, but they also indicate that target Fs are sensitive to environmental changes affecting the reproductive success of the fish stocks. The form of the stock-recruitment relationship matters and in high recruitment scenarios cannibalism also matters.

Multispecies evaluations with SMS showed that the herring and sprat populations remain within safe limits (former B_{pa} defined only for sprat), if cod is fished with the present target F = 0.3 and having recruitment as observed in the past 15 years. If cod recruitment is increased by about 125%, which would still be on a low level as compared to the recruitment in the mid-1980s, the present target fishing mortalities for herring and for sprat were too high to maintain the spawning stock biomasses of these pelagic stocks above precautionary thresholds with a high probability. Thus, the suggested management plan for Baltic sprat is only precautionary in a low cod recruitment scenario. If reproductive conditions for cod improve, a target F of 0.4 for sprat is too high. Apart from the direct predation effect, the simulations demonstrate that clupeid growth and thus also competition between sprat and herring matters, indicating that in periods of high growth rates, the stocks sustain a higher target F.

Long-term simulations with the BALMAR model indicate that the probability of stock collapse increases steeply and non-linearly with F and decreasing salinities. The target F = 0.3 may allow for sustainable exploitation of the cod stock, but only given moderately declining salinities. The degree to which species interactions may either buffer or accentuate the cod stock response to climate change depends on the nature of both positive and negative feedback loops within the food-web. It is evident that a sustainable strategy for managing exploitation of the cod stock and its prey must be adapted to several aspects of climate change. Based on the conducted simulations, it can be concluded that an ocean-scale biomanipulation of the Baltic by fishing down the sprat stock with the main focus of reinstating the dominance of Eastern Baltic cod is likely to be ecologically ineffective.

As in the North Sea, predatory interactions affecting early life stages are not considered in the simulations, apart from the statistical BALMAR in which they are implicitly considered. An analysis of the spatial and temporal variability in predation of cod eggs by sprat showed both a pronounced spatial, *i.e.*, vertical and horizontal, and seasonal overlap between sprat and cod eggs existed in the early 1990s. Currently, however, the seasonal overlap is limited, as cod spawning time has shifted to summer month during the mid-1990s, while sprat still spawns in spring, leaving after spawning the deep Baltic basins. The horizontal overlap is in general lower compared to the mid-1990's, because sprat is more easterly and northerly distributed with highest concentrations in the Gotland Basin, while cod spawning activity is centered in the Bornholm Basin. Thus, the importance of egg predation by sprat has declined throughout the last two decades, while the importance of herring as predator has increased, as the seasonal overlap is enhanced, with herring having returned in summer from their spawning in coastal areas to the deep basins, and the Central Baltic herring stock is increasing.

The occurrence of the ctenophore *Mnemiopsis leidyi* as a new invasive species in the Baltic Sea and the potential consequences for Central Baltic fish stock recruitment was investigated in UNCOVER, as *M. leidyi* has been shown to be an important predator on early life stages of fishes in other regions. The overall impact of *M. leidyi* was found to be low. Despite a vertical overlap with cod eggs, the seasonal abundance patterns do not indicate a substantial predation pressure on cod or sprat early file stages.

Bay of Biscay and Iberian Peninsula

The pelagic fish community is primarily exploited by 12 demersal fish species, with hake being the main piscivorous predator. There is no clear evidence for density-dependent feeding by hake on most pelagic fish, except for anchovy (*E. encrasicolus*). Most demersal fish exploited small prey species and individuals.

Available stomach data suggests that cannibalism in Southern hake averages 5% of the diet. This, combined with the hake's high energetic requirements, make cannibalism a significant source of mortality on younger hake. Thus, UNCOVER conducted an evaluation of the Southern hake management plan with a GADGET model including cannibalism. Southern hake is a depleted stock, which has been managed with a recovery plan since 2006. Uncertainty about hake growth is also taken into account. Combinations of fast/slow growth and with/without cannibalism revealed four scenarios to be included in the long-term simulations. Assuming fast growth, the impact of cannibalism is limited, but higher in the slow growth scenario. In general, the choice of the growth model has more impact on the plan performance, than cannibalism. The incorporation of cannibalism into the assessment model gives a more pessimistic view about the SSB recovery possibilities and future yield of Southern hake in the medium- and long-term.

A GADGET multispecies model has been set up for the Northern Hake population as predator and anchovy and hake as prey. Predictions simulating the current control rules are implemented for both species and the results are compared with those obtained by the relevant ICES Assessment Working Group. This study should be considered as one of the first steps to the introduction of multispecies assessment in the area.

4.4.3 Conclusions

The conclusion from UNCOVER is that models which include an estimation of predation mortality from multispecies interactions provide an important insight with respect to setting biological reference points and management measures. Most existing management plans, recovery plans and HCRs tend to focus on target species only and need to take greater account of multispecies interactions and trophic controls in order to be consistent with the EAM.

Predation on small fish has a high impact on recruitment success and hence recovery potential of commercially important fish species. Density dependent (*i.e.*, intra-specific), but often more important inter-specific trophic interactions lead to different and mostly slower recovery rates of depleted fish stocks, compared to single species predictions.

It is sufficient to model stock recovery scenarios using single species models as long as:

a) A dynamic density dependence is implemented (*i.e.*, increasing cannibalism with increasing stock biomass, beyond the properties of a Ricker or Beverton and Holt stock-recruitment relationship (SRR) as cannibalism affects not only pre-recruits); and
b) Predation by other species can be neglected; and
c) There is no dependence of the recovering species on specific prey stocks (either directly or via indirect effects like increased cannibalism at low prey stock sizes as in the Barents Sea cod-capelin interaction); and
d) The stock dynamics of other species (competitors or prey) are of no interest for other population dynamic rates, *i.e.*, growth and maturation;
e) Potentially existing important environmental processes affecting pre-recruits (including predation) can be taken into account in scenario tests with different SRRs.

However, these pre-requisites are not fulfilled in any of the UNCOVER Case Studies and probably not in any other fish stock.

A recovery of a predator stock has demonstrated consequences on the trajectories of other stocks interacting with this predator, either directly via predation or indirectly (competition). The next generation HCRs should take this fact into account.

It is not possible to simultaneously achieve yields corresponding to MSYs predicted from single-species assessments for interacting species. Therefore, an interpretation of the MSY concept within the ecosystem context is needed, mainly for the time after a recovery.

There is a need to set target levels for F and SSB for predator and prey fish stocks in a dependent manner. Reference limits for the harvested prey species (*e.g.,* herring and sprat in the Baltic Sea, capelin in the Barents Sea, and anchovy in the Bay of Biscay) cannot be defined realistically without considering changes in the biomass of their predators. Likewise reference limits for the predator species (*e.g.,* cod and hake) cannot be defined without considering changes in the biomass of its prey.

Credible fisheries-related multispecies models have several needs, including being supplied with data and knowledge concerning:

a) Stock/species distributions, from periodic survey data with good temporal and spatial coverage, collected by various means (*e.g.,* hydroacoustics, trawls, plankton nets); and
b) 'Who eats who' based on stomach sampling programs connected with a) above.

The latter has been largely ignored within the EU data collection framework, resulting in a situation whereby the necessary multispecies data either hardly exist (*e.g.*, Bay of Biscay) or are out-dated (*e.g.*, Baltic Sea, North Sea). Additionally, there is a requirement for continual advances in the development and application of current and new multispecies models, including bridging the gap between fisheries and ecosystem models with linkages to lower (*e.g.,* plankton and benthos) and higher (*e.g.,* marine mammals and seabirds) trophic levels. However, without new field-derived data covering these different trophic levels, it will hardly be possible to further reduce the uncertainties in multispecies model predictions. '*With a little luck, ecosystem models might at least help point us in the right direction or, better perhaps, tell us when we heading in the wrong one*' (Mackinson *et al.*, 2009).

The work conducted during the UNCOVER project, and described in this report, demonstrates the utility of using multispecies modeling tools to evaluate HCRs in a multispecies context. This represents an alternative to single species evaluations, and provides a tool enabling the assessment of whether fisheries management is being conducted in a precautionary manner for interacting fish species as well as for individual species.

4.5 Fisheries induced evolution

4.5.1 Background

Like any other group of organisms the genetic variability of marine fish is affected by four evolutionary forces: mutation, migration (gene flow), random genetic drift and selection. While mutation rates, except for perhaps extreme cases of pollution, can be considered unaffected by human activities, our actions in relation to management of exploited marine resources (which exceeds the direct impact of fisheries) can impact directly on the dynamics and nature of migration, selection and genetic drift. For example transplantation of fish through aquaculture activities or deliberate stocking of non-indigenous fish is expected to increase migration rates and associated gene flow among populations, leading to a genetic homogenization of populations and possibly loss of local adaptations. Likewise, increased random genetic drift is caused by reduced population size (genetically effective, "Ne") causing increased changes in allele frequencies over generations, ultimately leading to loss of genetic variability in small populations.

Finally, by targeting individuals with specific trait values (*e.g.,* size) in fisheries and aquaculture operations, or by altering habitat by bottom-trawling, and thus allowing specific segments of the population to have a smaller or larger reproductive output than under natural conditions, we are more or less consciously imposing "non-natural" selection (Allendorf and Hard, 2009) on marine fish populations. These human effects are not per se negative. It could even be argued that in some cases human activities could have a positive effect on marine fish populations. For example if individuals within specific populations are suffering from inbreeding, increased migration could be beneficial for restoring population fitness. Likewise, human induced non-natural selection on morphological, behavioural and life-history traits may render populations less susceptible to fishing and therefore less vulnerable to over-exploitation. Nevertheless, exploitation has several potential negative effects on the levels and distribution of genetic variability in marine fish population. By negative we mean both in relation to loss of fisheries yield, and as importantly the effect on the population 'evolutionary potential', *i.e.,* the ability of fish populations to adapt genetically to survive and thrive under future changes in the physical and biological environment.

The ***ultimate negative impact of exploitation*** on the genetic variability within a species is its extinction, thereby potentially removing the endpoint of thousands of years, or longer, of evolution. Fortunately, extinctions of marine fish are rare, but a recent example with taxonomic confusion of skates, where two distinct species have been erroneously confused since the 1920s under a single scientific name *Dipturus batis* (Iglesias *et al.*, 2009), highlights the potential of extinctions that we are not even aware of. Such fundamental uncertainty further emphasizes an additional point that identification and individual management of the evolutionary units exploited by fishing are of paramount importance. Still local extinctions appear to be generally widespread. Dulvy *et al.* (2003) reported more than 60 local extinctions of marine fish. Local populations have been shown to display adaptive trait variation in response to the local environment, and recently it has been demonstrated that such 'local adaptations' (Kawecki and Ebert, 2004) indeed have a genetic background, as identified through common garden experiments (Conover *et al.*, 2006; Hutchings *et al.*, 2007), or through identification of genes under selection in natural marine fish populations (Hemmer Hansen *et al.* 2007; Andersen *et al.*, 2009; Nielsen *et al.*, 2009).

Local adaptations ensure that populations can survive and proliferate under a variety of environmental conditions, but also represent reservoirs of evolutionary potential for the species as a whole. *I.e.* if the environmental conditions change over the species range, specific populations may spread or retract based on their adaptive genetic makeup. A particularly potent example of such links between population diversity, local adaptation and persistence across diverse environments was provided by long-term studies on Pacific Salmon (Hilborn *et al.*, 2003). Spawning stock abundance varied markedly over time in relation to alterations in climate and associated modifications to the ecology of spawning sites, demonstrating the importance of so-called "population biocomplexity" in persistence and fisheries yield. Thus the more locally adapted populations available within a species, the more robust it is towards future short and long term environmental perturbations.

The loss of populations or severe reductions in population size may also remove important stepping stones for migration and associated gene-flow within a species. For example, if populations are distributed in a more or less continuous way along a shoreline, then the extinction or reductions of local populations may impede gene flow among the remaining populations. Fragmented populations would then not be able to receive potentially valuable new genetic variation from other populations and would be more prone to the effects of genetic drift from small genetically effective population size. Accordingly, the loss of subpopulations and isolation of the remaining populations is likely to cause an overall loss of productivity. Loss or severe reductions of populations is not only likely to take place in relation to direct over-exploitation of a single population. It is likely to take place in mixed stock fisheries (*e.g.,* herring, see Ruzzante *et al.*, 2006) where the relative contribution of different populations to the mixed-fishery is unknown. In particular small and slow growing populations are likely to be severely affected in such cases. The loss of such populations may not be trivial since they may be small under a contemporary environmental setting but could be the most productive populations in the future, as illustrated by the Pacific salmon example above (Hilborn *et al.*, 2003).

While unnaturally low levels of gene flow may be problematic to secure future evolution and productivity of marine fish populations, unnaturally high levels of gene flow may be equally detrimental. Increased levels of migration may be mediated through unintentional escapes from marine fish aquaculture (*e.g.,* Atlantic cod) where ‘escapes’ of eggs and sperm poses an additional problem compared to traditional aquaculture of salmonid fishes (Bekkevold *et al.*, 2005). Likewise marine stocking of non-native fish can lead to the destruction of fine tuned interactions among genes involved in adaptation leading to ‘outbreeding depression’, which is fitness reduction associated with interbreeding of individuals from different populations. Additionally, this “swamping” of the native gene pools within a species increases vulnerability to environmental change such as the outbreak of new diseases.

It is also worth pointing out that as in all wild situations where fish are exposed to a plethora of natural and man-made changes simultaneously, effects on population structure driven by various fisheries practices might be augmented by independent environmental change. For example, populations that become increasingly fragmented through reduced dispersal and gene flow may be further influenced by elevated sea surface temperatures. Since increased developmental rate equates to shortened larval duration, and larval duration is positively correlated with dispersal distance, an increase in developmental rate would be predicted to reduce dispersal distance, with consequent effects on recruitment dynamics and population connectivity.

4.5.2 Fishery effects

Exploitation of marine fish populations may negatively affect levels of genetic variability through reduction of census population size. The census size is related to the genetically effective population size (Ne), which ultimately determines the rate of ***loss of genetic variation*** from the population (the effective population size is defined as the size of an ideal population that would experience the same rate of genetic change through drift as the population in question). It is generally believed that marine fish have relatively large effective population sizes (*e.g.,* Poulsen *et al.*, 2006) compared to freshwater and/or anadromous fish. However, the ratio between effective and census size (Ne/N) has been shown to be very low in classical marine fish, which are producing huge numbers of pelagic egg and larvae. Ratios as low as 10-5 has been reported (see Hauser and Carvalho, 2008 and references therein), indicating that marine fish populations with adult spawning populations ranging in the millions could still be vulnerable to effects of genetic drift. However, whether the relationship is constantly independent of census size remains to be explored. Likewise, while very small effective population sizes are relatively easy to measure, no adequate method is currently available for reliably measuring Ne«s ranging in the thousands. When are effective population sizes reduced to levels of concern? In conservation genetics there is a rough general rule of thumb, the "50-500 rule" (see Frankham *et al.*, 2002 and discussion therein), stating that the effective size should be at least 50 to avoid short term loss of heterozygosity resulting in inbreeding and potentially inbreeding depression, while the effective population size should be over 500 to avoid loss of genetic variation - the long term fuel of evolution. Accordingly, most classical marine fish populations should be relatively safe according to those rules. Still there is reason for concern, in particularly for species which are experiencing severe genetic bottlenecks going from very high effective population sizes to close to critical sizes. Here very large amounts of genetic variability are lost (see Ryman *et al.*, 1995), even in populations comprising millions of individuals. Additionally, individuals from historically large populations may be more susceptible to effects of inbreeding than individuals from more chronically low population sizes. Another group of marine fish of particular concern is long-lived slow reproducing species such as sharks and rays. They are expected to have relatively low effective population sizes and therefore minor reductions may push them below critical levels.

Fishing is commonly targeting a specific segment of the population, *i.e.,* fish of a certain size or with other desired traits. If these traits have a genetic background, fishing is inevitably going to change the genetic composition of the population. Such '***fisheries induced evolution***' has been the subject of much debate in recent years (*e.g.,* see J¿rgensen *et al.*, 2007, Andersen and Brander, 2009). The general idea is that fishing is targeting large, fast growing, late maturing individuals, thus leaving fish that are investing energy into early maturation (slow growth) with a selective advantage. Merely directing intense fishing to the immature part of the population is expected to lead to evolutionary change towards early maturation, as the probability of surviving to reproduction for late maturing individuals is significantly reduced (see Allendorf and Hard, 2009 and references therein). A lot of evidence of fisheries induced evolution has been collected using temporal comparisons of growth and maturation at decadal time scales (see Sharpe and Hendry, 2009; Enberg *et al.*, 2009). In particular in the form of "probabilistic maturation reaction norms" (Heino and Dieckmann, 2008), which attempts to estimate the genetic component of fisheries induced evolution and eliminating environmental effects on the observed phenotypic changes. Until now, however, the 'the smoking gun' of fisheries induced evolution, *i.e.,* evidence of genetic changes at the DNA level, has not been found, but is a priority topic within the field of marine fish genomics (Nielsen *et al.*, 2009).

Fisheries induced evolution can have a number of negative effects on the population in question. First of all selection removes the population from the optimum trait value under natural conditions, meaning for example that an overall reduction in average body size will reduce mean population fecundity, with direct consequences on levels of recruitment. At the same time, adaptation to fishing may involve a number of tradeoffs resulting in reduction of overall population fitness. For example, early maturation may increase the number of offspring produced under intense exploitation, which should be beneficial for the fish population in question. But at the same time small early maturing fish may produce offspring of lower average quality and have shorter spawning periods and therefore be less buffered against environmental instability within the spawning period. In particular for broadcast spawners in a match/mismatch scenario this could result in general lower recruitment and high recruitment variability among years, eventually leading to decreased yield. Another issue in relation to unnatural selection is that modeling work has shown that the process of reversal of the altered traits to the natural values is slower than the fisheries-induced shift (Enberg *et al.* 2009). This is due to the fact that natural selective forces are often weaker then the intense selection pressure imposed by fishing, though associated modifications to the gene pool may also mean that insufficient or inappropriate genetically-based variation in phenotypes exists to allow such reversal. If genetic variance in traits such as size and age at maturation and growth rates no longer exists within the over-exploited population, then directional change towards the original optimum trait values, even in the absence of harvesting, can occur only through immigration or long-term evolutionary mutations. Likewise, reversal to a situation without any exploitation (non-natural selection) is not very realistic.

Overall unnatural selection by exploitation has a potential high effect on the fitness and productivity, and the underlying genes, in natural marine fish populations. In concert with loss of variation from lowered effective population sizes and altered population structure, it is clear that human intervention has a large potential for having significant negative effects on the genetic variability of marine fish populations. Accordingly, to realize the different consequences of various exploitation and management patterns is of paramount importance for sustainable fisheries management.

Enberg *et al.* (2009) modeled the rebuilding process after harvesting ceased and came to the conclusion that the stock biomass rebuilding process was only lightly influenced by fisheries-induced evolution, whereas other stock characteristics such as maturation at age, spawning stock structure, and recruitment were substantially affected, recovering to new demographic equilibria below their preharvest levels. They concluded that natural selection driving recovery of some genetic traits is weaker than fisheries-induced selection. The slow rate of evolutionary recovery leads to incomplete biomass recovery on intermediate time scale, as full evolutionary recovery to original trait values can be very slow or even impractical.

4.5.3 General recommendations

Although exploited organisms vary in their life history, population structure and patterns of exploitation a number of general guidelines for management can be proposed which will avoid/reduce negative genetic effects (Allendorf *et al.,* 2008; Allendorf and Hard, 2009). In order to limit changes in population structure, and ultimately loss of local populations, it is of paramount importance to understand the existent population structure, including the spatial and temporal distribution of identifiable population units or 'stocks' (Carvalho and Hauser, 1994). Only if the number and distribution of populations subject to exploitation is known, can genetically sustainable management become possible, for example, in a mixed population fishery, the least productive populations will be lost. Basically it is possible to mitigate such effects in two ways; primarily by monitoring the contribution of each of the populations to the mixed-fishery. The fishery can then be opened and closed in areas and seasons according to the recommended exploitation rates of the populations appearing in the catch. This may sound relatively complicated, however, this is in fact the way mixed-fisheries on Pacific salmon is managed (see Waples *et al.*, 2008 and references therein). If this is possible for species with such a very high number of populations, it should be feasible for most species of marine fish given there is sufficient statistical power for robust identification of different population components. The alternative or supplementary option is to monitor changes in the genetic variability of local populations and identify critical changes in the genetic variability of different populations.

While ‘mixed stock’ management is proactive, ‘genetic monitoring’ is responsive and could result in significant loss of variability before appropriate management actions are negotiated and in place. As noted above, aquaculture operations could lead to increased migration among populations through transplantation of fish between geographically remote areas hosting natural populations of marine fish. Isolation of such transplanted fish should be secured. Likewise, supplementation of natural marine fish populations should not be conducted using fish of non-native origin. In general, alternatives should be considered before engaging in any process of supplementation of wild populations as a number of potential negative genetic effects are associated with such supportive breeding activities.

In relation to loss of genetic variation the important parameter to manage is the ***genetically effective population size***. Again it is important to bear in mind that the genetically effective population size may be several orders of magnitude smaller than the census size of adult breeders in the population. Accordingly it is important to maintain a sufficiently high number of breeders in (all) the exploited populations. Although it might be tempting to propose quantitative threshold estimates for optimum population sizes, such as derived from the 50-500 conservation rule of thumb, in reality this is not so simple. Reliable estimates on the ratio of census to effective population size first need to be obtained, followed by information on the level of population connectivity, and rate of population decline, which will influence directly the levels of allelic diversity (especially of rare alleles) and genomic heterozygosity. Monitoring of Ne, for example across several seasons, can provide a baseline from which unexpected or sudden changes can be detected, thereby alerting fisheries managers to the need for possible effort or selectivity-based restrictions. Here genetic monitoring may provide a useful mean for evaluation of potential changes in levels of genetic variability within populations.

Reduced harvesting is also recommended as a general tool to mitigate non-natural selection caused by fishing. As outlined previously, evolutionary changes in age and size at maturity are expected to take place just by increasing the mortality on immature fish. Thus more moderate selection by fishing will allow natural selection to play a more prominent role in shaping the underlying genetic composition responsible for trait variation. Therefore, multi-annual management plans recognizing population structure may be more beneficial than yearly TAC«s, as the intensity of fishing is expected to be lower. It has been shown that there are a number of discrepancies between management areas and population structure (Reiss *et al.*, 2009). Despite its simplicity, TAC regulation has been shown often to lead to overexploitation, race-to-fish, *i.e.,* where the quota is caught within a short time period, as well as ‘economic discard’ of legally caught fish of undesired size, sex or quality. Another option for avoiding selective changes caused by fishing is to reduce the selectivity. As fishing is generally targeting the largest fish, choosing gear types which are less size selective or having size windows allowing large fish (and small) to escape exploitation would result in less intense directional selection on growth and maturation.

However, size limit measures should in general be accompanied by technical measures such as type of fishing or changes in mesh size in order to be effective and to avoid increased discard. For instance, fixed gears such as long line and gill nets fishing are often recognized as being better for withstanding evolution of life history traits than trawling under most exploitation regimes (Hutchings, 2009; J¿rgensen *et al.*, 2009). Naturally, selective changes are not restricted to age and size at maturity. Other traits may also be subject to selection, such as timing of reproduction and behaviour (*i.e.,* fish which are more aggressive or active may be in greater danger of being caught). Selection on timing of reproduction may be highly maladaptive for recruitment and should be avoided. Accordingly, management tools which spread exploitation across the spawning periods are desirable. Another option which holds great promise for mitigating the effects of selection from fisheries is the use of closed areas (*i.e.,* Marine Protected Areas, MPA«s) (Allendorf and Hard, 2009). If areas are established where natural selection will be the prominent force of evolution, this will not only act as isolated reserves of end products natural evolution, but would be able to slow down or stop the effects of non-natural evolution in order areas of the population distribution. However, the effect on the population outside (and inside) the MPA is very dependent on the relative size of the areas, population components and the migration between the protected and non-protected areas. Accordingly, there may be large differences in the effectiveness of such areas depending on the geographic region and species in question. More modeling effort is needed in order to elucidate the potential benefits under a variety of scenarios (c.f., Dunlop *et al.*, 2009 for an example).

The previous sections highlight that exploitation is expected to have negative influences on the genetic diversity in marine fishes through alteration of population structure, loss of genetic diversity and selective changes. It is also clear that a number of general guidelines for mitigation of these effects can be given. It is evident that overexploitation, like in general for fisheries management, is the overarching problem affecting all types of loss of genetic diversity. It is, however, also clear that technical measures can be instated which will slow or halt the loss of diversity, though it is important to enhance our understanding of how additional environmental changes interact with the consequences of harvesting since synergistic effects are likely to generate additional variance in the distribution and levels of genetic diversity in the wild. The expected positive effect of different technical measures needs to be carefully modeled and there is a definite need for more specific quantitative guidelines to be implemented in management. Likewise, there is a clear need to identify and implement knowledge of genetic population structure into marine fish management. Further, genetic monitoring can be a powerful tool for evaluation changes in population structure, loss of genetic diversity as well as adaptive genetic changes over time in response to exploitation. Finally, we stress the need to set clear management goals for genetic diversity and explicitly implement them within the framework of fisheries management legislation.

4.5.4 Summary

There is growing knowledge that overfishing effects not only the stock biomass, stock age and population structure and reproductive potential (Marteinsdottir and Thorarinsson, 1998, Murawski *et al.*, 2001), but also phenotypic plasticity (*e.g.,* Lorenzen and Enberg, 2002; Kell and Bromley, 2004), and adaptive evolution to a different mortality regime (Law and Grey, 1989). It is hypothesized that on a higher level overfishing can also lead to changes in the ecosystem structure, potentially causing even ecological regime shifts and alternative stable states (Jackson *et al.*, 2001; Scheffer *et al.*, 2005), *inter alia* through cascading effects caused by the removal of top predators (Frank *et al.*, 2005).

Moreover, even though it is not yet hard proof for fisheries-induced evolution on the genetic level, there are numbers of indications that this may be so. The comparison of model results and field observations by Enberg *et al.* (2009) leads to the conclusion that the harvest-induced changes are within the expected range and therefore pertinent to considerations of empirical recovery processes.

In a precautionary sense for the recovery of the stocks it is important to take the possibility of fishery-induced evolution into account, since as a bottom line, because of the evolutionary changes that took place while the stock was harvested, some stock characteristics recover faster, some slower, and some incompletely, depending on the stocks and/or species. At a short to medium time scale (years to decades) the primary role of evolutionary trait changes is that they are expected to change population dynamics and thereby change the rules of stock recovery (Enberg *et al.*, 2009), and must be taken into account in rebuilding scenarios.

Thus, it is concluded from different investigations within UNCOVER that there are evolutionary effects of fishing on fish stocks. The effects are expected to result in changes in growth, size and age at maturation, and allocation to reproduction (J¿rgensen *et al.*, 2007). Rapid evolutionary effects have been demonstrated for collapsing stocks (c.f. Olsen *et al.*, 2004), but in general evolutionary responses are likely to be small compared with the direct effects of overfishing and the direction of change in affected traits are dependent on details in the imposed fishing mortality (Anderson and Brander, 2009). Accordingly, evolutionary changes are therefore not expected to be generally responsible for a lack of recovery, even though they may contribute to a slower recovery rate (Enberg *et al.*, 2009). On these grounds Andersen and Brander (2009) have emphasized that dealing with evolutionary effects of fishing is less urgent than reducing the direct, detrimental effects of overfishing on exploited stocks and on their marine ecosystems.

4.6 Invasive alien species, and new and recurring pathogens and diseases

4.6.1 The problem and the human vectors causing it

Major threats to wild fish stocks in the European seas, at various stages of their life histories, arise from invasive alien species (IAS, also called non-indigenous, exotic, etc.) of phytoplankton and macroalgae, invertebrates, fish, and new and recurring pathogens and diseases (Sindermann, 1990; LeppŠkoski *et al.,* 2002). They can cause impacts on living marine resources that may or may not be economically utilized, but which directly or indirectly may affect fish and fisheries (Bax *et al.*, 2003; Hopkins, 2002; 2005). Accordingly, such organisms may both contribute towards declines in fish stocks as well as hinder recovery plans for such stocks.

Introductions and transfers of IAS, including genetically modified organisms, between continents, regions and countries can have far-reaching and harmful impacts on the recipient marine ecosystems (LeppŠkoski *et al.,* 2002). IAS may act as vectors for new pathogens and diseases, alter ecosystem processes and modify habitats, reduce biodiversity, and cause socioeconomic consequences for humans (LeppŠkoski *et al.,* 2002). Thus, IAS are one of the primary and growing environmental concerns affecting the conservation of biodiversity, including impacts on ecosystems, habitats and their associated species (CBD, 2002; Bax *et al.*, 2003; Hopkins, 2005). The geographical spread of alien marine species and novel pathogens is predicted to increase, due to a lack of physical barriers in the sea and expanding trade, and climate warming affecting northern seas will probably facilitate wider establishment of cosmopolitan organisms. (Stachowicz *et al.* 2002; McCallum *et al.,* 2003; Rahel and Olden, 2008; US EPA, 2008). The overall rate of increase of new IAS recorded in the European regional seas since the beginning of the last century has been rapid and remains unabated in most areas (Figure 4.3) (EEA, 2007). Thus, despite many international agreements and instruments (*e.g.,* UNCLOS, 1982; CBD, 1992, 2002; ICES, 2003; IMO, 2004) promoting the requirement to prevent, reduce, monitor and control the introduction and transfers of IAS, these are obviously ineffective in hindering the increasing establishment of marine IAS (LeppŠkoski *et al.* 2002; Hopkins, 2005).

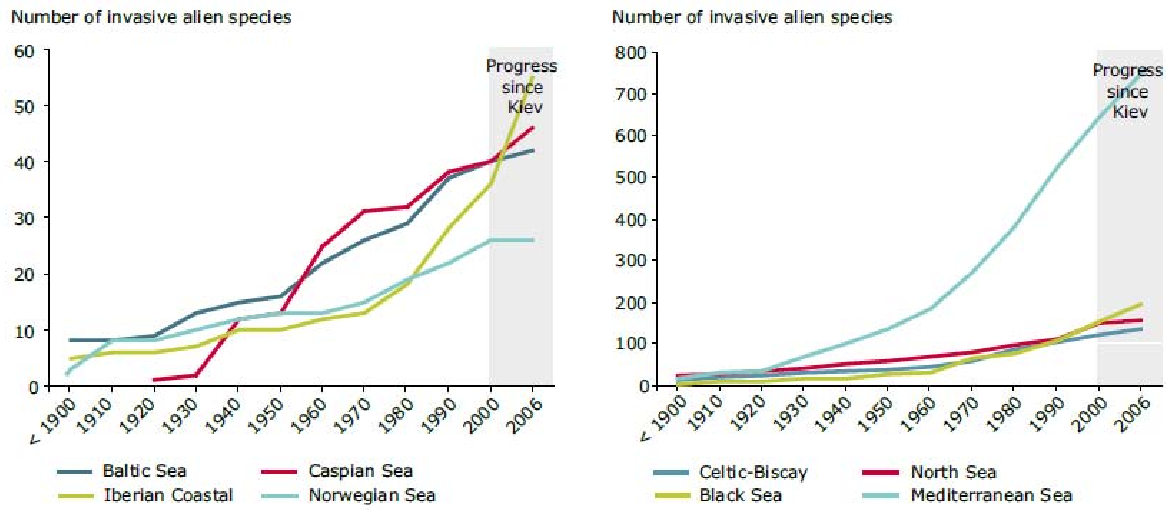


Figure 4.3. Change in numbers of marine invasive alien species recorded in eight pan-European seas. Source: http://www.eea.europa.eu. Copyright EEA, Copenhagen, 2007.

Shipping (*e.g.,* via ballast water discharge, hull fouling) and aquaculture (*e.g.,* via import of alien species, and non-intended spread of escapees and 'stowaways') are the vectors responsible for about 90% and 10%, respectively, of the introductions of marine alien species in the North-East Atlantic and adjacent seas (Gollasch and LeppŠkoski, 1999; Minchin and Gollasch, 2002). Other vectors that pose significant potential threats include the live seafood and aquarium trade, tourism and recreational activities, and removal of natural barriers (*e.g.,* construction of man-made canals and waterways) (Ruiz and Carlton, 2003). Once introduced to an area, natural transfer processes (*e.g.,* dispersion by water currents) facilitate further spread of IAS.

As the boundary between capture fisheries and aquaculture grows less distinct, due to expansion of extensive aquaculture and sea-ranching, there is an increasing risk for transfers of pathogens and diseases between 'farmed' and 'wild' living resources, as well as 'escapees' transferring their farm-adapted genetic makeup to wild populations that have adapted to survive under natural environmental conditions (Naylor *et al.,* 2001; Cataudella *et al.*, 2005). In aquaculture, intended introductions of alien species have provided farmed resources with major socioeconomic benefits (Silva *et al.,* 2009). A few unintentional and intentional shellfish introductions in European seas have become the targets of lucrative harvesting (*e.g.,* Hjelset *et al.,* 2009). 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 (LeppŠkoski *et al.*, 2002).

4.6.2 Plankton

Detrimental effects of phytoplankton IAS may be relatively immediate and potentially seasonally recurrent on an annual basis in the form of harmful algal blooms (HABs, *e.g., Gymnodinium aureolum*; *Alexandrium tamarensis*; *Chatonella* sp.) which may have serious impacts in terms of toxic effects (*e.g.,* tainting and mortality) (Wallentinius, 2002; Hopkins, 2002). Such HABs are primarily threats to sessile or poorly motile biota or life stages (*e.g.,* benthos, fish eggs and larvae) which are unable to avoid the blooms. In 2001, the first description was made of the toxic dinoflagellate *Pfiesteria* from the Oslo fjord, Norway (Jakobsen *et al.*, 2001). Toxic *Pfiesteria* thrives in estuarine waters affected by nutrient over-enrichment and is renowned for causing major kills of both juvenile and adult pelagic fish on the US Atlantic and Gulf coasts (Burkholder and Glasgow, 1997). Other types of harmful, but non-toxic, invasive phytoplankton in the case study areas may also cause concern. *Coscinodiscus wailesii* can, for example, form dense mucus secreting blooms which are not easily grazed by zooplankton due to its large size and mucus production (Edwards *et al.,* 2001; Laing and Gollasch, 2002). Other phytoplankton IAS which do not form HABs, such as *Odontella sinensis*, may form dense blooms with unclear ecological and economic impacts (Wallentinius, 2002).

The alien invasive, zooplankton 'comb jelly' *Mnemiopsis leidyi* can eat large numbers of pelagic fish eggs and larvae, and potentially cause recruitment failure of pelagic fish (GESAMP, 1997). The species has been recorded since 2006, and rapidly increased in abundance, in the North Sea, Skagerrak, and Baltic Sea (Boersma *et al.,* 2007; Haslob *et al.,* 2007). Originally distributed along the USA's Atlantic coast, the species was introduced into the Black Sea in the early 1980's and expanded in the 1990s into the Azov Sea and Caspian Sea, leading to decimation of stocks of small pelagic fish with dire consequences for fisheries (GESAMP, 1997). Having a broad prey spectrum, *M. leidyii* also competes with fish larvae and juvenile fish for food such as copepods (Oguz *et al.,* 2008). *M. leidyii* can live in waters with very wide ranges in temperature (4–32 ¼C) and salinity (3–39 psu) facilitating its invasion of new areas (GESAMP, 1997).

4.6.3 Macroalgae

Numerous alien macroalgae species (*e.g., Sargassum muticum, Fucus evanescens*) have colonized and spread across many of the European seas and can displace native species including kelps and seagrasses (Wallentinius, 2002). Native species of the latter (*e.g., Fucus vesiculosus*, *Zostera marina*) are important habitat constituents contributing to successful spawning and nursery grounds of some local stocks of Norwegian spring-spawning herring as well as Baltic Sea herring which spawn and utilize vegetated rocky and soft bottom habitats (Runnstr¿m, 1941; Haegele and Schweigert, 1985; Aneer, 1989; Polte and Asmus, 2006).

4.6.4 Microorganisms and fungi

New and recurring bacterial, viral and fungal agents are a major concern for fish health worldwide owing to their difficulty in detection and ease of transmission, even across fish species (Woo and Bruno, 1999). They are important limiting factors for some wild fish populations, and *Ichthyophonus hoferi* is one of the most serious pathogens of fish (Sindermann, 1990). An *I. hoferi* epizootic was noted for the first time in herring in the European seas in 1991 and spread, with resultant mass mortalities, in herring stocks in the North Sea, Skagerrak, Kattegat and the Baltic Sea before waning (Mellergaard and Spangaard, 1997). Concern was due to the serious effects of epizootics of this potent pathogen in the 1950s that affected herring stocks in North American Atlantic coastal waters. Additionally, the introduction of new marine fish species to commercial cultivation could expand the host range for existing pathogens, and may generate new diseases and pathogens, as yet unknown (Bricknell *et al.,* 2006). Regarding Atlantic cod in the Case Study areas, the bacteria *Vibrio* (*Listonella*) *anguillarum* and atypical *Aeromonas salmonicida*, and the viruses Infectious Pancreatic Necrosis Virus (IPNV) and Nodavirus, and Viral Haemorrhagic Septicaemia Virus (VHSV) are the major diseases facing farmed gadoids, and so may threaten wild cod (Bricknell *et al.,* 2006).

4.6.5 Shellfish and finfish

The red king crab (*Paralithodes camtschatika*) is an IAS which was intentionally released in the Kola Peninsula area of Russia in the 1960s and which has subsequently invaded the southern Barents Sea and the coast of northern Norway (Petryashov *et al.,* 2002). It may compete for food with both benthic invertebrates and fish, and occasionally eat demersal fish eggs (*e.g.,* capelin, herring and lumpsucker (Petryashov *et al.,* 2002). The red king crab is a host for a leech vector of a trypanosome blood parasite which has the highest incidence of infection in cod in areas of the Barents Sea with the highest density of king crabs (Hemmingsen *et al.*, 2004)

There are few cases of fish IAS which have formed self-sustaining populations in the four Case Study areas (LeppŠkoski *et al.,* 2002). The most notable is the round goby (*Neogobius melanostomus*), a demersal fish species of Ponto-Caspian origin, which was introduced to the Baltic Sea in the early 1990s and is increasing in abundance and expanding its distribution in the southern and eastern Baltic Sea (Sapota, 2006). Currently, there is little evidence that this species provides either a direct or indirect threat to cod, herring or sprat in the Baltic Sea ecosystem.

4.6.6 Mitigation measures

A series of important international agreements and instruments have played a critical role in fostering the requirements to prevent, reduce, monitor and control the introduction and spread of IAS (CBD, 2002; ICES, 2003; IMO, 2004). To help counteract the introduction and further spread of IAS in the European seas, specially devised regional monitoring, early warning and risk assessment programmes need to be established (Hopkins, 2005). However, marine IAS are notoriously difficult to eradicate once they have become established as, once introduced to an area by human vectors, natural transfer processes (*e.g.*, dispersion by water currents and wind) often supplement the further spread of IAS. Thus, measures aimed at potential containment—that are generally only effective for larger species (*e.g.*, shellfish and finfish) which, for example, can be can be fished down—tend to be the only remaining form of mitigation.

4.7 Constraints arising from the human factor

As would be expected, the situations found in both fishing communities and fishing fleets that have been affected by recovery plans vary considerably. In general, in order for effects of the recovery plans to be felt, fleets and fishers must actually change their behaviour. If the short-term costs are viewed as being too high and if the plan does not have ‘buy-in’, then fleets and fishers may not alter their actions and comply as desired by managers for rebuilding. Incentives exist to cheat when catches are lower due to their need to operate as businesses; they must compensate for revenue losses.

The findings of UNCOVER's socio-economic research, however, include several similar patterns that were identified across recovery plans. The first was the importance of whether or not fishing fleets and communities are relatively specialized or seek to remain generalists. Specialization makes it difficult to switch between species and or gears. The variable emerged in recovery plans and was an important component in both the bio-economic and anthropological analyses.

Impacts from recovery plans have strikingly different impacts on different groups within the communities. These impacts are not only of different degree, they happen at different times. Differences are found in the subsectors that would be expected, such as fishing support services, fish buyers, and the catching sector. But other divisions are important as well. In some communities families suffer a greater impact because wives are an integral part of the fishing enterprise. Different age-groups also suffer different impacts, with older people often finding the recovery plans more difficult to navigate. Care and attention also needs to be paid to the problem of cumulative impacts on the fishing industry and fishing communities.

Impacts will obviously only be seen if fishers/fleets are compliant. Compliance with the Northern Hake Recovery Plan was not an issue as quotas were still set beyond where what fishers wished to catch, and in spite of the stock continued to recover. However, compliance with the North Sea Cod Plan, especially in the early years, was a continuous problem. The North Sea experience, however, eventually demonstrated that a combination of more effective enforcement, long-term planning, and avenues for stakeholder input into the process substantially changed both attitudes and compliance behaviour. The anthropological research showed that increased regulation and enforcement, without the perception of a say in the process can increase *anomie* and stress in communities and fleets. The UNCOVER research also found that incorporating compliance indicators into the bio-economic modeling is feasible, but requires a realistic view of compliance by being able to specify a full range of compliance levels in the models.

From a decision making perspective, recovery plans represent a loose consensus that a focus on the most depleted stocks is justified, particularly if this focus leads to a long-term management plan. This desire for a long-term approach was found among high-level stakeholders and in every fishing community. The basic approach taken by stakeholders to these long-term plans also represents a compromise position: the industry is willing to accept a lower quota over the long term if it means that catches at that lower level can remain stable with a degree of insulation from both biological and political sources of instability. The desire for long term plans reflects the real need for business planning, which also acts as a political constraint on recovery plans which often are asking for a large short term cut in fishing effort followed by a need to assess the results.

Broad support can be seen among stakeholders for the idea that setting limits on human activities is more important than setting management targets. This was a clear consensus, for example, among the stakeholders represented on the NSRAC in the document on cod recovery. This does not mean that targets are not important, especially the conservation NGOs believe they have a role to play, but the main focus of the scientific and management effort needs to be on how to reach those targets – meaning the setting of limits – rather than on the precision of inevitably imprecise and uncertain targets. The first job of the management system is to make sure it is moving in the right direction, *i.e.,* getting the trends right. The NSRAC position is based on an agreement that the causes of both decline and recovery is very uncertain, particularly the relative weight of all the different causal mechanisms that apply in any given situation. What the NSRAC is saying is that this uncertainty can neither be ignored nor used to block progress.

The need for cross-scale interaction in decision-making presents a political challenge that constrains the development of plans. Recovery plans need some decisions, for example regarding multispecies interactions, to be made at the level of regional seas. They need other decisions, for example, understanding stock dynamics and their implications for measures, at the level of a stock. Many decisions then have to be made at the level of fleets or mŽtiers. These different problems and scales mean mobilizing different kinds of expertise and creating flexible management institutions.

For recovery plans in general, the most difficult areas of stakeholder consensus are found when recovery plans take place in mixed-fisheries. In this situation the contradiction between the single-species nature of recovery plans and the need for broader approaches creates the most direct problem. Severe disagreements emerge as stock recovery begins because of different perspectives on when a stock is recovered, problems that are exacerbated by the issues of juvenile fish and regulatory discarding. Mixed-fisheries also make effort-based approaches more attractive. This has led to hybrids of input-control and output-control management systems that are confusing, extremely intrusive into fishing operations, and which intensify the problem of cumulative impacts of management measures on the fishing industry and fishing communities. These hybrid approaches undermine political support for the recovery plans among both the fishing industry and some EU Member State governments.

5 THE SCIENTIFIC KNOWLEDGE REQUIRED FOR QUANTIFYING AND REDUCING THE SOURCES OF UNCERTAINTY

Quantifying uncertainty is actually harder than reducing it. If we identify a source of uncertainty, it is usually clear how we can reduce this with extra resources. But it is often not trivial to obtain a reasonable estimate of that uncertainty. For example, one could reduce uncertainty in catch data with onboard observers or video cameras, better sampling at sea or in ports/harbours, improved vessel monitoring systems (VMS), *etc*. However, obtaining an accurate estimate of the existing of historical uncertainty is much more difficult to do. Furthermore, uncertainty is more than just variance or random error, it also includes bias. Bias is often harder to identify and quantify than random errors, but can be much more important in stock understanding and forecasting. Moreover, some uncertainties cannot be quantified at all.

If one is to conduct a management strategy evaluation (MSE), or evaluate a recovery strategy, then quantifying this uncertainty becomes critical. Such plans are often phrased in terms of having a certain chance of avoiding an undesirable consequence. Being able to produce reasonable estimates of the uncertainty is therefore critical. If higher fishing is permitted at lower uncertainties (where B_{pa} comes closer to B_{lim}) then the current assessment of uncertainties needs to be right. If we move to F_{MSY}, with a biomass limit reference point set to remain near F_{MSY}, then that reference point is derived from the uncertainty distribution, and quantifying the uncertainties again becomes critical. In addition, simulating a recovery strategy faces further uncertainties. Depleted fish stocks are generally data poor, recovery trajectories are uncertain, the target stock size and structure is not well known, and minimizing implementation errors are critical to the recovery plan. It is necessary to incorporate all these uncertainties and make a very precautionary recovery strategy.

One critical uncertainty in these cases is compliance (*e.g.*, implementation error) with the management rule. Any analysis of likely yields from a given HCR must include uncertainty on compliance, both in terms of the likelihood of the managers following the plan, and in terms of excess fishing mortality above that specified in the plan (discards, IUU fishing, *etc.*). An analysis that does not include this cannot be considered to be a realistic evaluation of the HCR or recovery strategy. Analyzing such uncertainty should involve input from socio-economics or anthropology, in order to investigate the degree to which economic and social aspects may affect compliance.

Time lags in the management process also contribute uncertainty to the management. Lags between data collection and quota implementation can mean that corrective action following stock fluctuations can be delayed. This becomes worse where data are of poor quality, as it may take a number of years to identify a trend. Changes in management control rules can take even longer, and impose greater uncertainty on the stock projections.

Managing fish in a multispecies context—either by taking into account predation mortalities occurring within the food-web or via mortality arising from mixed-fisheries catches—facilitates the identification of uncertainty in more processes, and can help resolve processes that are critical to the management of the system. In this context, for example, it is vital to collect stomach content data at regular intervals (*e.g.*, 'year of the stomach' sampling programs).

Forecast modeling generally assumes that the historic error distribution will accurate reflect that which would be observed in the future, which may not be the case; particularly if there are future changes to the structure and function of ecosystems. Such changes are certainly possible since ecosystems are dynamic. Moreover, successful implementation of a recovery strategy will change the system beyond the range of the recent data. It is important to not only predict future trends (with associated uncertainty) but also to estimate the error distribution associated with those trends. Simply running models to reach stable states under a range of trends will underestimate uncertainty. Fish stocks generally experience periods of favourable and unfavourable environmental conditions, and stock collapses due to overexploitation are more likely to occur during the latter conditions. In other words, the uncertainties and the interactions between the uncertainties matter. Long datasets, and a knowledge of underlying processes are required to provide the best estimates of error distributions and the combined influences of uncertainty in multiple factors on future stock trajectories. Since the trajectories are uncertain, the recovery plan has to be formulated so as to be precautionary to these uncertainties, and this may imply stringent reductions in fishing impacts early in the time series.

Many of the sources of uncertainty affecting fisheries are external to the marine environment. Fluctuations in global or local markets are an important source of uncertainty in predicting fishers' behaviour. These fluctuations, in turn, may be affected by a variety of other factors (climate change, increasing population, availability of aquaculture fish, *etc.*). Other human impacts can also dramatically affect the fisheries (*e.g.*, oil-related activities, coastal development).

Sustainable fishing can be considered as taking surplus production of fish from the ecosystem. In this context, it is important to monitor stock productivity (*e.g.*, recruitment, rates of growth and mortality, maturation). Fisheries management should be adjusted to reflect stock productivity changes. Enhanced knowledge about the processes impacting stock productivity will reduce uncertainty with regard to management options.

There are a number of available techniques than can, to some extent, quantify and reduce uncertainty. Bayesian modeling can serve as a framework to combine different sources of knowledge to gain a better understanding of the uncertainties. This can reduce and analyze uncertainty, provided there is knowledge available to do this. Borrowing knowledge from other stocks can reduce quantifiable uncertainty (within projections) but increases unquantifiable uncertainty as it remains uncertain as to whether the borrowed information is correct. Running scenarios within single models and running multiple models (ensemble modeling) can give information on the range of likely outcomes but do not generally provide distributions. Environmental risk assessments provide a framework to include a broad range of quantifiable and unquantifiable uncertainties into a single assessment of a fishery.

The **key points from this section** are summarized as:

- Quantifying uncertainty is harder than reducing it, but may be more important;
- Evaluations of management plans should consider as wide a range of uncertainties as possible;
- Any valid evaluation of a management plan must include uncertainties due to implementation errors;
- Providing realistic assessments of uncertainty requires the integration of biological, environmental and social knowledge, and quantitative and qualitative uncertainties;
- Bayesian analysis provides a tool to integrate and analyze available knowledge on numeric uncertainty;
- Environmental Risk Assessment gives a framework to combine quantitative and qualitative uncertainties into a single assessment;
- Identifying which uncertainties are the most significant for a particular stock is important in focusing management and research;
- The major sources of uncertainty identified by the UNCOVER project vary across the studied target fish stocks/fisheries in their respective European regional seas. However, important sources of uncertainty include lack of compliance (*e.g.*, implementation error) with the management plan, unaccounted fishing mortality resulting from IUU fishing, discarding, and other forms of undependable fishery statistics. Additionally, uncertainties arising from significant changes in stock productivity (*e.g.*, recruitment, rates of growth and mortality, and maturation and spawning success) due to multispecies interactions and trophic controls, climate change and variability, environmental conditions and regime shifts, must be carefully monitored.
- Thus, management and recovery plans must be formulated so as to be precautionary to such uncertainties.

6 UNCOVER CASE STUDIES

6.1 Preamble

The UNCOVER project has produced a comprehensive report for each of the four Case Study (CS) Areas. Due to their substantial size, these CS reports are provided as appendices to this synthesis report:

1) CS Report for the Norwegian and Barents Seas (Appendix 1);
2) CS Report for the North Sea (Appendix 2);
3) CS Report for the Baltic Sea (Appendix 3);
4) CS Report for the Bay of Biscay and Iberian Peninsula (Appendix 4).

The CS reports were produced according to a common format whose main focus, for each area, was:

a) 'Environment, ecosystem and climate drivers';
b) 'Final recovery scenarios' for each of the target fish stocks/fisheries; and
c) 'New developments arising from UNCOVER' covering:
    i. Evaluation of strategies for stabilization and rebuilding of depleted fish stocks/fisheries and mitigating the impacts of fisheries on the marine ecosystem;
    ii. Consideration of stock regulating environmental processes into potential rebuilding strategies;
    iii. Incorporation of fisheries effects on stock structure and reproductive potential into recovery plans;
    iv. Consideration of changes in habitat dynamics due to global change into fisheries management plans;
    v. Incorporation of biological multispecies interactions into rebuilding strategies;
    vi. Incorporation of technical multispecies interactions and mixed-fisheries issues into rebuilding strategies;
    vii. Further development of the precautionary approach in fisheries management;
    viii. Consideration of socio-economic consequences of existing and alternative recovery plans.

Regarding c) i-vii, these are points highlighted in the project proposal, related to WP6, as being areas where the UNCOVER project will provide potential impacts to policy development.

Here, in section 6, we present a synopsis of the main results and conclusions of the four CS reports in the context of fish stock/fishery recovery.

6.2 Environment, ecosystem and climate drivers

6.2.1 Preamble

This theme covers the main issues of relevance to prudent and cohesive ecosystem-based management that, in turn, may influence the depletion and eventual recovery of the 11 targeted fish stocks in the four CS areas. It is important to recognize that: a) fisheries potentially affect the ecosystem and the fish stocks are affected by the ecosystems; b) humans form an integral part of ecosystems; and c) ecosystem-based management depends on the integrated management of human activities for promoting sustainable use of the seas by humans and conservation of healthy marine ecosystems.

The main substance of sub-sections 6.2-6.4 is based on information arising from the four Case Study reports. However, note should also be taken of section 4 ('Potential scientific constraints imposed on recovery strategies') of this report, namely sub-sections:

- 4.2 'Unaccounted fishing mortality: IUU fishing and discards';
- 4.3 'Climate change and variability, environmental controls, key habitats and system constraints';
- 4.4 'Multispecies interactions and trophic controls;
- 4.5 'Fisheries induced evolution';
- 4.6 'Invasive alien species, and new and recurring pathogens and diseases; and
- 4.7 'Constraints arising from the human factor'.

Sub-sections 4.2-4.7 variously include integration of the best available knowledge generated by both UNCOVER and other sources. Thus, the reader should be familiar with the above-mentioned issues in order to fully comprehend the overall context into which sub-sections 6.2 - 6.4 are placed.

6.2.2 Norwegian and Barents Seas

Our focus within this Case Study is on the Barents Sea—particularly on cod, herring and capelin. Connections with the Norwegian Sea are included when they are important for stocks found in the Barents Sea during parts of or all their life-cycle. We do not include a general description of the Norwegian Sea ecosystem, but refer the reader to Skjoldal (2004). The description of the Barents Sea ecosystem given here is to a large extent taken from the most recent status report for the Barents Sea ecosystem (Stiansen *et al.*, 2009).

Connections between the Norwegian Sea and the Barents Sea

Our CS focuses primarily on the Barents Sea. However, as there are several strong connections between the Norwegian Sea and the Barents Sea, it is relevant to take the Norwegian Sea into account in the study. The main connections are:

- Inflow of water masses from the Norwegian Sea to the Barents Sea. This affects the oceanographic conditions in the Barents Sea, also zooplankton advection is important.
- Herring and blue whiting only occur in the Barents Sea as juveniles. The main part of the juvenile herring (ages 0-3) is found in the Barents Sea, while the adult population of herring is found in the Norwegian Sea and the adjacent spawning areas on the Norwegian coast. The Barents Sea is only part of the nursery area for blue whiting, as both juvenile and adult blue whiting are found in the Norwegian Sea, with the main spawning area located west of Ireland.
- Minke whales have temperate/tropical mating and calving areas during winter and feeding areas in the Norwegian Sea and the Barents Sea in spring-autumn.

General geography and oceanography

The Barents Sea is a shelf area of about 1.4 million km^2, which borders the Norwegian Sea in the west and the Arctic Ocean in the north, and is part of the continental shelf area surrounding the Arctic Ocean. The extent of the Barents Sea is limited by the continental slope between

Norway and Spitsbergen in the west, the continental slope towards the Arctic Ocean in the north, Novaya Zemlya in the east and the coast of Norway and Russia in the south. The average depth is 230 m, with a maximum depth of about 500 m at the western entrance. There are several bank areas, with depths between 50–200 m.

The general circulation pattern in the Barents Sea is strongly influenced by topography. Warm Atlantic waters from the Norwegian Atlantic Current defined by salinity > 35 psu flows in through the western entrance. This current divides into two branches, one southern branch, which follows the coast eastwards against Novaya Zemlya and one northern branch, which flows into the Hopen Trench. The relative strength of these two branches depends on the local wind conditions in the Barents Sea. South of the Norwegian Atlantic Current and along the coastline flows the Norwegian Coastal Current. The Coastal Water is fresher than the Atlantic water, and has a stronger seasonal temperature signal. In the northern part of the Barents Sea fresh and cold Arctic water flows from northeast to southwest. The Atlantic and Arctic water masses are separated by the Polar Front, which is characterized by strong gradients in both temperature and salinity. In the western Barents Sea, the position of the front is relatively stable, although it tends to be pushed northwards during warm climatic periods. In the eastern part, the position of the front has large seasonal and year-to-year variations. Ice conditions show also large seasonal and year-to year variations. In the winter, the ice can cover most of the northern Barents Sea, while in the summer the whole sea may be ice-free. In general, the Barents Sea is characterized by large year-to-year variations in both heat content and ice conditions. The most important cause of this is variation in the amount and temperature of the Atlantic water entering the Barents Sea.

<u>Pollution status including eutrophication</u>

The Barents Sea is a cleaner environment than many other European seas, due to few local sources of pollution and large inflows of Atlantic water. However, for some types of pollutants there are well-known reasons for concern. Industries on the Kola Peninsula emit a wide spectrum of pollutants to the marine environment. The Barents Sea is influenced also by pollution originating outside the area, which is transported into the area by ocean currents, ice drift or by the atmosphere. Long-range atmospheric transport is the most widespread source of pollution affecting the Barents Sea.

The increasing oil and gas exploration activity and the transportation of oil along the coast of the Barents Sea are potential sources of contamination to the area. At present oil extraction activities are located in the North Sea and the Norwegian Sea. However, it is possible that future oil development will occur near the Lofoten Islands or in the Barents Sea. As such there would be an increased risk of pollution from oil spills or the normal running of the oil rigs impacting on the Barents Sea’s fish stocks. The major spawning areas and migration routes of several key species overlap with suspected oil reservoirs, and it seems likely that oil activity will in the future pose potential risks of environmental_impacts that could adversely affect the Barents Sea’s stocks. A project to develop a Decision Support Tool for use in the oil industry is being developed by a consortium involving IMR Bergen, Arktos, CEES and Statoil. The project aims to integrate oceanographic, plankton, larval and fisheries models into the existing risk assessment tools developed by Statoil. This will improve the level of biological realism in the risk assessment process, and reduce the uncertainties involved. The project will link existing models in order to track the impacts of an oil spill from the estimate of size, location and duration of a spill through effects on plankton and larvae, and impacting on the fish populations and fisheries of the Barents Sea.

Plankton

The Barents Sea is a spring bloom system, and during winter the primary production is close to zero. The timing of the phytoplankton bloom is variable throughout the Barents Sea, and has also high inter-annual variability. In early spring, the water is mixed but even though there are nutrients and light enough for production, the main bloom does not appear until the water becomes stratified. The stratification of the water masses in the different parts of the Barents Sea may occur in different ways: Through fresh surface water along the marginal ice zone due to ice melting, through solar heating of the surface waters in the Atlantic water masses, and through lateral spreading of coastal water in the southern coastal (Rey, 1981). As in many other areas, the dominating algal group in the Barents Sea is diatoms (Rey, 1993).

Zooplankton biomass has shown large annual variation in the Barents Sea. Crustaceans form the most important group of zooplankton, among which copepods of the genus *Calanus* play a key role in the ecosystem. *C. finmarchicus*, which is the most abundant in the Atlantic waters, is the main contributor to the zooplankton biomass. *C. glacialis* is the dominant contributor to zooplankton biomass of the Arctic region of the Barents Sea. The *Calanus* species are predominantly herbivorous, feeding especially on diatoms (Mauchline, 1998). Krill (euphausiids) and amphipods are two other groups of crustaceans playing a significant role in the ecosystem as food for both fish and marine mammals. The advection of species brought from the Norwegian Sea depends on the intensity of the Atlantic water inflow (Drobysheva, 1967; Drobysheva *et al.*, 2003).

Shellfish

The commercially most important crustaceans are Northern (pink) shrimp (*Pandalus borealis)* and Red king crab (*Paralithodes camtschatica*). Northern shrimp is an important prey for several fish species, especially cod, but also other fish stocks like blue whiting (Dolgov *et al.*, 2007). Consumption by cod significantly influences shrimp population dynamics (Berenboim *et al.*, 1992, 2001; Worm and Myers, 2003). The estimated amount of shrimp consumed by cod is on average much higher than shrimp landings. Shrimp are most abundant in the central parts of the Barents Sea and close to Svalbard, mostly at depths of 200–350 m (Aschan, 2000). Shrimp are common close to the sea floor, preferably silt or fine-grained sand. Shrimp in the southern parts of the Barents Sea grow and mature faster than shrimp in the central or northern parts. Red king crab was introduced to the Barents Sea in the 1960s (J¿rgensen *et al.*, 2003). The stock is growing and expanding eastwards and along the Norwegian coast westwards.

Fish communities

The Barents Sea is a relatively simple ecosystem with few fish species of potentially high abundance. These are Northeast Arctic cod, haddock, Barents Sea capelin, polar cod and immature Norwegian spring-spawning herring. In 2003-2006, blue whiting was also found in high abundance in the western part. The composition and distribution of species in the Barents Sea depends considerably on the position of the Polar Front. Variation in the recruitment of some species, including cod and herring, has been associated with changes in the influx of Atlantic waters into the Barents Sea. The geographical distribution of the fish stocks is closely linked to the temperature conditions. For example, cod is rarely found in water <0 ¡C. There are also strong interactions between the species, which influence stock recovery processes (Dolgov, 2009).

Capelin plays a major role in the Barents Sea ecosystem, even though the stock has fluctuated greatly in recent years. In summer, they migrate northwards and feed on the zooplankton as the ice margin retreats. Here, they have continuous access to new food resources in the productive zone that has just become ice-free. In September-October, the capelin may reach 80½N before migrating southwards again to spawn on the coasts of northern Norway and Russia. In the central and southern Barents Sea, capelin form prey for cod. Some marine mammals and seabirds also have a strong preference for capelin. Their feeding migration means that capelin function as transporters of biomass from the ice margin to the Norwegian coast, and that the production from areas covered by ice in winter is available for the cod. The capelin were heavily fished in the 1970s and the first half of the 1980s, at a time when there were few herring in the area. In the mid-1980s, the stock collapsed and has since varied greatly. Fishing is permitted when the stock is both strong enough for good recruitment and there is sufficient biomass to cover consumption needed by cod.

The three stock collapses of capelin (1985-1989, 1993-1997, and 2003-2006), with > 95% declines in biomass, caused impacts both downwards and upwards in the food-web, as highlighted by Gj¿s¾ter *et al.* (2009). Zooplankton abundance increased during the capelin collapse periods due to release in predation on them by capelin. Drastically reduced capelin biomass detrimentally affected its predators in various ways. Cod individual growth decreased, maturation was delayed and cannibalism increased. Various seabird species exhibited increased mortality rates and total recruitment failures, and breeding colonies were abandoned. Harp seals experienced food limitation and increased mortality from invading coastal areas and being caught in fishing gears, and recruitment failures. The effects were most serious during the 1985-1989 collapse and much less evident during the subsequent collapses, probably owing to greater availability of alternative food sources during the last two capelin collapses.

Cod are the most important predator fish in the Barents Sea and take a variety of prey. They spawn along the Norwegian coast from M¿re to Finnmark, and after hatching they are dependent on *C. finmarchicus* nauplii in the initial phase of their growth before they begin to take larger plankton and small fish. Cod is the most important predatory fish species in the Barents Sea. It feeds on a large range of prey, including the larger zooplankton species, most of the available fish species and shrimp. Cod prefer capelin as a prey, and feed on them heavily as the capelin spawning migration brings them into the southern and central Barents Sea. Fluctuations of the capelin stock may have a strong effect on growth, maturation and fecundity of cod (Gj¿s¾ter *et al.*, 2009). Capelin also indirectly affects cod recruitment, as cod cannibalism is reduced in years with high capelin biomass. The role of euphausiids for cod feeding increases in the years when capelin stock is at a low level (Ponomarenko and Yaragina 1990). Inter-annual changes of euphausiid abundance are important for the survival rate of cod during the first year of life (Ponomarenko 1973, 1984). *C. finmarchicus* are the main prey item for cod larvae. The *C. finmarchicus* parent stock overwinters in deep waters in the North Atlantic and the Norwegian Sea. They ascend to surface waters to spawn during late winter and early spring, when the spring bloom occurs. Their spawning time is closely related to temperature. At low temperatures they spawn so late in spring that most cod larvae, which hatch in April, do not find food (Ellertsen *et al.*, 1989; Solemdal, 1997; Sundby, 2000). This explains why in years with high temperatures, both strong and weak year-classes are produced while strong year-classes are absent when the temperature is low.

Norwegian spring-spawning herring spawn along the Norwegian coast from Lindesnes in the south to Vesterålen, grow up in the Barents Sea and feed in the Norwegian Sea as adults. In years when recruitment is good, most of the 0-group individuals drift passively into the Barents Sea, where they remain until they are about three years old. The young herring are predators on capelin larvae, and when there are many herring in the Barents Sea the capelin recruitment and the capelin stock will be depleted. This has major consequences for the balance between the species of fish in the area and for the ecosystem in general. A depleted capelin stock means less transport of production from the northern to the southern Barents Sea, and less supply of capelin as forage for cod and other predators. Herring only to a limited extent replaced capelin as prey for cod, so there will also be less production of species that depend upon capelin. Fishing of young herring is banned in the Barents Sea, but some catches of adult herring are taken in the southwestern part of the management area.

Haddock (*Melanogrammus aeglefinus*) is an important demersal gadoid species which undertakes extensive migrations to and from its spawning grounds in the Barents Sea. Haddock feed primarily on relative small benthic organisms including crustaceans, molluscs, echinoderms, worms and fish. They are omnivorous, however, and also feed on plankton. During capelin spawning, haddock prey on capelin and their eggs. The stock has substantial natural fluctuations, but is currently strong.

Blue whiting (*Micromesistius poutassou*) has its main distribution in the southern part of the northeast Atlantic. It mostly eats plankton, but larger individuals also take small fish (Dolgov *et al.*, 2010). It enters the southern Barents Sea in warm years, and is then preyed on by cod.

Polar cod (*Boreogadus saida*) are adapted to cold water and live mainly in the eastern and northern Barents Sea. They are an important prey for many marine mammals and seabirds, and are also preyed upon by cod, but have little commercial significance.

Deep-water redfish (*Sebastes mentella*) and golden redfish (*Sebastes marinus*) are slow-growing, long-lived deep-water species that have been heavily fished, and their fishing is now strictly regulated to recover the stocks. Redfish fry eat plankton, whereas larger individuals take larger prey, including fish.

Greenland halibut (*Reinhardtius hippoglossoides*) have an extensive distribution in deep water along the continental slope between the Barents Sea and the Norwegian Sea. It is also found in the deeper parts of the Barents Sea and north of Spitsbergen. Juveniles live in the northern parts of the Barents Sea. Fish, squids, octopus and crustaceans are the most important food of the species. Currently, the stock is depleted and fishing is strictly regulated.

<u>Seabirds and marine mammals</u>

The Barents Sea region is of paramount importance for supporting one of the largest concentrations of seabirds in the world (Belopol'skii, 1957; Norderhaug *et al.*, 1977; Anker-Nilssen *et al.*, 2000). About 40 species are thought to breed regularly around the northern part of the Norwegian Sea and the Barents Sea. The most typical species belong to the auk and gull families. In summer, most seabirds are closely associated with land for breeding whilst feeding themselves and chicks from the nearby sea. By winter, many birds disperse to the sea, seeking shelter in ice-free protected bays and fjords, or leave the region for southern climates. Seabirds play important roles in the Barents Sea ecosystem due to their abundance and position as predators at various levels in the pelagic food-web (Furness and Tasker, 1999; Mehlum and Gabrielsen, 1995; Anker Nilsen *et al.*, 2000; Barrett *et al.,* 2002).

About 20 million seabirds in the Barents Sea region consume about 1.2 million t of fish (*e.g.*, capelin, herring) and invertebrates (*e.g.*, crustacean plankton, shellfish), most of which is accounted for by Brünnich's guillemots, Atlantic puffins and northern fulmars (Barrett *et al.,* 2002). Compared with other predators (*e.g.* cod, whales, seals) and humans, seabirds account for a minor part (8–15%) of the total fish harvest and even less (5–11%) of the fish harvest of top predators in the Barents Sea (Barrett *et al.*, 2002). However, collapses in capelin and herring stocks have demonstrated the susceptibility of guillemots, puffins, and kittiwakes, in particular, to such collapses as evident from marked, related declines in the breeding success of these seabirds in various colonies in Norwegian and Russian coastal areas of the Barents Sea (Furness and Barrett, 1985; Barrett *et al.*, 1987; Vader *et al.*, 1990; Barrett and Krasnov, 1996).

About 24 species of marine mammals regularly occur in the Barents Sea, comprising seven pinnipeds (seals), twelve large cetaceans (large whales) and five small cetaceans (porpoises and dolphins). Some of these species (including all the baleen whales) have temperate/tropical mating and calving areas and feeding areas in the Barents Sea and the Norwegian Sea, while others reside in the Barents Sea all year round. The most important marine mammals in the ecosystem are minke whale (*Balaenoptera acutorostrata*) and harp seal *(Phoca groenlandica).* Minke whales are found both in the Norwegian and Barents Sea during spring-autumn. Two harp seal populations inhabit the Northeast Atlantic: one in the Greenland Sea (West-Ice), which breeds and moults just north of Jan Mayen; and the East-Ice stock, which congregate in the White Sea to breed and stays in the Barents Sea the rest of the year. Parts of the West-Ice stock can also be found in the Barents Sea in summer/autumn. The Norwegian coast has experienced periodic invasions of harp seals.

Marine mammals are significant ecosystem components. In the Barents Sea the marine mammals may eat 1.5 times the amount of fish caught by the fisheries. Minke whales and harp seals may consume 1.8 million and 3–5 million t of prey per year, respectively (*e.g.*, crustaceans, capelin, herring, polar cod and gadoid fish; Folkow *et al.*, 2000, Nilssen *et al.*, 2000). Functional relationships between marine mammals and their prey seem closely related to fluctuations in the marine systems. Both minke whales and harp seals switch between krill, capelin and herring depending on the availability of the different prey species (Lindstr¿m *et al.*, 1998, Haug *et al.*, 1995, Nilssen *et al.*, 2000).

6.2.3 North Sea

<u>General geography and oceanography</u>

The North Sea is a mid-latitude, relatively shallow, continental shelf sea covering about 570 000 km^2 with an average depth of about 90 m (Jones, 1982). It is bounded by the coasts of Norway, Denmark, Germany, the Netherlands, Belgium, France and Great Britain and recognized as a Large Marine Ecosystem (McGlade, 2002). The continental coastal zone (mean depth 15 m) represents an area of about 60 000 km^2, under strong influence of terrigenous inputs (Mackinson and Daskalov, 2007). The dominant physical division in the North Sea is between the north and the south. The shallow (<50 m) southeastern part is sharply separated by the Dogger Bank from a much deeper (50–100 m) central part that runs north along the British coast. The central northern part of the shelf gradually slopes down to 200 m before reaching the shelf edge. Running east along the Norwegian coast into the Skagerrak is the Norwegian Trench with depths up to 500m, leading to the Kattegat which has depths similar to the main part of the North Sea (ICES, 2008b).

Circulation in the North Sea forms an anticlockwise gyre. However, evidence suggests that wind-forcing may temporally reverse this pattern or split into two separate gyres in the north and south (Kauker and von Storch, 2000). Variations in circulation may be important for specific life history stages of various species because they can affect the transport of eggs and larvae to specific nursery areas or feeding conditions. The main inflow is of relatively warm and more saline North Atlantic water along the shelf break into the Norwegian Trench, and also around the Shetland and Orkney Islands. The residence time of North Sea water is about one year. Changes in zooplankton and fish distributions have been linked to the strength of these inflows.

The temperature of surface waters is largely controlled by local solar heating and atmospheric heat exchange. Temperature in the deeper waters of the northern North Sea is influenced largely by the inflow of Atlantic water (ICES, 2008b). Tidal mixing and local heating force the development of a seasonal stratification from April/May to September in most parts of the North Sea (Sharples *et al.*, 2006). In these stratified waters the density boundary between the mixed and stable water divides the inorganic nutrient rich bottom water layer from the wind mixed upper layer where nutrients may be limiting. This stratification is absent in the shallower waters of the southern North Sea, which remains mixed for most of the year. The extent and duration of this mixed area is probably an important environmental factor for fish in this area (ICES 2008b).

The inflow of Atlantic water shows large seasonal and annual variability, driven by winds and pressure gradients along the continental slope from Iceland to Gibraltar, known as the North Atlantic Oscillation (NAO) (Pingree, 2005). This has a large impact on the salinity and temperature variations in the North Sea and has been linked to population dynamics. For example, changes in the inflow of water driven by the NAO have been related to changes in plankton abundance and composition in the North Sea (Reid *et al.* 2003), and also to the variance in recruitment or distribution of the five major North Sea fish populations (Svendsen *et al.*, 1995).

Evidence suggests that sea surface temperatures of the North Sea have been increasing since June 2001. Sea surface temperatures of North Atlantic and UK coastal waters have warmed by 0.2 – 0.6 ^{o}C decade^{-1}. North Sea bottom temperatures in winter have risen by 1.6 ^{o}C over 25 years and a 1 ^{o}C increase occurred in 1988-1998 alone (Dulvy *et al.*, 2008a). Surface salinity also rose in recent years but from a recent low value to close to the long-term average (ICES, 2008b).

The level of nitrates and phosphates has increased over recent decades due to higher concentrations from rivers, coastal runoff and atmospheric inputs. The extensive inputs of these nutrients and the restricted nature of the North Sea's circulation have led to an increase in eutrophication events, algal blooms and macroalgal mats (Mackinson and Daskalov, 2007). There is marked eutrophication in some areas of the North Sea, particularly in the Wadden Sea area, the southern part of the Kattegat and coastal part of the Skagerrak, as well as in shallow waters and estuaries along the UK and European mainland coast (ICES, 2008b).

The variation in the physical and chemical environment of the North Sea is reflected in the variety of flora and fauna.

Fish communities and catches

A total of 224 fish species have been recorded in the North Sea. These species originate from three zoogeographical regions: 66 species are of Boreal (northern) origin, 110 species are Lusitanian (southern) and 48 species are Atlantic. Diversity is lower in the shallow southern North Sea and eastern Channel (Rogers *et al.*, 1998). Inshore, where there is more variation in sediment types and a higher level of spatial patchiness, the species diversity is generally higher (Greenstreet and Hall, 1996). Estimates of the total biomass of North Sea fish in the 1980s were about 12 million t, approximately 67% of which consisted of the major eleven exploited species (Daan *et al.*, 1990). Throughout the year, the pelagic component is dominated by herring. Mackerel (*Scomber scombrus*) and horse mackerel (*Trachurus trachurus*) are mainly present in summer when they enter the area from the south and from the northwest. Dominating gadoid species are cod, haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), and saithe (*Pollachius virens*), whereas the main flatfish species are common dab (*Limanda limanda*), plaice, long rough dab (*Hippoglossoides platessoides*), lemon sole (*Microstomus kitt*), and sole (*Solea vulgaris*). The major forage fish species are sandeels (*Ammodytes marinus*), Norway pout (*Trisopterus esmarki*), and sprat, but juvenile herring and gadoids also represent an important part of the forage stock (ICES, 2008b).

The North Sea supplies about two million t of fish each year from the three main sectors. Industrial fisheries provide roughly one million t of this, which is processed into fishmeal and fish oil, not for human consumption. The pelagic fishery is the next biggest proportion (approximately 700 000 t). The demersal fisheries accounts for approximately 300 000 t. However, many of the demersal stocks have been overexploited and catches have been decreasing continuously since the early 1980s. North Sea cod is at the lowest levels ever recorded and is subject to a recovery plan. It is thought to be suffering from reduced reproductive capacity and is at risk of being harvested unsustainably (ICES, 2009a). Plaice is currently considered to have full reproductive capacity and is being harvested sustainably (ICES, 2009b).

Total catches of North Sea fish since 1800s provide the broader context for the declines seen over the last few decades (Mackinson and Daskalov, 2007).

Pelagic, planktivorous fish are a very important component of the North Sea ecosystem. North Sea herring and mackerel were heavily overfished in the 1960s and 1970s and the stocks collapsed. The herring stock has recovered following a closure of the fishery in the late 1970s. North Sea stocks of mackerel have not recovered. However, mackerel from the Western stock (in the NE Atlantic) is abundant and uses the northern North Sea as part of its feeding area (ICES, 2008b). Herring is considered to have a major impact on most other fish stocks as prey and predator and is itself prey for seabirds and sea mammals. Herring spawning and nursery areas, being near the coasts, are particularly sensitive and vulnerable to anthropogenic influences. The most serious of these is the increasing extraction of marine sand and gravel and the development of wind farms on existing and historic spawning beds (ICES, 2009c).

Seabirds and marine mammals

About 2.5 million pairs of seabirds breed around the coasts of the North Sea, belonging to some 28 species. Due to differences in life history strategy, seabirds do not represent a single homogeneous group that responds to fisheries in a uniform way. There is a significant and high degree of relatedness between seabirds and both pelagic and demersal fisheries and fish stocks. Local breeding success of some species has been low in some recent years and this has been related to a local shortage of forage fish (ICES, 2008b).

Sixteen species of cetacean commonly occur in the North Sea, the most frequently observed being the harbour porpoise (*Phocoena phocoena*). Other species of toothed cetacean that are sighted regularly include long-finned pilot whales (*Globicephala melas*), the common dolphin (*Delphinus delphis*), the whitesided dolphin (*Lagenorhynchus acutus*), Risso's dolphin (*Grampus griseus*) and the killer whale (*Orcinus orca*) (OSPAR, 2000). However, most of these must be considered vagrants and only a few constitute resident representatives of the North Sea ecosystem (ICES, 2008b).

Two species of seal are regularly observed and breed in the North Sea, the grey seal (*Halichoerus grypus*) and the harbour seal (*Phoca vitulina*). The grey seal is most abundant in exposed locations in the northwest, while the harbour seal is more widespread, preferring mud and sand flats (Mackinson and Daskalov, 2007). Estimated annual prey consumption increased almost 3-fold from 49 000 t in 1985 to 161 000 t in 2002 due to increases in seal population size. In 2002, grey seals in the North Sea consumed mainly sandeel (69 000 t), cod (8 300 t), haddock (6 500 t), and plaice (5 200 t), but commercial species such as whiting, saithe, ling, and herring were also taken. Scottish fishers claim that the increasing grey seal population, rather than their own activities, is responsible for the reduced availability of commercial fish species, and they advocate the culling of seals (ICES, 2008b). Inclusion of the new grey seal diet data and seal population abundance are expected to reduce only slightly the historic estimates of cod consumption in the North Sea by seals. This suggests that the new estimates of seal predation will not alter the current perception of North Sea cod stock dynamics (ICES, 2009a).

Environmental drivers

Environmental events affect the status of the North Sea ecosystem, including its fishery and the considerable variation in SSB of demersal stocks, including plaice and cod, show that the combined impacts of fishing and environmental drivers are hard to separate (ICES 2008b). In 2007, ICES concluded that no environmental signals were identified to be specifically considered in assessment or management (ICES 2008b). However, recruitment of some commercially important gadoids is at a low level and this has led to speculation that the ecosystem may be changing in an irreversible direction.

One of the most important examples of how environmental drivers can affect stock dynamics is the 'gadoid outburst' during the late 1960s up to the early 1980s, which was characterized by a sudden increase in the abundance of large, commercially important gadoid species. During this period cod, haddock, whiting, and saithe all produced a series of strong year-classes. The most likely explanation for the gadoid outburst is climate forcing (Cushing, 1984). Following the outburst there was a decline in stock levels. As the high fishing pressure, which had already reduced the spawning potential of cod, did not decline fast enough in line with the environmentally induced decline in recruitment, the stock collapsed (Caddy and Agnew, 2004).

Haddock and saithe have since recovered but the decline of cod has continued largely due to fishing pressure which was so high in the 1990s that the stock was predicted to collapse (Cook *et al.*, 1997). However, the warm climate and low zooplankton abundance (particularly of *C. finmarchicus*) have also been implicated in the decline, and lack of recovery of cod (Planque and Fredou, 1999; Beaugrand *et al.*, 2003; Drinkwater, 2005; Rindorf and Lewy, 2006).

Current recovery plans generally assume that there has been no underlying change in environmental conditions, and hence that the 'carrying-capacity' and the structure of the food-web of the North Sea ecosystem has not changed. It is now widely appreciated that this might not be the case as the North Sea ecosystem has undergone a regime shift in the 1980s, centered in two periods of rapid changes (1982-1985 and 1987-1988). The changes in large-scale hydro-meteorological forcing, affecting also local hydrographic variability, have caused drastic changes in plankton communities, which have gone on to have impacts across the ecosystem. For example, fish recruitment success has decreased in gadoids and initial increased in flatfish recruitment followed by a more variable phase after the second centre period (Beaugrand *et al.*, 2003; Reid *et al.*, 2003).

Generally, the period after the regime established the new state in 1988 is characterized by warmer temperature, low abundance of northern fish and zooplankton species (Beaugrand *et al.*, 2002), and increasing abundance and diversity of southern plankton (Reid *et al.*, 2003) and fish (Beare *et al.*, 2004a) species. These changes purportedly had a negative impact on North Sea cod recruitment as *C. finmarchicus* is a major prey for cod larvae (it is the right size and occurs at the right time of year). Consequently, the loss of this vital prey species could impact the ability of cod to recover because of anticipated failures in future cod recruitment (Beaugrand *et al.*, 2003). Regime shifts have profound implications and should be incorporated into management strategies, consistent with ecosystem-based management (Rothschild and Shannon, 2004).

'Non-stationarity' of natural ecosystems has also been a confounding factor influencing the apparent success or failure of closure areas in the North Atlantic area, including the southern North Sea 'Plaice box' (van Keeken *et al.* 2007). In the North Sea, juvenile plaice are typically concentrated in shallow inshore waters and move gradually offshore as they become larger. Surveys in the Wadden Sea however have shown that 1-group plaice is almost absent from the area where it once was very abundant. This is probably linked to changes in the productivity of the region but also the changing temperature of the southern North Sea which has warmed considerably in recent years. The 'Plaice Box' is now much less effective as a management measure in comparison with the situation 10 or 15 years ago.

Sandeels are a vital forage component of most piscivorous fish species (Daan, 1989; Hislop *et al.*, 1997) as well as birds (Wanless *et al.*, 1998) and marine mammals (Santos *et al.*, 2004). However, the spawning biomass of sandeel has declined since a peak in 1998 and recruitment has been low since 2002. This situation is expected to have severe implications for the North Sea ecosystem (ICES 2008b).

Reliable information on trends in biomass of benthic species is largely lacking. Although there is a substantial body of evidence that towed bottom-gears kill off large quantities of benthic animals and direct effects are undoubtedly large (Collie *et al.*, 2000; Kaiser *et al.*, 2006), the long-term impact is mainly unknown. Large-scale discarding of a variety of macrobenthos species occurs in the mixed demersal trawl fisheries and this may cause a shortage of food for demersal fish (ICES, 2008b).

6.2.4 Baltic Sea

<u>Environmental conditions including climate and multispecies considerations</u>

The Baltic Sea is a semi-enclosed inland sea, forming one of the world's largest brackish water bodies, connected with the North Sea by narrow and shallow sounds that limit water exchange, particularly inflows of more saline, oxygen-rich water. The Baltic Sea receives a larger amount of freshwater via riverine discharges, run-off from land and precipitation than it loses via evaporation, resulting in a surplus of freshwater (LeppŠranta and Myrberg, 2009). Thus, it has a characteristic estuarine circulation in which a surface layer of lower salinity water flows outwards into the North Sea, and a compensatory sub-surface layer of more saline water moves in the opposite direction (Fonselius and Valderema, 2003). There is very slow mixing between the two layers, due to almost permanent stratification caused by the marked salinity gradient (halocline), that hinders oxygen from the overlying water from mixing downwards in the water column, and which is exacerbated by the lack of tides (LeppŠranta and Myrberg, 2009). In the central Baltic Sea ('Baltic Proper'), with its three associated deep basins (Bornholm, Basin, Gdansk, and Gotland Deep)—forming the geographical focus for the fish stocks highlighted in this paper by the UNCOVER project—the halocline occurs at 50-100 m.

The Baltic Sea ecosystem is highly susceptible to climatic and oceanographic variability and change, including the frequency and magnitude of sporadic, dense, saline water inflows from the North Sea which form the only effective means of flushing and increased oxygenation in the deeper basins (MatthŠus and Franck, 1992; MatthŠus and Schinke, 1994; Jansson and Dahlberg, 1999). Stagnation periods follow these inflows in the main basins with declining oxygen and salinity. Larger inflows happened about every four to five years until the 1980s, but in recent decades the time between two inflow events has doubled with the last major inflows occurring in 1983, 1993 and 2003 (HELCOM, 2007). The most stagnant conditions prevail in the Baltic Proper's basins (Leppäranta and Myrberg, 2009). The biological oxygen demand due to eutrophication, and the long average retention time of water in the Baltic with an exchange rate of 32 years for one complete exchange of the water body, makes the Baltic Sea more sensitive to long periods between inflows (Jansson and Dahlberg, 1999).

Baltic Sea fish are a mixture of marine, brackish and freshwater species (Jansson and Dahlberg, 1999). Cod, herring and sprat dominate the marine fish community in numbers and biomass, and generally constitute >90% of the total annual fisheries catch in the Baltic Proper (Sparholt, 1994; Thurow, 1997; Hammer *et al.*, 2008). Multispecies interactions in the Baltic Sea ecosystem are dominated by these three fish species, including adult cod preying on herring and sprat as well as cannibalistically on small cod, herring and sprat preying on cod eggs and larvae, and sprat being cannibals on their eggs (Sparholt, 1994; Kšster and Mšllmann, 2000a,b; Uzars and Pliksh, 2000).

Climate change has already manifested itself on the Baltic Sea environment and is predicted to continue during this century (HELCOM, 2007; MacKenzie and Schiedek, 2007). The Baltic Sea's temperature rose about six times faster than the global ocean average over the past 25 years, exhibiting one of the highest increase rates of any large marine ecosystem (EEA, 2008; Belkin, 2009). Thus, the Baltic Sea ecosystem and fisheries management should be viewed in the context of a rapidly changing environment with mean annual sea surface temperature predicted to rise by ca. 2¼4¼C by the end of the 21st century, and anticipated increased freshwater input and reduced levels of marine inflows leading to reduced salinity, stronger stratification and reduced oxygenation of the deeper waters (HELCOM, 2007). Marine tolerant species will be relatively disadvantaged and their distributions will partially contract as the marine domain of the Baltic Sea shrinks (MacKenzie *et al.*, 2007a).

Reduced inflows from the North Sea and warm temperatures combined with heavy fishing pressure on cod during the past three decades has caused a shift in the fish community from cod to clupeids (herring and sprat) by first weakening cod recruitment (Jarre-Teichmann *et al.*, 2000; Kšster *et al.*, 2005a), thereby releasing sprat from predation pressure by cod (Kšster *et al.*, 2003a) and subsequently generating favourable recruitment conditions for sprat, thereby causing increased clupeid predation on cod early life stages (Kšster and Mšllmann, 2000a) and essential prey for cod larvae (Mšllmann *et al.*, 2003). Such changes are major features of a comprehensive regime shift experienced by the Baltic Proper ecosystem, moving from a cod to a sprat dominated system (Mšllmann *et al.*, 2008, 2009). Some key system dynamics are outlined as follows.

Cod and sprat spawn in the deep Baltic basins, with overlapping spawning times, but climate affects the recruitment of cod and sprat differently, with a high NAO index being negatively associated with recruitment of the former and positively associated with recruitment of the latter (Kšster *et al.*, 2003a). The physical conditions in the Baltic Sea respond to climate change through: i) direct air-sea interaction, ii) the magnitude of freshwater run-off, and iii) interactions with the ocean at the open boundary (Stigebrandt and Gustafsson, 2003). Surface temperatures are determined by the dominance of either westerly winds with mild 'Atlantic air, (*i.e.*, high NAO) or easterly winds with cold 'continental air' resulting in low temperatures and extensive ice cover (*i.e.*, low NAO). River run-off affects salinity by directly freshening surface waters. Renewal of the bottom water of the deep Baltic basins by inflows of saline and oxygenated water from the North Sea via the Kattegat and Belt Sea is indirectly prevented because increased zonal atmospheric circulation increases the freshwater input (MatthŠus and Schinke, 1999). The period of high NAO index since the late 1980s resulted in an increase in average water temperatures (Fonselius and Valderrama, 2003). The dominance of 'westerly weather' increased further the amount of run-off, thereby drastically decreasing salinities (HŠnninen *et al.*, 2000).

Important processes affecting recruitment of cod and sprat in the Baltic are the: i) spatial distribution of egg production is dependent on ambient hydrographic conditions (cod: MacKenzie *et al.*, 2000; sprat: Parmanne *et al.*, 1994); ii) quantity of egg production in relation to food availability (cod: Kraus *et al.*, 2002; sprat: Alekseeva *et al.*, 1997); iii) egg developmental success in relation to oxygen concentration for cod (Nissling *et al.*, 1994; Wieland *et al.*, 1994) and temperature for sprat (Nissling, 2004) at depths of incubation; iv) egg predation by clupeids dependent on predator-prey overlap (cod: Kšster and Mšllmann, 2000a; sprat: Kšster and Mšllmann, 2000b); v) larval development in relation to hydrographic conditions (cod: Nissling, 1994, sprat: Baumann *et al.*, 2006) and food availability (cod: Hinrichsen *et al.*, 2002a; sprat: Voss *et al.*, 2009 this vol.); and vi) predation on juveniles (cod: Sparholt, 1994; sprat: Kšster *et al.*, 2003a). All the above processes are driven by hydrographic and climatic conditions negatively affecting the cod population (Kšster et. al., 2003a), while the sprat stock benefited from them (Kšster *et al.*, 2003b; Voss *et al.* 2009) despite a developing industrial fishery targeted at the latter.

For example, successful spawning, fertilization and egg development in cod only occurs in deep-water layers with oxygen concentrations >2ml l^{-1} and a salinity of >11 psu, with the volume of water where this is fulfilled known as the cod ‘reproductive volume’ (RV) (MacKenzie *et al.*, 2000). Processes affecting the RV are: i) the magnitude of inflows of saline oxygenated water from the western Baltic (MacKenzie *et al.*, 2000); ii) temperature regimes in the western Baltic during winter, which affect the oxygen solubility prior to advection (Hinrichsen *et al.*, 2002b); iii) river run-off (Hinrichsen *et al.*, 2002b); and iv) oxygen consumption by biological processes (Hansson and Rudstam, 1990). Climate induced reduction in the inflow of North Sea water since the 1980s has substantially shrunk the available cod reproductive volume thus resulting in high cod egg mortality, especially in the more eastern Gdansk Deep and Gotland Basin compared with the Bornholm Deep (MacKenzie *et al.*, 2000).

The predation intensity by sprat on cod eggs increases in stagnation periods, contributing to the low reproductive success of cod in the last three decades. Sprat eggs float at a shallower depth than cod eggs, due to a different specific gravity, and their survival is less affected by poor oxygen conditions then by temperature. Weak year-classes of sprat tend to arise after cold winters which generate low temperatures (<4¡C) in the intermediate water layer during spawning in spring. Accordingly, the trend for warmer winters, and associated favorable hydrographic conditions for egg survival, contributes to the high reproductive success of sprat (MacKenzie *et al.*, 2008).

Zooplankton availability as food may also affect both cod and clupeid larval survival. In the Baltic Proper, comparatively high cod and herring SSB and recruitment is associated with increased abundance and biomass of the copepod *Pseudocalanus acuspes* during cooler, higher salinity/oxygen conditions connected with good inflow, while sprat recruitment is favoured by increased abundances of the copepods *Acartia* spp. and *Temora longicornis* and warm spring temperatures connected with a strong NAO index (Mšllmann *et al.*, 2000, 2003; Alheit *et al.*, 2005; Mšllmann *et al.*, 2005).

Also fluctuations in herring and sprat growth are influenced by climate (Mšllmann *et al.*, 2005), with a substantial reduction in herring weight at age resulting in a continuous decline of the total biomass since the early 1980s (Kšster *et al.*, 2003a). Growth of cod has been described as density dependent and affected largely by the relative availability of clupeid prey (Baranova and Uzars, 1986; Baranova, 1992). Thus, concurrent with the decline in stock size an increase in weight-at-age is observed (Kšster *et al.*, 2005b). The increase continued until the early 1990s, followed by a decline in age-specific weight, potentially related to the cod spawning time changing from spring to summer (ICES, 2006a)

The different driving forces (climate change, fishing, eutrophication, species invasions) interact with each other, and even in isolation would have major and complex impacts on the Baltic ecosystem (MacKenzie *et al.*, 2007a). However, forecasting how fish populations will respond to the combination of these changes will require much greater understanding of how food-webs are structured than is presently available (MacKenzie *et al.*, 2007a).

Considered in isolation, the consequences of the changes in temperature (warmer) and salinity (lower) on the major fish populations may be relatively easy to forecast (MacKenzie *et al.*, 2007a). For example, warm temperatures improve reproductive success in fish species near their northern limits of distribution, including some northern Baltic herring populations (Kornilovs, 1995; Axenrot and Hansson, 2003), the Baltic sprat population (MacKenzie and Kšster, 2004; Baumann *et al.*, 2006) and possibly the Kattegat sole population. However, an expected reduction in average salinity (Meier, 2006) will restrict spawning habitats of these and other marine-brackish water species (Nissling *et al.*, 2002; Ojaveer and Kalejs, 2005). As a result the beneficial effects of higher temperature on the reproduction of some species and populations will be partly counteracted by the reduction in salinity. The relative importance of these two effects is not presently clear, partly because at the temporal and spatial scales relevant for fish life-history it is not known by how much temperatures will rise, by how much salinities might fall, nor how some of the various fish species would react physiologically and genetically (ICES, 2005a) to these changes.

Similarly, it is difficult to forecast how the eastern Baltic cod population will react to future climate change. Cod egg survival and recruitment is improved when salinities and oxygen concentrations in deep water are both high (Plikshs *et al.*, 1993; Vallin *et al.*, 1999; Kšster *et al.*, 2003a). The anticipated reduction in salinity (Meier, 2006; Meier *et al.*, 2006) will further constrain cod spawning habitats (Plikshs *et al.*, 1993; Vallin *et al.*, 1999; MacKenzie *et al.*, 2000). Moreover higher water temperatures will increase oxygen consumption rates in the deep parts of the Baltic where cod eggs live, thereby further reducing the size of cod spawning habitats (MacKenzie *et al.*, 1996). Higher water temperatures in winter in the western Baltic will also reduce oxygen concentrations because of the lower solubility of oxygen in warmer water flowing from the western Baltic to eastern Baltic deep basins during winter (Hinrichsen *et al.*, 2002b). Although nutrient loading is expected to decrease over the coming decades (Gren *et al.*, 2000), large pools of nutrients and organic matter in the deep water and sediments of the Baltic (Conley *et al.*, 2002) and its watershed will persist for many years (HELCOM, 1996). As a result, oxygen conditions in the deep layers will only slowly improve as nutrient loading rates decrease. Lastly, if predators of cod eggs (*e.g.* herring, sprat; Kšster & Mšllmann, 2000a) benefit more from climate change than cod itself, then predator–prey interactions among the fish species will also suppress the cod population. Consequently, the present clupeid-dominated regime in the Central Baltic fish community (Kšster *et al.*, 2003b; Alheit *et al.*, 2005) could become stabilized.

Changes in exploitation have a strong potential to alter food-web structure and thus to modify the outcome of climate-induced changes. For example, a lower exploitation of cod would increase the chance of high reproductive success despite a generally low carrying capacity. Surviving cod offspring would increase predation pressure on sprat, whose biomass would fall, thereby lowering also the predation by sprat on cod eggs and *Pseudocalanus acuspes*. This interaction would have a feedback because the reduced sprat biomass would lead to higher reproductive success of cod and enhanced feeding conditions for cod larvae, as well as juvenile and adult herring and sprat. Clupeid growth rates would also increase (MacKenzie *et al.*, 2007a). However, the earlier considerations on the reproductive biology of cod suggest that the eastern Baltic cod stock will suffer under future climate change and could collapse completely, as has happened previously for dab and plaice in the central Baltic (Temming, 1989; Nissling *et al.*, 2002), unless some of these negative effects are counteracted by both lower cod fishing mortality rates and an increase in inflow intensity and frequency.

General predictions regarding climate change and fish communities

Despite the uncertainties and contrasting effects of how climate change might affect the fish community in the Baltic region, two general predictions are possible at the present time. First, a systematic change in the hydrographic environment, for example towards warmer, fresher conditions (RŠisŠnen *et al.*, 2004; BACC, 2008; Meier *et al.*, 2006), will lead to relative changes in the existing species composition and their distribution within the Baltic. For example, the ranges of marine species can be expected to contract, and the habitats of cold-adapted species whose habitats are presently restricted by warm temperatures, such as salmon (Alm, 1958), can also be expected to shrink. Second, a decrease in salinity will inhibit invasion by new species unless they are tolerant to these conditions (Elmgren and Hill, 1997; Schiedek, 1997; LeppŠkoski *et al.*, 2002). Hence, among those temperate marine fish species which have recently been expanding their geographic ranges northwards (*e.g.* Brander *et al.*, 2003), only a small number will successfully colonize the Baltic because few will be able to reproduce successfully in its low salinity (Ojaveer and Kalejs, 2005). A reduction in salinity, particularly in the Belt Sea (Meier, 2006) where the horizontal salinity gradient in the Baltic is largest (HELCOM, 2002), will, therefore, lead to further restrictions in range and biomass of existing 'marine' fish species such as plaice, cod, sole and sprat, which may not be compensated by immigration of new species. Moreover, recovery of other marine species which have already collapsed (*e.g.* dab) will be inhibited or perhaps prevented by further reduction in salinity. These processes could lead to a decrease in the overall species richness and biodiversity of the Baltic fish community.

Whether the decrease in production and biomass of marine species will be offset completely by increases by freshwater species (thereby maintaining a similar overall level of fish production), is unclear because of uncertainties in how individual species will respond to climate change, interactions among species within the foodweb and rates of adaptation by species living in the Baltic Sea and also by those which will immigrate and invade. The changes in species composition and distribution will differ spatially, depending on each species' physiological tolerance for low salinity and the existence of saline water masses having sufficient oxygen concentrations to sustain life stage development. For example, sprat will still be able to spawn successfully in the southern and central Baltic, but its spawning habitat will likely become further restricted in northern and eastern areas; in contrast the spawning habitats of some coastal freshwater and brackish species such as perch and pikeperch could expand. The salinity and temperature-mediated changes in spatial distribution will affect fishing opportunities and catches in the Baltic: fishing fleets whose target species are the more marine species will have to relocate to different (*i.e.* higher salinity) fishing areas, or remain in present locations and target the existing and any immigrating species which tolerate brackish conditions.

Climate change will not only alter the abiotic conditions in the Baltic, and therefore only the physiological suitability of existing fish habitats. Changes in salinity and temperature, as well as seasonal heat and water budgets, will also lead to changes in stratification and, therefore, the characteristics of food-webs (*e.g.* species composition of the plankton and benthic communities, timing and duration of spring blooms). For example, the predicted reduction in ice cover (and therefore improved underwater light conditions) should lead to an earlier onset of stratification and the spring phytoplankton bloom (BACC, 2008). However, the warmer temperatures will also lead to an intensification of stratification, and therefore, less vertical mixing of nutrients into the photic zone during the post-bloom period. In the open ocean, increased stratification in the recent (post-1999) warm period has reduced primary production (Behrenfeld *et al.*, 2006). As primary production rates are positively related to fish production and yield in marine ecosystems (Nixon, 1988; Nielsen and Richardson, 1996; Ware and Thomson, 2005), overall fish production might decrease if stratification increases. These effects might be relatively more pronounced in the southern Baltic, which is less frequently covered by ice.

Future climate change will interact with eutrophication in the Baltic Sea. The projected increase in annual and winter precipitation will lead to increased runoff of nutrients (nitrogen and phosphorous) stored in the Baltic watershed (BACC, 2008). This supply could offset the negative effects of increased stratification on primary (and probably fish) production. It is, therefore, uncertain how the combined effects of climate change and eutrophication will affect lower trophic levels and overall fish production.

6.2.5 Bay of Biscay and Iberian Peninsula

Geography, oceanography and fish communities

The area of the Bay of Biscay and Iberian Peninsula extends from 48ºN to 36ºN and from 11ºW to the coastlines of France, Spain and Portugal. This area corresponds biogeographically to a subtropical/ boreal transition zone (OSPAR, 2000). Its topographical diversity is reflected in the ecological richness of the area, containing a wide distribution of fish species, some of them with commercial relevance for the surrounding countries.

The Bay of Biscay is an open oceanic bay located in the eastern North Atlantic, between 43.5¡ and 48.5¡ N and 8.5¡ and 1.5¡ W. The continental shelf in the French sector of the Bay of Biscay is between 150-180 km wide at the northern extreme (Armorican shelf), becoming narrower, about 50 km wide, towards the southern part (Aquitaine shelf). From coast to offshore, the depth increases almost regularly down to 200 m. In contrast, the continental shelf in the Spanish sector (Cantabrian Sea) is extremely narrow, with a mean width between 30-40 km, a steep slope and a rough bottom.

Within the fish community, European hake, anchovy, and tunas (*Thunnus alalunga* and *T. thynnus*) currently are the most important commercial fish species in the Bay of Biscay. Whilst tunas are a large-scale migratory species, European hake and anchovy are the main fisheries restricted to the Bay of Biscay ecosystem (considering the ecosystem and the use by human communities).

The Bay of Biscay lies in the inter-gyre region that separates the major oceanic gyres of the North Atlantic: the sub-polar, extending approximately between 45¡-65¡N and driven by the Icelandic low pressure system, and the sub-tropical, between 10¡-40¡N and forced by the anticyclonic atmospheric circulation around the Azores high pressure cell (Pollard *et al.*, 1996). The properties and origin of Eastern North Atlantic Central Water (100-600m) and Mediterranean Water (600.1 500m) interact with other physical features affecting the dynamics in the area (Koutsikopoulus and Le Cann, 1996).

General circulation is dominated by the mesoscale activity (Friocourt *et al.,* 2008); the oceanic domain of the Bay of Biscay presents a weak anticyclonic circulation (1-2 cm•s-1) at the levels of ENACW and MW. Over the continental slope a stronger poleward current is observed, the Iberian Poleward Current (IPC), named also 'Navidad' (Christmas) current (Pingree and Le Cann, 1990, 1992) or Portugal Coastal Counter Current (PCCC) (ç lvarez-Salgado *et al.*, 2003).

Recent observational and modeling studies have confirmed previous interpretations of the IPC, but stressed its permanent, seasonally varying, character, the role of large-scale meridional thermal gradient as primary driving mechanism and of regional wind pattern as modulator of its intensity, position relative to shelf break and depth, and the strong eddy shedding activity (so-called 'swoddies') associated with the current (Peliz *et al.*, 2005; Gil 2008). Observations demonstrate the possible effect of the IPC on the distribution of several ecosystem components, from plankton (Fern‡ndez *et al.*, 1991; Calvo-D'az *et al.*, 2004; Bode *et al.*, 2006; Cabal *et al.*, 2008) to fish larvae (Santos *et al.*, 2004), and processes such as primary production (ç lvarez-Salgado *et al.*, 2003), bacterial production (Mor‡n *et al.*, 2007) or fish recruitment (S‡nchez and Gil, 2000).

Over the shelf, residual currents are mainly governed by the wind, tides and water density. Over the Armorican shelf the residual current is weak and north-westward oriented (Pingree and Le Cann, 1989) while in the Aquitaine shelf it shows a strong seasonality, being towards the north-west from autumn to winter (Lazure *et al.*, 2008) and to the south-east the rest of the year (Le Cann, 1990). The situation is more variable in the south-eastern corner of the Bay of Biscay (Cape Breton) and in the Cantabrian shelf due to the interaction between the complex topography (*i.e.* coastline orientation, steeper shelf) and a more variable wind pattern (OSPAR, 2000). Wind-driven coastal upwelling is relatively frequent in summer along the Spanish and French shelves driven by easterly (Botas *et al.,* 1990; Lav'n *et al.*, 1998) and northerly winds (Jegou and Lazure, 1995) respectively. In the vicinity of estuaries (mainly Loire and Gironde), and river mouths (e.g., from the Adour and the small Cantabrian rivers), the presence of plumes of variable intensity, extent and persistence induce significant buoyancy currents, which promote significant mesoscale variability (Lazure and Jegou, 1998). In addition to eddies and river plumes, upwelling events and lower-salinity lenses also occur over the shelf (Puillat *et al.*, 2006).

All these hydrodynamic processes have a strong seasonal and medium-term varying character. There is not a single major driver of the system in the Bay of Biscay, but rather a complex interplay between several drivers influencing the distribution and variability of the ecosystem components, among them fish, from mesoscale to regional scale.

Three different areas can be distinguished in the Iberian Peninsula: i) the Cantabrian Sea, with a diminishing Atlantic influence towards the interior of the Bay of Biscay; ii) the Galician and Portuguese coasts with high Atlantic influence driven by the Gulf current and important upwelling phenomena in the northern part; and iii) the Gulf of Cadiz area which is a border between the Atlantic and the Mediterranean and also between the Iberian Peninsula and the African Coast. Within these areas the topographic diversity and the wide range of substrates result in many different types of coastal habitat.

The main pelagic species are sardine, anchovy, mackerel, horse mackerel and blue whiting. To the south, chub mackerel (*Scomber japonicus*), Mediterranean horse mackerel (*Trachurus mediterraneus*) and blue jack mackerel (*T. picturatus*) are common too. Seasonally, albacore (*Thunnus alalunga*) occur along the shelf break. The main commercial demersal fish species caught by the trawl fleets are hake, megrims and anglerfishes.

The circulation of the west coast of the Iberian Peninsula is characterized by a complex current system subject to strong seasonality and mesoscale variability, showing reversing patterns between summer and winter in the upper layers of the slope and outer shelf. Another important feature of the upper layer is the Western Iberia Buoyant Plume (WIBP) which is a low salinity, surface water body fed by winter-intensified runoff from several rivers from the north-west coast of Portugal and fjord-like lagoons (Galician Rias). The intermediate layers are mainly occupied by a poleward flow of Mediterranean Water (MW), which tends to contour the south-western slope of the Iberia, generating mesoscale features (so-called Meddies), which can transport salty and warm MW over great distances in the North Atlantic (ICES, 2004c).

On the Portuguese and Galician coast, during the spring and the summer, the surface currents generally flow towards the south following the coastline; these currents together with the persistent equator-wards winds produce an important upwelling, mainly on the Portuguese coast from the NazarŽCanyon to the north-west corner of the Iberian Peninsula, where the coastline is more regular, there are no important capes and northern wind stress is more constant (Cunha, 2001). The upwelling phenomena provides nutrients and affects the thermal stratification leading to an important biological production and important concentrations of zooplankton feeders in the shelf break, as snipefish, blue whiting (mainly younger stages) and boarfish. In the Cantabrian Sea, the surface currents generally flow eastwards during winter and spring and change westwards in the summer. These changes in the currents direction produce seasonal coastal upwellings and high biological production phenomena, with variable importance depending on the strength of the currents.

<u>European hake</u>

European hake is distributed widely throughout the Northeast Atlantic, from Norway in the north to the Guinea Gulf in the south and in the Mediterranean and Black Sea; being more abundant from the British Isles to the south of Spain (Casey and Pereiro, 1995). The population is divided by ICES into two stocks: the northern (ICES Subareas II, III, IV, VI, VII and Div. VIIIa,b,d) and the southern stock (ICES Div. VIIIc and IXa). The boundary between these stocks, Cap Breton Canyon, was defined mainly based on management considerations.

Hake is a demersal and benthopelagic species, found mainly between 70-370 m depth. However, it occurs also from inshore waters (30 m), to depths of 1000 m. It lives close to the bottom during daytime but, during the night, moves up and down in the water column (Cohen *et al.*, 1990). The juvenile and small hake usually live on muddy beds on the continental shelf, whereas large adult individuals are found on the shelf/slope, where the bottom is rough and is associated with canyons and cliffs. Different studies have indicated that this species spawns several times within the reproductive season, *i.e.* it is a batch-spawner, or a fractional spawner, species (Andreu, 1955; PŽrez and Pereiro, 1985; Sarano, 1986). The transportation of early life stages, from spawning grounds to coastward juvenile recruitment areas, can be foreseen in relation to the general water mass circulation, as postulated by Koutsikopoulos and Le Cann (1996). In fact, ç lvarez *et al.* (2004) inferred a north and northeast dispersion of eggs and larvae due to the main pattern of oceanographic processes such as wind induced currents and geostrophic flow.

Hake recruitment indices have been related to environmental factors. High recruitments occur during intermediate oceanographic scenarios and decreasing recruitment is observed in extreme situations. In Galicia and the Cantabrian Sea, generally moderate environmental factors such as weak poleward currents, moderate upwelling and good mesoscale activity close to the shelf lead to strong recruitments. Hake recruitment leads to well-defined patches of juveniles, found in localized areas of the continental shelf. These concentrations vary in density according to the strength of the year-class, although they remain generally stable in size and spatial location. In Portuguese continental waters the abundance of small individuals is higher between autumn and early spring. In the Southwest, the main concentrations occur at 200-300 m depths, while in the South they are mainly distributed at coastal waters. In the North of Portugal recruits are more abundant between 100-200 m depths. These different depth-area associations may be related with the feeding habits of the recruits, since the zooplankton biomass is relatively higher at such areas.

There is an increasing uncertainty associated with the validity of the age determination criteria used for the European hake, particularly in the light of results from tagging experiments on hake conducted in 2002 in the Bay of Biscay, which suggest that individual hake grow faster than historically assumed (de Pontual *et al,*. 2006). The last ICES workshop (ICES, 2010) addressing this issue recommended replacing the previous criteria for hake age-estimation with new evolving guidelines that lead to a faster growth pattern. Nevertheless, the workshop was not able to give a new validated growth pattern for hake and recommended to work on the analysis of tagging data and daily ring counting in order to estimate a growth model and to develop an error transition matrix between ages identified with the previous protocol and ages identified with the new guides. Different growth patterns lead to different perception of the stock status and stock dynamics and so, the management of the stock is affected (Bertignac and de Pontual, 2007).

<u>Anchovy</u>

The main pelagic species in the Bay of Biscay are sardine and anchovy (small pelagic) and mackerel and horse mackerel (middle-size pelagic). These species form the basis of important fisheries that represent a major source of income for local economies.

The distribution of anchovy in Atlantic European waters is currently mainly concentrated in two well defined areas: the Bay of Biscay and the Gulf of C‡diz (Uriarte *et al.*, 1996; ICES 2008a). Some residual coastal populations exist also along the Iberian coast, English Channel, Celtic Sea and North Sea (Beare *et al.*, 2004b; ICES, 2007b).

Anchovy in the Bay of Biscay may grow to >20 cm and their life-span rarely exceeds three years. It forms large schools located from 5-15 m above the bottom during the day (MassŽ, 1996), although changes in the schooling pattern of anchovy have been noted since the beginning of the 2000s (ICES, 2008a). It is a serial spawner (several spawnings per year) and reproduces in spring. The spawning area is located southward of 47¡ N and eastward of 5¡ W. Most spawning takes place over the continental shelf in areas influenced by the river plumes of the Gironde, Adour and Cantabrian rivers (Motos *et al.*, 1996). Recent studies have suggested that anchovy in the Bay of Biscay may recruit partially offshore (Irigoien *et al.*, 2007). However, it is not clear to what extent individuals recruited off the shelf contribute to the total population (Irigoien *et al.*, 2008), partly because modeling studies have suggested that off-shelf waters do not fulfill the conditions for larvae survival (Allain *et al.*, 2007a,b). As spring and summer progresses, anchovy migrates from the interior of the Bay of Biscay towards the north along the French coast and towards the east along the Cantabrian Sea, where it spends the autumn. In winter it migrates in the opposite direction towards the east and southeast of the Bay of Biscay (Prouzet *et al.*, 1994). It has a high and very variable natural mortality. Mesoscale processes in relation to the vertical structure of the water column (stratification, upwelling and river plume extent) appear to have a great influence on the survival of larvae (Allain *et al.*, 2001). However they may only act as limiting factors (Planque and Buffaz, 2008), and the mechanisms through which these physical processes impact biological oceanography and recruitment require better knowledge.

As all short-lived species, the anchovy stock is very dependent on recruitment, and so these recruitment failures lead to the low biomass levels observed in recent years. A reduction of the distribution of anchovy in the Bay of Biscay has been observed both in the acoustic and egg production surveys (ICES, 2007b) and changes in the school composition have also been described (MassŽ and Gerlotto, 2003). In the past century, the anchovy population has almost disappeared from the Spanish coast and spawning grounds have been lost (ICES, 2004a). Based on circulation models, larval drift reveals that the larvae born in the French spawning grounds move towards Spanish coasts but fail to re-colonize there (Vaz and Petitgas, 2002). Although anchovy juvenile surveys show that early juveniles are found alone, separated from the adults, in the oceanic area and along Spanish coasts (Uriarte *et al.*, 2001; ICES, 2008a), afterwards juveniles are found together with the adults along the French coasts (Petitgas *et al.*, 2004, ICES, 2008a).

According to previous studies (Motos *et al.*, 1996; Uriarte *et al.*, 1996), anchovy populations appear to have density-dependent strategies of spawning area selection. Different hypotheses have been suggested to explain inter-annual and long-term variations in anchovy abundance which are often attributed to important variability in recruitment levels, and are ultimately linked to variations in ocean processes. Changes in global and local environmental indexes have also been described for the Bay of Biscay, such as the NAO index and Polar Eurasia and East Atlantic patterns (ICES, 2007c; Borja *et al.*, 2008), and upwelling and stratification indices (Borja *et al.*, 1998; Alain *et al.*, 2001; Huret and Petitgas, 2008).

<u>Recent changes</u>

The oceanographic conditions were hindcasted (1972-2009) using IFREMER's coupled physical-biogeochemical model of the Bay of Biscay. This revealed a warming trend over the Bay of Biscay continental shelf, with a trend of about +0.3¡C decade^{-1} since the 1980s (Huret *et al.*, 2009), similar to the SST trend analyzed from *in situ* and satellite data over the whole Bay of Biscay (Michel *et al.,* 2009). This trend shows a seasonal dependence with higher values in summer (G–mez-Gesteira *et al.,* 2008; Michel *et al.,* 2009). Also this fast warming trend followed a cooling period, so the trend is slower (0.2¡C decade^{-1}) compared with 1965-2005 (Michel *et al.,* 2009).

In the last decade, the spatial distribution of anchovy eggs in spring has expanded northward compared with the distribution of the anchovy eggs in the 1960s and 1970s (Bellier *et al.*, 2007). Anchovy populations in northern areas seem to have increased in recent years (Beare *et al.*, 2004b; ICES, 2004a).

6.3 Final Recovery Scenarios

By its conclusion, the UNCOVER project had contributed to the development and evaluation of LTMPS, recovery plans and HCRs, for 11 targeted fish stocks/fisheries in the four Case Study areas with the aim of maintaining commercial fish stocks within safe biological limits (SBLs) and/or recovering depleted stocks to above agreed threshold levels.

In the following sub-sections, a review is provided of the main elements of the '***Final recovery scenarios***' concerning for the 11 stocks/fisheries, and highlights their strengths and weaknesses and the apparent reasons for these. Besides the usual precautionary type reference points and potential target levels, where appropriate the level of F_{MSY} (or its proxy) is indicated as a recognition of the 2002 WSSD aims to '*maintain or restore stocks to levels that can produce the maximum sustainable yield: for depleted stocks on an urgent basis and where possible not later than 2015.*' From the presentations, including figures, it is possible to see what movements in the status of the stocks are required to attain MSY and fulfill WSSD obligations.

6.3.1 Norwegian and Barents Seas

The management plans and stock history of the three target species in this Case Study area are described below. In each case attention is drawn to measures beyond simply setting target F that are believed to have been important in the successful recovery and management of these stocks.

Northeast Arctic cod

The current management reference points and their corresponding values for NEA cod are shown in table 6.1.

Table 6.1. NEA cod current management.

NEA cod	
Reference point	**Value**
B_{pa}	460 000 t
F_{pa}	0.4
$F_{B=0}$	0.0 (linear reduction from F_{pa} to $_{FB=0}$)
Discards permitted	No
Other measures	Minimum landing size, temporary closure of areas with many undersized fish, reduction of unreported landings, reduction of bycatch in shrimp fishery, limit on speed of quota changes suspended below B_{pa}

Extensive efforts have been made to enhance data collection and assessment of the NEA cod stock over many years. As a result, there is good knowledge of stock size and structure. Current assessment work is single species-based with cannibalism included.

High fishing pressures led to the NEA cod stock being reduced to a historical low SSB in the mid 1980s. The stock then recovered quickly due to a strong reduction in fishing pressure and improved environmental conditions around 1990. The fishing pressure then increased again, and the stock size remained at low-intermediate levels in the period 1995-2005. Since then reduced fishing pressure, combined with some good years of recruitment, has led to a dramatic increase in stock size, and the stock is currently the largest cod stock in the world and above the long-term mean. It should be noted however that the diverse age structure seen in the past has not returned, with fewer old fish in the present population than in the first half of the 20^{th} century.

The current management plan was first implemented in 2004, and is set with F=0.4 where SSB is above 460 000 t, and a linear decrease to F=0 at SSB=0.This rule can be considered precautionary for moderate stock sizes. With reducing stock sizes the F is reduced, and simulations show that this is effective in allowing the SSB to recover to above B_{pa}. Evaluations have been conducted within UNCOVER to establish that the HCR appears to be precautionary in a multispecies context, and remains so under a range of plausible future recruitment scenarios. Additionally, long-term stochastic simulations were used to determine the MSY and corresponding F-value. This was done with/without density-dependence, and for two different cannibalism models and three different exploitation patterns. The MSY values were found to be in the range 800-900 thousand t without cannibalism and 600-700 thousand t with cannibalism included. In an MSY context, Kovalev and Bogstad (2005) found little variation in the yield for Fs in the range 0.25-0.6, with a sharp decrease in yield for F values above 0.7. Thus, the F of 0.4 can be considered to be a reasonable proxy for F_{MSY}, but from a precautionary point of view the lower end of a range of Fs that produce similar yields should be considered preferable. So, the current management rule can be considered to approximate to MSY management. Under sustained large SSBs the HCR may not approach MSY, but it is expected to remain precautionary.

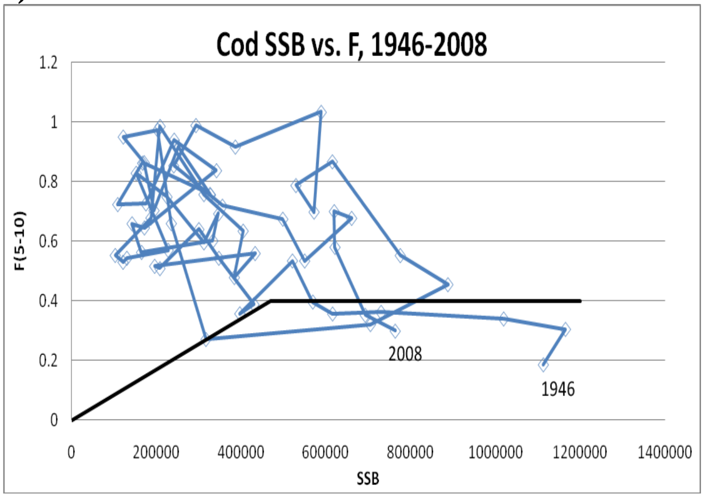
Nevertheless, for low stock sizes the fact that fishing is permitted at low SSB levels may pose a danger of collapsing, or at least delaying the recovery, of the cod stock. This may not be shown in the models given the lack of data on such small stock sizes. If a situation arose where the stock was at such a low level then a recovery plan would need to be formulated and implemented. *This process would imply a possible delay between becoming aware of the problem and beginning to tackle it.* The management does contain any B_{lim} beyond which emergency measures would be needed. *This absence is a serious weakness, since it undermines the ability of management to respond rapidly and appropriately to serious stock collapses.*

In some years, unreported catches have been very large, posing a threat to the effective management of the stock. In recent years, this situation is believed to have improved. However, the possibility of there being large uncontrollable black landings might pose a limitation on how quickly fishing mortality could be reduced if the stock was perceived to be threatened. Additionally, although the HCR has mostly been followed there have been years in which the quota was allowed to exceed it.

The present management plan can, therefore, be considered to be precautionary at current stock levels and ecosystem conditions. However it may lack sufficient measures to respond to a possible future significant depletion of the stock without the need for a specific recovery plan having to be agreed and implemented. In particular the lack of a B_{lim} beyond which emergency measures would be triggered is a key flaw in the management plan.

The SSB trajectories for NEA cod are shown in figure 6.1.

a)



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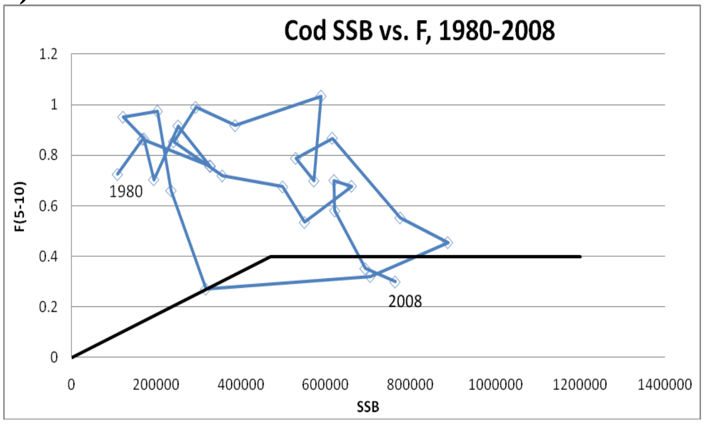


Figure 6.1. **Spawning stock biomass against F for the NEA cod. (a) 1946-2008, (b) the period of the increase from the early 1980s (1980-2008).**

Norwegian-spring spawning herring

The current management reference points and their corresponding values NSS herring are shown in table 6.2.

Table 6.2. NSS herring current management.

NSS herring	
Reference point	**Value**
B_{pa}	5 000 000 t
B_{lim}	2 500 000 t
F_{pa}	0.15
F_{target}	0.125
F_{lim}	0.05
Discards permitted	No
Other measures/factors	Minimum landing size close to mean size at maturity, $F_{target}<F_{pa}$, agreed international management plan, straddling stock but becomes a national stock at reduced stock sizes

The NSS herring stock collapsed at the end of the 1960s following several years in which fishing pressure remained high despite the rapidly declining stock. A long recovery period (*ca.* 20 years) with low stock sizes and exploitation rates followed. After the occurrence of the very strong 1983 year-class, the stock size increased considerably, and by the mid-1990s the stock could be considered as fully recovered. During the recovery period, the spatial dynamics of the stock varied considerably, from remaining close to the Norwegian coast, through to the present with herring migrating into the North Atlantic. The stock is currently considered to have full reproductive capacity and to be harvested sustainably (ICES, 2009). However, data and assessments are less certain than for cod and capelin.

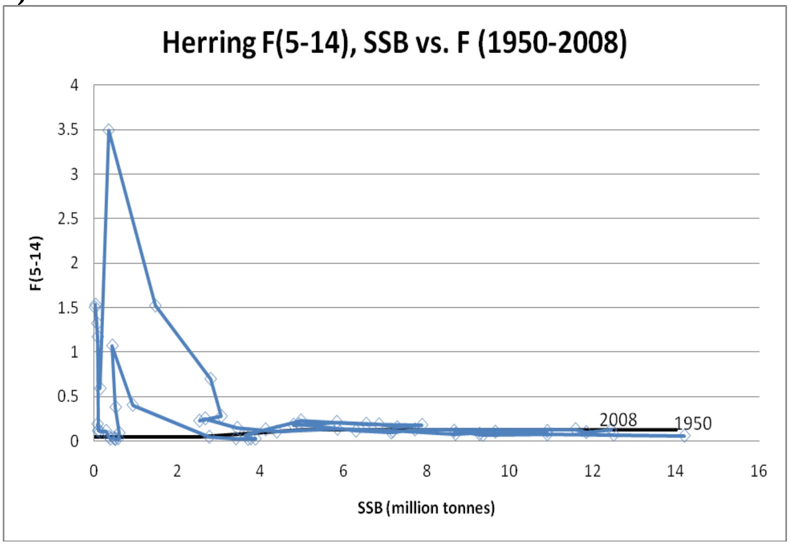
The EU, Faroe Islands, Iceland, Norway, and Russia agreed in 1996 to implement a LTMP for NSS herring. The plan was part of the international agreement on total quota setting and sharing of the quota during the years 1997–2002. From 2003–2006, there was also no agreement between the Coastal States regarding the allocation of the quota. In this period quotas were set unilaterally and in some countries quotas were raised during the year. Since 2007, the Coastal States have agreed to set a TAC in accord with the plan. ICES uses the reference points B_{lim}=2.5 million t, B_{pa}=5.0 million t and F_{pa}=0.150. The Coastal States have agreed upon managing the stock according to a target reference point (F_{target}=0.125). There is also a strictly enforced minimum landing size of 25 cm. Descriptions of the development of the management objectives and harvest control rules for this stock are given by Tjelmeland and R¿ttingen (2009). They found that the current harvesting strategy (F_{target}=0.125) is somewhat on the conservative side with respect to maximum optimal yield, and the fishery is thus considered to be fished below MSY.

Simulations suggest that at current stock levels, and under current environmental conditions the herring stock is likely to remain high when managed in accordance with the current management procedure. However, the management rule has F remaining constant as SSB approaches zero. *This clearly has the possibility to produce suboptimal management at low stock sizes. Additionally, the nature of the herring as a straddling stock, entering international waters, makes the stock vulnerable to political decisions to raise quotas by individual countries.* In mitigation to this, at lower but still viable population levels, the stock remains confined to Norwegian waters. *Finally there is a higher degree of uncertainty on the assessment of NSS herring than for cod or capelin, leading to greater uncertainty in the herring management.*

As a result, the management rule, considered only in terms of F, may not be precautionary to a large collapse in the herring stock, where a separate recovery strategy would be required. This is especially true for a schooling species where fishing can remain economically feasible at low stock sizes. *However, the minimum landing size probably provides a sufficient degree of protection to the stock as a whole to prevent fishing out, and thus helps enhance the precautionary nature of the plan. The known behaviour of the stock to remain within Norwegian waters at low stock sizes also provides a precautionary protection, by removing the vulnerability to international fisheries as the stock declines. This illustrates that the precautionary nature of a plan is not just based on the target F, but is due to target F levels, other fishing regulations, and the biology of the stock. These must be considered in combination when designing and evaluating a viable recovery strategy or management plan.*

The trajectories of SSB plotted against F for NSS herring over time are shown in figure 6.2.

a)



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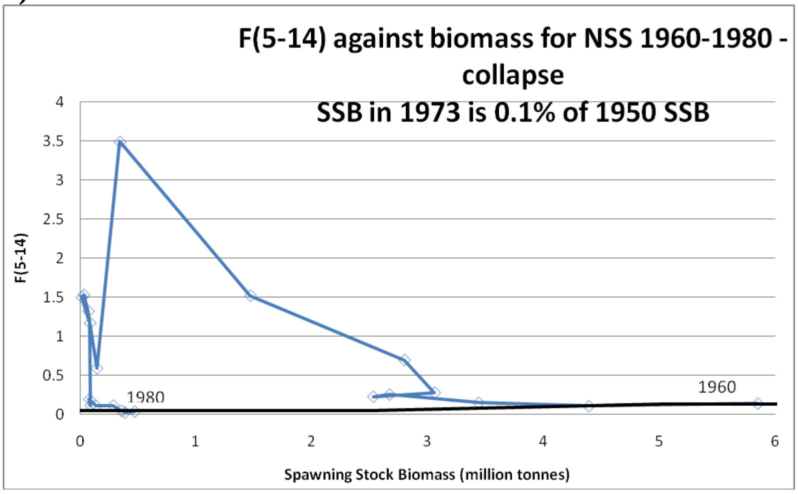

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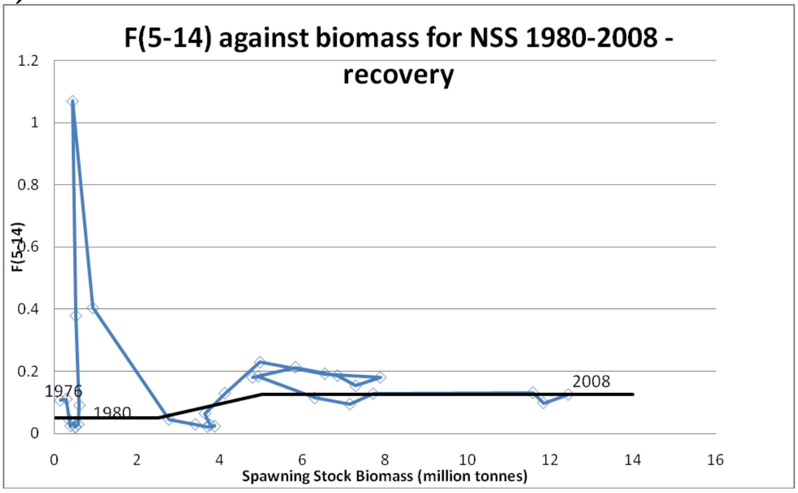

Figure 6.2. Spawning stock biomass against F for Norwegian spring-spawning herring. (a) 1950-2008, (b) the period of the collapse, 1960-1980, (c) the period of the recovery (1980-2008)

Barents Sea capelin

The current management reference points and their corresponding values for Barents Sea capelin are shown in table 6.3. The biomass and catch of Barents Sea capelin are shown in figure 6.3.

Table 6.3. Barents Sea capelin current management.

Barents Sea capelin	
Reference point	**Value**
B_{lim} (escapement biomass)	200 000 t
Discards permitted	No
Other measures	F set to give 95% chance of remaining above target escapement biomass (including multi-species effects), closed the fishery on immature individuals, shortened the data-assessment-quota implementation cycle

There are extensive surveys covering the entire capelin population which, combined with very strong signals in biomass trends, give a good level knowledge on the state of the stock. Current assessment is single species, but cod abundance is included as a source of predation mortality.

The management rule is to set a TAC that gives a 95% probability of keeping the spawning stock to be above B_{lim} (200 000 t). The advice from ICES based on this rule has been followed by the managers, and unreported catches are not believed to be a problem.

The rule has been successful in ensuring that the capelin has been able to recover from the periodic stock collapses. However, the collapses are more frequent now than in the past, and the management rule has not succeeded in reversing this. The increased frequency of capelin collapses may be due to the frequent occurrence of strong year-classes of young herring in the Barents Sea, and if this is the main driver, fishing down the herring could be the only management procedure, which could reverse this. *Model simulations within UNCOVER suggests that the management rule is precautionary under a range of different multispecies conditions. However, given the lack of understanding of the mechanism of changes in stock dynamics it is not possible to model what would be required to return to the previous dynamics.*

The rule can be considered precautionary at all stock sizes, since it gives effective protection to low stocks under the current ecosystem conditions. It may also be a reasonable approximation to a MSY, provided that escapement biomass of 200 000 t is high enough to avoid recruitment overfishing. Since the mid-1990s, the fishery has been directed only on mature capelin in spring; previously both immature and mature capelin was fished in autumn while only mature capelin was fished in spring. This change in exploitation pattern has also made management more precautionary. Previously, the quota for the autumn fishery on a mixture of immature and mature capelin was set based on the survey made the previous autumn. This implied that a 1.5-year prognosis of stock size had to be made, whereas currently only a 0.5-year prognosis has to be made in order to calculate the TAC. Tjelmeland (2005) used a multispecies model (Bifrost) to calculate the long-term yield of capelin and cod, given a fixed harvesting rule for herring. He found that the capelin yield depended strongly on the cod fishing mortality, and that the capelin yield increased with increasing target SSB up to 400 000 t (approximately equivalent to the 95% chance of being above 200 000 t in the current rule), but that there was little gain in increasing the target SSB further. However, it is important to continue to assess and review the changes in the ecosystem in order to evaluate whether the 200 000 t escapement continues to avoid recruitment overfishing.

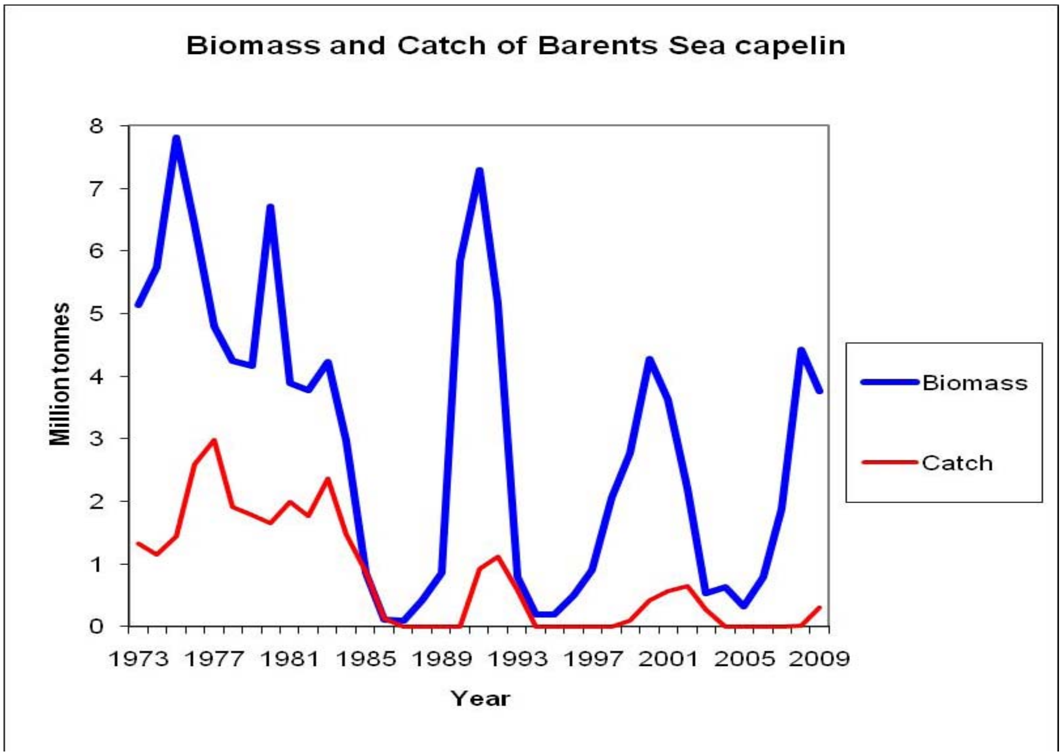

Figure 6.3. Biomass and catch of Barents Sea capelin. Note that F is not calculated for this stock, since management is based on an escapement strategy rather than F.

6.3.2 North Sea

North Sea cod

The precautionary and management reference points for NS cod are shown in table 6.4, and the yield/recruit, SSB/recruit and corresponding F reference points are shown in table 6.5. The precautionary (pa), limit (lim) and management (mgt) reference points concerning fishing mortality (F) and spawning stock biomass (SSB) for management of North Sea cod are shown in figure 6.4.

Table 6.4. North Sea cod current precautionary and management reference points.

North Sea cod	
Reference point	**Value**
B_{lim}	70 000 t
B_{pa}	150 000t
F_{lim}	0.86
F_{pa}	0.65
F_{mgt}	0.4

Table 6.5. North Sea cod yield and spawning stock biomass per recruit, and F-reference points (after ICES, 2009). FMSY will be Fmax = 0.25 y-1.

North Sea cod			
	$F_{bar\ 2-4}$	**Yield/R**	**SSB/R**
F_{max}	0.25	0.69	2.1
$F_{0.1}$	0.16	0.69	3.2
F_{med}	0.81	0.51	0.3

Cod SSB has declined since the early 1970s. There are serious problems with recruitment: 1996 was the last large year-class; the 2005 year-class is relatively strong; while the subsequent year-classes are weak.

Fishing mortality (F) has decreased but recent F-values are highly uncertain. There has been a recent increase in F due to discarding and it is now estimated that the discard mortality constitutes the major part of the fishing mortality.

The failure of the cod recovery has been attributed to several factors, which are often compounded, including:

- Quotas have been consistently set above scientific advice;
- Poor recruitment;
- Damaged stock structure (compounded by high Fs on young age-groups);
- High levels of discarding.

The possible biological / environmental / ecological reasons for poor recruitment are many (*e.g.*, temperature change, predation).

In the absence of profound knowledge on the most important processes affecting recruitment, the current best course of action may be to protect the stock until recruitment improves by, for example, reduction of F on lower age-classes.

The plan is complicated. It essentially has two stages: Decrease F in 2009 and 2010, then:

- If SSB > precautionary biomass, F = 0.4.
- If SSB between precautionary and minimum biomass, F is based on a function of SSB that results in F between 0.2 and 0.4.
- If SSB is below minimum biomass, F = 0.2.
- But TAC cannot change by ±20%.

In 2008, the then proposed EU and Norway recovery plans for North Sea cod were evaluated at ICES AGCREMP using tools that had been developed under UNCOVER. Models were structured that applied the proposed EC and Norwegian Plans to simulated assessments of simulated stocks.

The full results of the evaluation of the proposed cod recovery plans are presented in the ICES AGCREMP report (ICES, 2008g). The results and conclusions are summarized here. As noted in the text of the report:

'*Management Strategy Evaluations are notoriously difficult to summarize…*'.

In general, the difference between results from the two proposed plans was small and results were summarized as:

'*… both plans will lead to stock recovery in similar time frames and with similar probabilities*'.

However, differences exist between the scenarios. For example, under the lower recruitment scenarios the probability of SSB and F being in their target domain by 2015 is reduced from 76% and 88% for the EU rule and Norwegian rule to 52% and 62% respectively for the base case scenarios. The Norwegian rule is slightly more robust to biases in the catch and leads to higher probabilities to be above B_{lim} or B_{pa} in these scenarios. However, the EC rule leads to slightly higher probabilities when unknown changes in natural mortality are assumed. The probability of a recovery depends on the assumed dynamics underlying the simulation. For both HCRs, 1/3 of scenarios resulted in a stock recovering above B_{lim} in 2015 with a 95% probability. Under certain combinations of assumptions of bias in the catch data, natural mortality rates and assessment models, rebuilding has a low probability of occurrence by 2015. These are the scenarios with the assumption of low recruitment and an uncorrected bias in natural mortality.

The overall conclusion of the report was that the simulations do not provide a basis for selecting either of the rules. There is no advice on the suitability of the Plans in relation to the precautionary approach because generally agreed criteria are lacking for Recovery Plans. Future Plans should state their objective about the target date for recovery and the acceptable level of risk that recovery does not occur by that date.

The current plan was adopted in 2009 and is through TAC and technical measures. Effort management (kilowatt-days), based on mŽtier and gear, was introduced in 2009.

The current plan is considered to be precautionary against the precautionary reference points *if it is implemented and enforced adequately*. However, this qualifier is likely to be difficult to achieve given the mixed-fishery concerns.

Cod is fished in a mixed-fishery but the management plan is single species. Work performed under the 2009 ICES Workshop on Mixed-fisheries Advice for the North Sea (WKMIXFISH) showed that one can expect over-quota catches of cod when evaluating the current management plan using mixed-fisheries models (particularly given the current healthy state of haddock). This is given more weight from the observation that discard mortality is greater than the human consumption mortality. Consequently, evaluations of the plan that do not fully consider the mixed-fishery implications are likely to overestimate recovery probability. The recent evaluations included discards in the simulations but this an overly simplistic representation of mixed-fishery dynamics.

Multispecies evaluations of the management plan demonstrated, furthermore, that conducted single species evaluations overestimate the recovery potential of the stock, as they ignore density dependent processes and changes in large-scale spatial predator- prey overlap. To overcome the indicated predator pit, a growing cod population first has to outgrow the abundance range with rapidly increasing predation mortalities before it reaches spawning stock sizes that will have a positive effect on year-class strength. The spatial overlap between cod and its predators was found to increase with increasing temperature. However, more information on processes responsible for distribution changes of predator and prey populations are needed to enable more accurate forecasts of cod population dynamics under climate change.

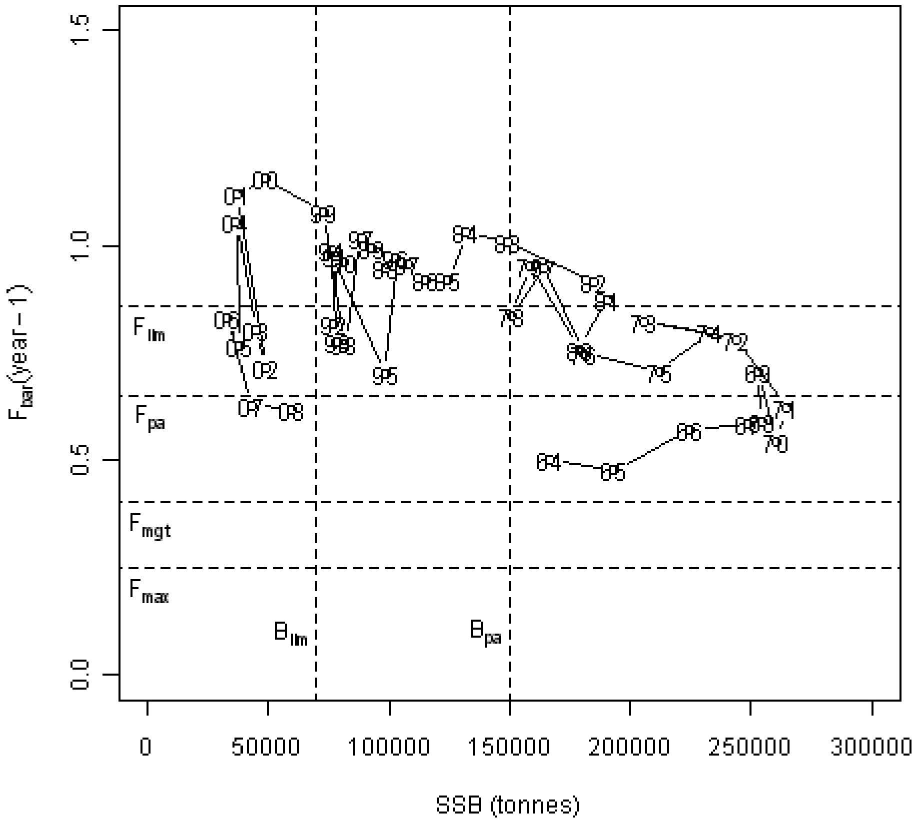

Figure 6.4. Precautionary (pa), limit (lim) and management (mgt) reference points concerning fishing mortality (F) and spawning stock biomass (SSB) for management of North Sea cod.

<u>Summary:</u>

- Discarding is a serious problem (discard mortality > human consumption mortality).
- The current plan is only precautionary if implemented and enforced adequately.
- Cod is fished as part of a mixed-fishery but the plan has been devised on a single species basis. It has been shown that using a single species cod management plan in a mixed-fishery is likely to lead to catches over-quota.
- This suggests that the qualifier for the precautionary nature of the plan (that it must be implemented and enforced adequately) is unlikely to be met. Thus, it can be argued that the plan is simply unrealistic.
- The impact of multispecies interactions also needs to be considered more thoroughly.

Autumn-spawning herring

The current precautionary and management reference points for AS herring are shown in table 6.6.

Table 6.6. AS herring current precautionary and management reference points. The management plan of F = 0.25 is assumed to be F_{MSY}.

AS herring		
Type	**Value**	**Note**
B_{lim}	800 000 t	
B_{pa}	1.3 million t	Trigger biomass from old HCR
F_{lim}		Not defined
F_{pa}	$F_{0-1} = 0.12$ $F_{2-6} = 0.25$	Target Fs from old HCR
F_{mt}	$F_{0-1} = 0.05$ $F_{2-6} = 0.25$	If SSB > 1.5 million t. (new trigger biomass) (based on simulations)
	$F_{0-1} = 0.05$ $F_{2-6} = 0.25 – (0.15 * (1500000\text{-SSB})/700000)$	If SSB between 0.8 and 1.5 million t. (based on simulations)
	$F_{0-1} = 0.04$ $F_{2-6} = 0.10$	If SSB < 0.8 million t (based on simulations)

For North Sea herring, the management plan with actual fishing mortalities and SSBs are shown in **figure 6.5**, while precautionary (pa), limit (lim) and management (mgt) reference points concerning fishing mortality (F) and spawning stock biomass (SSB) for management are shown in **figure 6.6**.

The decrease of the herring stock to below B_{pa} was caused by a failure to comply with the management plan. Despite warnings that a series of poor recruiting year-classes had occurred and that substantial reductions in TAC were required to maintain the stock above precautionary biomass reference points, smaller reductions were enacted. This leads to an increase in fishing mortality and a correspondingly swift reduction in SSB. Poor recruitments were caused by an increase in the larval mortality, which was environmentally driven.

Extensive simulations had suggested that the plan was precautionary. They assumed an implementation error of 10%. However, the simulations did not assume that annual negotiations would occur between stakeholders to deviate from the management plan targets. Whilst the plan may have been precautionary, it was not followed (*i.e.*, not appropriately implemented).

Extensive simulations had suggested that the plan was precautionary. They assumed an implementation error of 10%. However, the simulations did not assume that annual negotiations would occur between stakeholders to deviate from the management plan targets. Whilst the plan may have been precautionary, it was not followed (*i.e.*, not appropriately implemented).

While mixing between management units is often recognized as a problem affecting the accuracy of an assessment, ignoring that a stock may, in fact, represent a metapopulation with several spawning components may be an even more serious problem. Recent studies and the results of an EU-funded project (WESTHER) indicate that the population structure of stocks may be complex and that fisheries and management are apparently not always linked to discrete populations. Therefore, the development of appropriate assessment and management procedures to maintain separate spawning components in a healthy state where fisheries exploit multiple components is crucial. The long-term management of a stock representing a metapopulation has been simulated in a case study based upon herring to the west of the British isles, where stocks are currently assessed and managed by management area, although there is evidence of mixing between stocks (in terms of connectivity, migrations, and exploitation) (Kell *et al.*, 2009). It was decided to use herring West of the British Isles instead of North Sea Autumn-spawning herring due to the availability of data. The general conclusions are also applicable to North Sea Autumn-spawning herring. The simulations raise some important issues related to the maintenance of population structure within a stock that is currently considered to represent a single population, even if it is known to comprise several spawning components (*e.g.*, North Sea herring), as well as to the quality of the advice for stocks that are known to cross the management areas (such as the herring stocks west of the British Isles). The work on metapopulations based upon herring to the west of the British Isles (described in the Case Study report on the North Sea) showed that assessment based on VPA of the metapopulation could fail to detect overexploitation of stocks and fail to detect and distinguish between the effects of exploitation and regime shifts (Kell *et al.*, 2009). This can have important consequences for stock recovery. Assessing a metapopulation as a single stock will overestimate the probability of recovery and underestimate the risk of stock collapse. For example, the extirpation of a population may not be detected by the assessment when stocks are considered as a single unit. Also, the causes of changes in stock productivity may be not deduced by the assessment method. For example, a decrease in survival of recruits (*i.e.*, F_{MSY}) and a change in carrying capacity (*i.e.,* B_{MSY}) lead to indistinguishable results. As any management advice should depend on changes in specific reference points, this means that without additional information, it will be difficult to provide advice on appropriate actions in terms of HCRs based on reference points. These results are also important for North Sea herring, which is also known to have metapopulations.

Although the herring stock recovered post-collapse after the fishing moratorium, only three of the four North Sea herring stocks actually recovered, the fourth stock (Downs) taking substantially longer to recover (Dickey-Collas *et al.*, 2010). This demonstrates that recovered stocks might not be as productive as they were during overfishing.

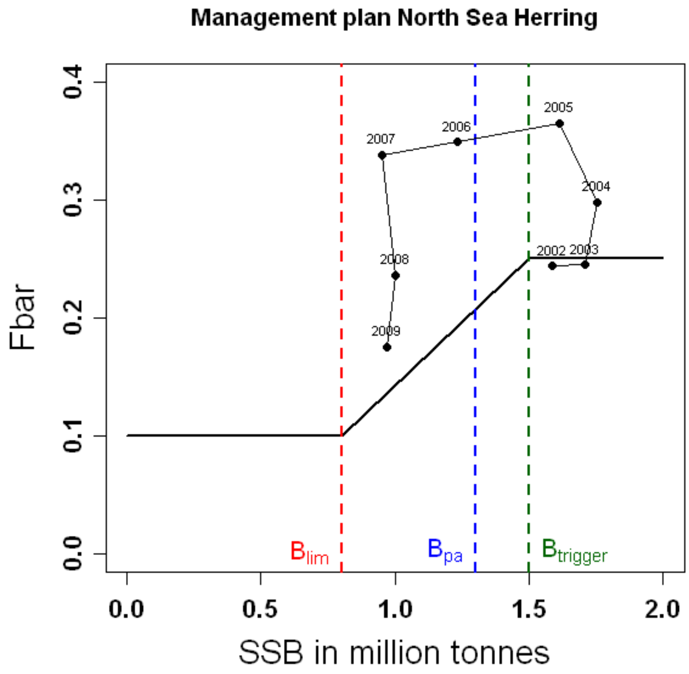

Figure 6.5. Management plan for North Sea herring with actual fishing mortalities and SSBs that resulted from annual deviations from the agreed plan.

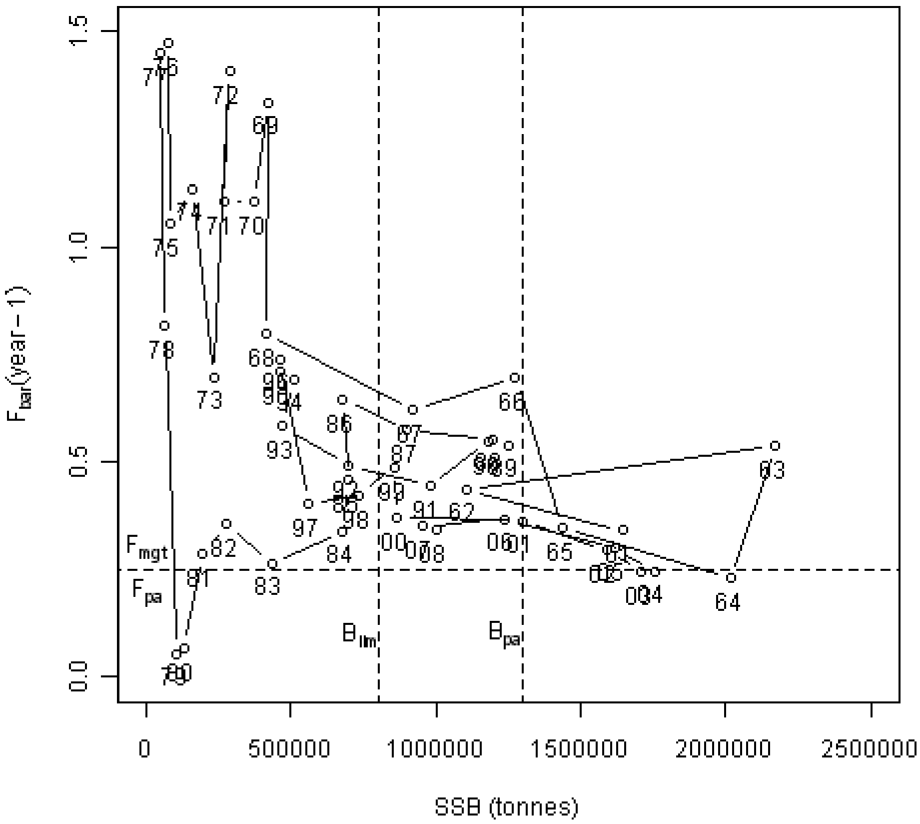

Figure 6.6. Precautionary (pa), limit (lim) and management (mgt) reference points concerning fishing mortality (F) and spawning stock biomass (SSB) for management of North Sea herring.

Summary

- There are parallels between North Sea herring and cod. Implementation error has been identified as possible causes for the failure to recover (cod) and failure of long-term management (herring), exacerbated by changes in productivity. Both had plans that were considered to be precautionary, yet the outcome for both was the opposite of what was expected. This can also be compared to plaice where implementation of the management plan was likely to be good as a result of the reduction in capacity and sustained recruitment levels.

–

North Sea plaice

For NS plaice, precautionary and management reference points are shown in table 6.7, and the yield/recruit, SSB/recruit and corresponding F reference points are shown in table 6.8. The precautionary (pa), limit (lim) and management (mgt) reference points concerning fishing mortality (F) and spawning stock biomass (SSB) for management are shown in figure 6.7, while the yield per recruit analysis is shown in figure 6.8.

Table 6.7. North Sea plaice current precautionary and management reference points. ICES estimates Fmax at 0.17 and considers it as proxy for F_{MSY}.

NS plaice	
Reference point	**Value**
B_{lim}	160 000
B_{pa}	230 000 t (approximately 1.4 x B_{lim})
F_{lim}	0.74
F_{pa}	0.6
F_{mgt}	0.3

Table 6.8. Yield and spawning biomass per Recruit F-reference points (ICES, 2009). F_{MSY} will be F_{max} = 0.17 y-1.

NS plaice			
	Fbar 2-6	**Yield/R**	**SSB/R**
Average last 3 years	0.31	0.09	0.55
F_{max}	0.17	0.10	1.25
$F_{0.1}$	0.12	0.10	1.74
F_{med}	0.42	0.07	0.32

The current plan has two stages (recovery, followed by long-term management) and operates through a combination of TAC and effort control. It is a mixed-fishery plan in that it also considers sole. However, the mixed-fishery concerns are far simpler than those for cod (*i.e.*, only two species and one major gear type).

The LTMP was evaluated in 2008. However, it has not yet been concluded that it is consistent with the precautionary approach.

For two successive years, ICES has classified the stock as within safe precautionary limits, fulfilling the first phase of the management plan. This is largely due to a reduction in fishing mortality. The increase in stock occurred under average recruitment conditions and is not thought to be caused by higher productivity. This allowed the stock to take advantage of the reduction in fishing mortality. This is different from cod where, even though fishing mortality had been reduced, recruitment remained poor (see above).

Several factors have been proposed that contribute to the decrease in F including:

- The management plan;
- The reduction in fishing capacity;
- The increase in fuel prices.
-

It is not yet possible to attribute the recovery of the stock to any single one of these factors (STECF, 2008). This case study demonstrates that a combination of reducing F (by whatever means) and reasonable recruitment can lead to rebuilding of the stock, even within a (relatively simple) mixed-fishery. It is likely that the reduction in capacity allowed the plan to be accurately implemented (unlike with cod). This suggests that although effort and TAC control work in theory, reduction in fleet capacity is helpful in implementing the plan. This is particularly likely to be the case for mixed-fisheries where effort limitations for one stock can be redirected to another, leading to bycatch of the original stock.

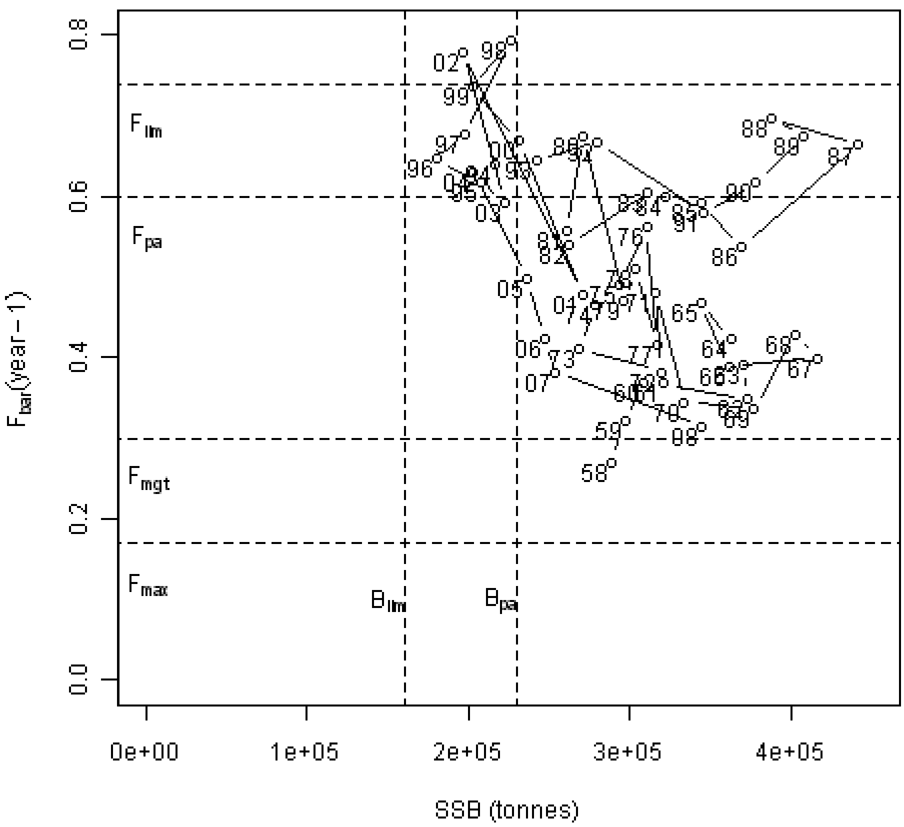

Figure 6.7. Precautionary (pa), limit (lim) and management (mgt) reference points concerning fishing mortality (F) and spawning stock biomass (SSB) for management of North Sea plaice.

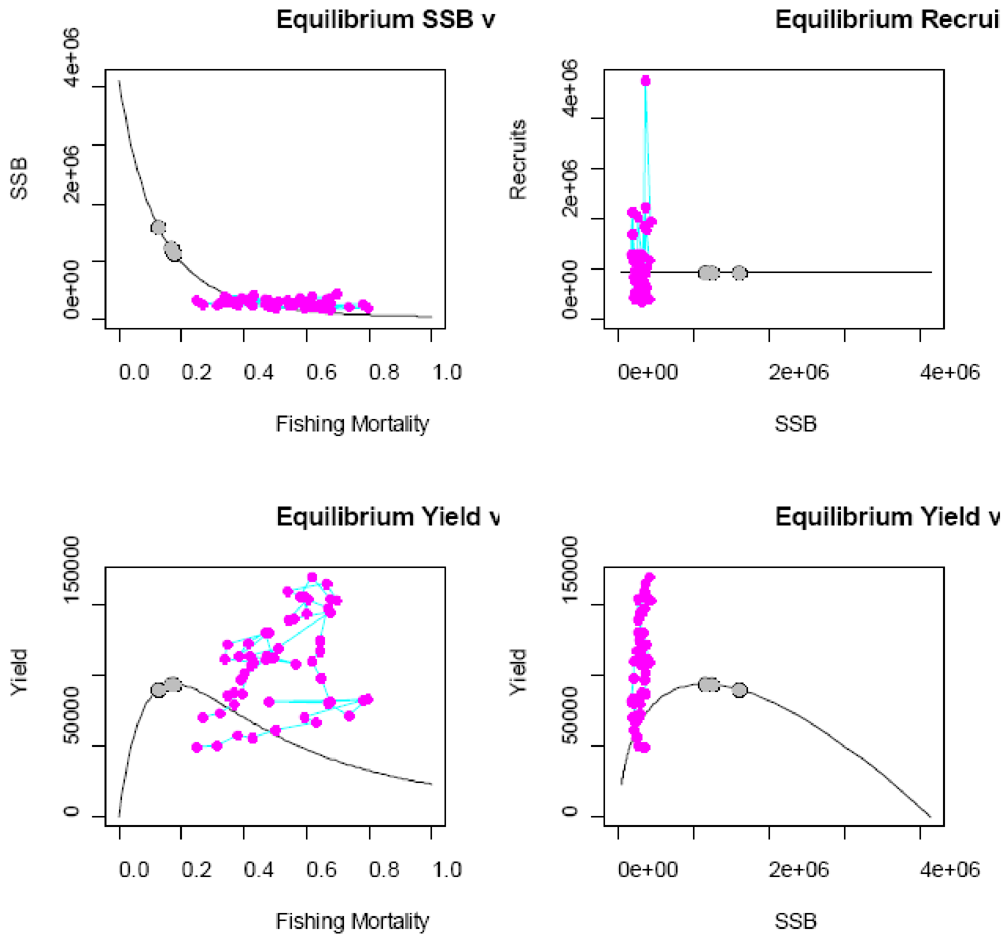

Figure 6.8. Yield per recruit analysis for North Sea plaice (after ICES, 2009)

Summary

The recent plaice recovery provides an interesting counter to cod. Both had collapsed, both had LTMPs but only one recovered. The difference between the success of plaice and the continued failure of cod can probably be attributed to two factors:

- *Implementation of the plan*

  a) The mixed-fishery nature of cod makes implementation difficult;

  b) The reduction in fleet capacity for plaice probably allowed accurate implementation.

- *Recruitment*

  a) For plaice, recruitment was average;

  b) For cod, recruitment was poor (although the plan should be robust to this).

6.3.3 Baltic Sea

Eastern Baltic cod

For Eastern Baltic cod, the state of the stock, and reference points for Eastern Baltic cod are shown in table 6.9. and table 6.10, respectively. Its spawning Stock Biomass plotted against fishing mortality is shown in figure 6.9.

Table 6.9. State of the stock for Eastern Baltic cod.

Eastern Baltic cod				
Spawning biomass in relation to precautionary limits	**Fishing mortality in relation to precautionary limits**	**Fishing mortality in relation to highest yield**	**Fishing mortality in relation to agreed target**	**Comment**
Undefined	Harvested sustainably	Appropriate	Below target	EC management plan implemented in 2008 with a target fishing mortality of 0.3

Table 6.10. Reference points for Eastern Baltic cod.

Eastern Baltic cod			
	Type	**Value**	**Technical basis**
Precautionary approach	B_{lim}	Not defined* (160.000 t until 2008)	
	B_{pa}	Not defined* (240.000 t until 2008)	
	F_{lim}	0.96	F_{med} (estimated in 1998)
	F_{pa}	0.60	5th percentile of F_{med}
Targets	F_y	0.3-0.4	AGLTA 2005, ICES WKREFBAS 2008, simulations
	F_{mgt}	0.3	EC Multiannual Management Plan for the Cod Stocks in the Baltic Sea 2007 (EC No. 1098/2007)

*A recent integrated ecosystem assessment (ICES Doc. CM/BCC:04) shows a major shift in food-web composition and in environmental drivers in the Central Baltic. Therefore, the previously defined biomass reference points ((B_{pa}, B_{lim}) are no longer considered appropriate and they were not used in advising on the stock status.

Eastern Baltic cod is taken in a targeted fishery, in most areas of the Central Baltic with minimal bycatches of other commercially important fish. However, there are potential bycatch and discards issues concerning small/undersize recruiting cod.

Currently, bottom trawls, and to a much lesser extent Danish seines, are the main mobile fishing gears used to catch cod in the region. Since the 1990s, cod have accounted for >85% of the annual landings taken from demersal stocks in the Baltic Sea. The dominant share (ca. 50-60%) of the total cod landings taken in the Baltic Sea is by bottom trawls, particularly otter trawls, followed by the passive gear fisheries from gillnets and longlines (their use increased substantially in the 1990s) accounting in 2007 for about 30% of the total cod landings.

Technical measures intended to improve the selectivity of trawl fisheries by reducing the bycatch and discarding of young cod, in the form of a 'Bacoma' codend with a 120-mm mesh were introduced by IBSFC in 2001 in parallel to an increase in diamond mesh size to 130 mm in traditional codends. The expected effect of introducing the Bacoma 120-mm exit window was counteracted by compensatory measures in the industry such as tampering with trawl panels. In October 2003, the regulation was changed to a 110-mm Bacoma window to enhance compliance and to be in better accordance with the minimum landing size, which was changed to 38 cm in the same year. However, ICES emphasized that gear regulations should not be substituted for reduction in fishing mortality.

Misreporting of cod catches has been a significant problem from 1993-1996 and from 2000-2007, being in the order of ca. 40-45% under-reporting. Misreporting, mostly in the form of unreported landings, resulted from a combination of: a) restrictive quotas, b) the absence of other fishing opportunities, and c) inadequate inspection. ICES has emphasized that age-readings of cod are uncertain, reducing confidence in assessments.

Precautionary reference points were established by ICES in 1998. The first attempt to determine B_{lim} and B_{pa} for cod in the Central Baltic was done by the ICES Study Group on the Precautionary Approach (SGPA), suggesting a B_{lim} equaling B_{loss} of 79 000 t. A B_{pa} of 140 000 t and an F_{pa} of 0.81 were determined, based on stock recruitment data from 1976 to 1996.

However, the Study Group on Baltic Fisheries Systems did not follow these suggestions, and determined B_{pa} instead as 240 000 t and B_{lim} as 160 000 t, with B_{pa} corresponding to the former Minimum Biologically Acceptable Level (MBAL) estimated from a Ricker stock-recruitment relationship (with data covering 1976-1994) as that particular SSB at which 50% of the maximum recruitment (age-group 2) originated. The F_{pa} was set accordingly to 0.75 or 0.65 (accounting for recent changes in growth), based on medium-term simulations. The goal was to determine an F_{pa} at which there is less than 10% probability of SSB being below B_{lim}.

The ICES Working Group on Baltic Fisheries Assessment (WGBFAS) revisited the F_{pa} determination again using the same methodology and stock recruitment relationship, but slightly altered the input data for the simulation. Accordingly F_{pa} was determined as 0.65 leading to an SSB corresponding to the 10% lower fractile of SSBs above B_{pa}.

The ICES Advisory Committee on Fishery Management (ACFM), in 1998, finally revised F_{pa} to 0.6 as the 5% percentile of F_{med}, derived from a stochastic stock recruitment relationship covering the 1966-1995 year-classes applying updated weight-at-age data for the stock, but period-specific maturity ogives. F_{lim} was set to 0.96 determined as F_{med}. As a result, F_{pa} of 0.6 and F_{lim} of 0.96 were officially adopted as limit reference points in 1998.

Already in 1998, ICES Study Group on Management Strategies for Baltic Fish Stocks (SGBFS) and ICES WGBFAS suggested determining the F reference points with a truncated time series to account for productivity shifts in the Baltic system, leading to reduced recruitment success since the first half of the 1980s.

1999 – A Long-Term Management Strategy for Cod Stocks in the Baltic Sea was adopted by the International Baltic Sea Fishery Commission (IBSFC), specifying a target fishing mortality of 0.6 and defined decision rules in relation to annual TACs dependent on SSB. Additionally, the introduction of technical measures was stipulated.

2001 – A first recovery plan was adopted by IBSFC in 2001, which included—besides a target fishing mortality of 0.55—detailed technical measures to recover the Eastern Baltic cod stock. The measures included a summer ban on cod fishing, closed areas, gear design and size restrictions, minimum mesh- and landing-sizes.

2002 – ICES SGPA, reviewing the suggestions by ICES SGBFS came to the conclusion that: 1) the identification of time periods corresponding to 'regimes' is not straightforward, and may be an over-simplification of the true environmental variation. Furthermore, a regime shift that occurs in one direction could presumably be reversed at some time in the future, being difficult to predict; 2) Changes to reference points annually or over longer, but unpredictable time spans, could cause significant operational difficulties. Thus, it may be appropriate to place the emphasis on fishing mortality reference points, especially as it is fishing mortality that managers can influence and not the environment.

2003 – The ICES Study Group on Precautionary Reference Points (SGPRP) developed a framework for the revision of reference points, stating with respect to the Eastern Baltic cod that the relation between stock and recruitment (and thus B_{lim}) may change if the natural regime changes. This has been demonstrated to be the case in the Baltic Sea. In such cases, it may be relevant to limit the analysis to data representing the present regime. Such a procedure should, however, be implemented with caution because it might be difficult to identify the extent of a regime and because a precautionary approach should include a consideration that the regime may have changed recently or may do so in the near future. An alternative approach may be to focus on reference points based o fishing mortality rather than biomass. This would require a specific framework to be developed because the F reference points in that case might need to be dependent on the state of the biomass.

2005 – ICES WGBFAS dealt with the necessity to revise the limit reference points for Eastern Baltic cod, stating that medium-term projections indicate a substantial reduction in F to be required to have a reasonable probability of rebuilding the stock above B_{pa} in the medium term. The stock has been below B_{lim} since 1991, except for a brief period around 1995 when its biomass increased in response to a reduction in fishing mortality. There are no indications that recruitment has been further diminished due to this low stock size. Instead the indications are that the reduction in recruitment is primarily environmentally driven and that the spawning stock has decreased following the decline in recruitment rather than *vice versa*. WGBFAS further pointed out that the stock and recruitment data did not indicate any difference in recruitment above and below B_{lim} of 160 000 t. As a result, WGBFAS found it difficult to justify B_{lim}, although for similar reasons it felt it equally difficult to suggest a more appropriate value. The 2005 simulations show that target fishing mortalities close to 0.3 (age-groups 4-7) would result in a low risk to reproduction as well as high long-term yields.

2006 - ICES WGBFAS reiterated that the strong environmental influences on the recruitment of Eastern Baltic cod could possibly mean that it is impossible to define a single biomass value below which recruitment is impaired. WGBFAS noted that there is a tendency to downplay the role of limit reference points for management advice in favour of target reference points, but that the limit reference points are likely needed for establishment of future management plans and evaluation of these to be precautionary, and not least because EC Council Regulation 2371/2002 separates between recovery plans for stocks being in a depleted state and management plans for stocks being within safe biological limits requiring a definition when one or the other state is reached, as cited in ICES.

2007 - Based on simulations conducted by ICES *Ad Hoc Group* on Long-Term Advice (AGLTA), ICES ACFM advised the European Commission on a suitable target fishing mortality (F_{target} of 0.3), which formed the central part of the HCR of a proposed management plan for Baltic cod stocks. The EC eventually agreed on the management plan in September 2007: The essentials of that are a F_{target} = 0.3, achieved by 10% annual reductions of F and accompanied by a corresponding 10% reduction in effort. The change of TAC shall be no more than 15% unless F>0.6. In that case, the TAC is taken as that which causes a reduction of F by 10%. The management plan was not evaluated at that point to be in accordance with the precautionary approach.

Based on a review of available information by WGBFAS, ICES advice on the stock in 2007 (for 2008) provides a catch option for harvesting at F_{target} of 0.3. However, the management plan was not formally adopted at the time that ICES issued the advice (early June 2007), and thus could not serve as the basis for the advice. In addition, ICES was not in a position to evaluate whether the proposed management was in accordance with the precautionary approach, as the formulation of the HCR was ambiguous. In the absence of an implemented management, ICES concluded that the stock should be harvested within precautionary limits. This resulted in advice that no catch be taken in 2008, as even a closure of the fishery could not bring the SSB above B_{pa} in the short-term.

2008 - The biomass reference points (B_{pa}=240 000 t, B_{lim}=160 000 t) were abandoned by ICES, because the ICES Workshop on Integrated Assessment of the Baltic (WKIAB) and ICES Workshop on Limit and Target Reference Points (WKREF) demonstrated a shift in food-web composition and environmental drivers. UNCOVER as a contribution to the ICES Workshop on Reference Points in the Baltic Sea (WKREFBAS) performed simulations to derive a range of sustainable fishing mortalities for cod, and concluded that target Fs of 0.3 to 0.4 are appropriate and that a substantial reduction in assessment and implementation errors might allow a higher F., but the poor landings data, uncertain discard data, and age-reading problems will need to be addressed first. In the absence of applicable biomass reference points, ICES could not evaluate the stock status with regards to these, but based on the most recent estimates of fishing mortality (for 2007), ICES classified the stock as being harvested sustainably in 2008 but F was above F_{target}. The agreed EC management plan was still not evaluated at the time when the advice for 2009 was issued. In the absence of limit reference points, and without an evaluated management plan, ICES advised in the context of the management plan with the rationale that the expected fishing mortality in 2009 when applying the management plan was closer to the target (F_{MSY}) suggested by ICES, thus resulting in benefits for the long-term yield. Advising for a fishery at F_{pa} (based on the precautionary approach), in the absence of biomass reference points, would have resulted in a much slower increase of SSB and thus an extended period to attain recovery.

Long-term simulations conducted in UNCOVER suggest that fishing at F_{pa} of 0.6 may not recover the cod stock, neither to B_{pa} when applying a hockey stick stock-recruitment relationship based on data covering a period of unfavourable environmental conditions and low reproductive success (1987-2005) with an inflection point of 160 000 t, nor to B_{lim} when applying the same data and an inflection point of 92 000 t. Applying a geometric mean recruitment instead of using a stock-recruitment relationship, yields in general more conservative stock and yield trajectories, but the differences are limited for the unfavourable environmental scenario as long as SSB stays above the inflection point, *i.e.,* recruitment is independent of SSB. Including cannibalism in the simulations makes a difference only for stock recovery to B_{pa}; for recovery to B_{lim} it is of very limited importance, because of the relatively low adult predator stock size.

In contrast, the present F_{pa} may be sustainable in a high productivity system as indicated by single species simulations using a hockey stick stock-recruitment relationship based on the entire data series (1976-2005). Including cannibalism results in somewhat less optimistic trajectories, with stock size being below B_{pa} with 10% probability when fishing at F_{pa}. At higher F, the risk of SSB being below B_{pa} is increasing faster with increasing F in singles species simulations, *i.e.,* the compensatory mechanism of cannibalism gives more stability against high F, however, it requires lower F to reduce the risk of being below B_{pa}.

Simulated SSB and yield at equilibrium depend mostly on the time span used to fit the recruitment model, with next important being the choice of the inflection point defining the SSB below which there is a relationship between SSB and recruitment. Assuming low inflection points (or geometric mean recruitment) creates in multispecies simulations increasing yield curves with F, which is counter-intuitive and is also not the case in multispecies simulations using stock-recruitment relationships with higher inflection points. Choosing different stomach content data, representing periods of high and low cannibalism has only limited impact on the simulation results.

2009 - ICES based on UNCOVER work evaluated the EC management plan in March 2009, and concluded that this management plan is in accordance with the precautionary approach and thus, the advice for 2010 is given in the framework of the management plan. Performance and robustness of the plan was tested with a management strategy evaluation model (MSE). Stochastic simulations are carried out under different scenarios of recruitment and sources of uncertainties. Under the different magnitudes of errors investigated, the plan in its current design is likely to reach precautionary targets by 2015. It is, however, more sensitive to implementation errors (*e.g.,* catch misreporting) than to observation errors (*e.g.,* data collection) when the (i) current settings of the ICES single-stock assessment model are maintained, (ii) intended fishing effort reduction is fully complied with, and (iii) biological parameters are assumed constant. Additional sources of uncertainties from fishery adaptation to the plan are tested using a fleet-based and spatially explicit version of the model. These spatially explicit evaluations covered two cod recruitment regimes and various fleet adaptation scenarios. The tested management options included total allowable catch control, direct effort control, and closed areas and seasons. The modeled fleet responded to management by misreporting, improving catching power, adapting capacity, and reallocating fishing effort. The simulations revealed that the management plan is robust and likely to rebuild the stock in the medium term even under low recruitment. Direct effort reduction limited underreporting of catches, but the overall effect was impaired by the increased catching power or spatio-temporal effort reallocation.

Fishing closures had a positive effect, protecting part of the population from being caught, but the effect was impaired if there was seasonal effort reallocation. Simulations with the ISIS model revealed that reduction of effort and thus fishing mortality as imposed by closed seasons is more efficient than reduction of spawner disturbances through the implementation of spatially restricted spawning closures. Even a “large spawning closure scenario” affecting year around about one fifth of the entire fishing area performed remarkably worse than the tested seasonal closures. Although this scenario effectively removed all effort from dense pre-spawning and spawning concentrations, the capacity of the cod fleets was high enough to compensate the closure effect to a large degree by reallocating the effort into open areas maintaining high catch levels.

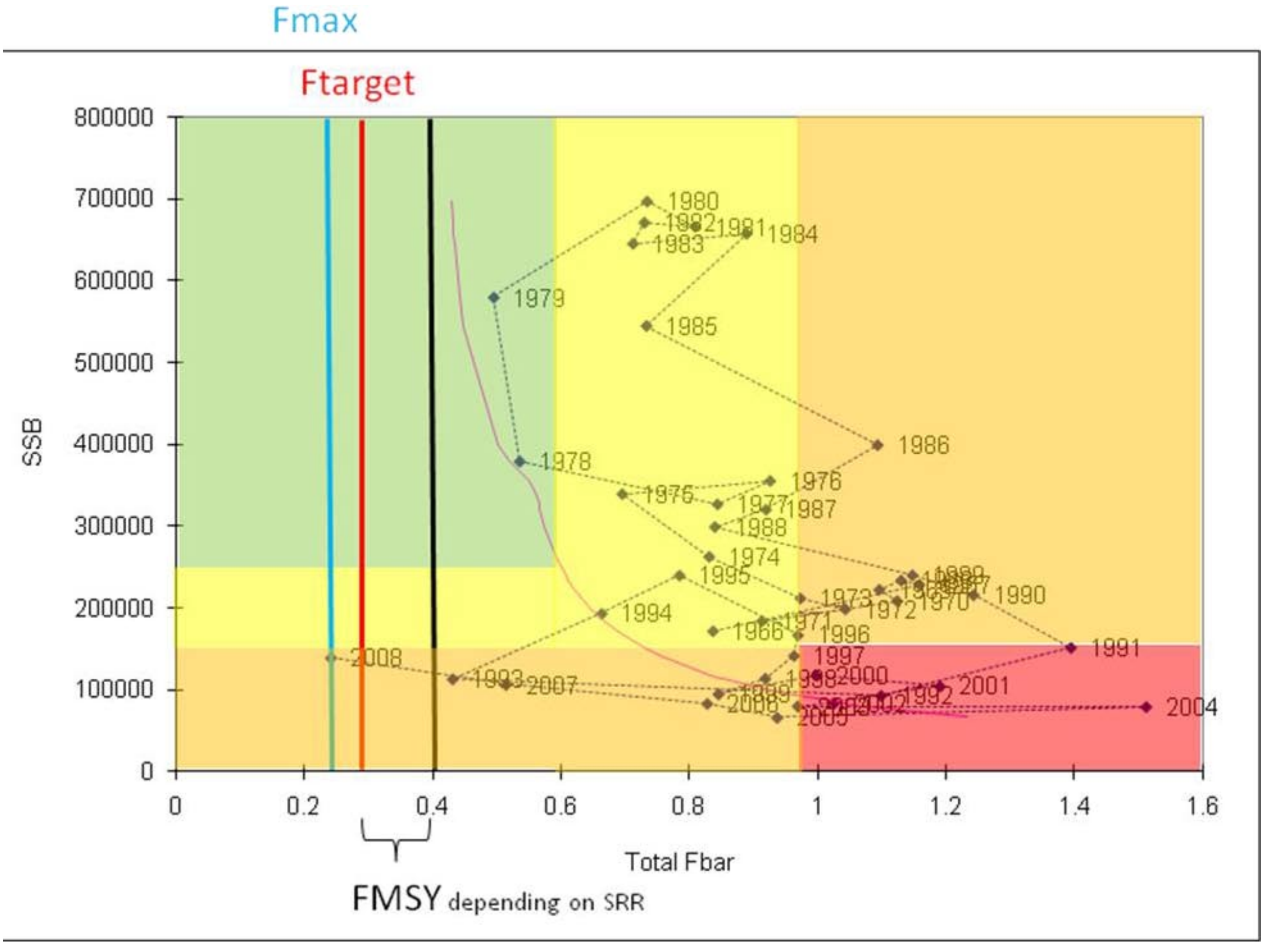

Figure 6.9: Spawning Stock Biomass (SSB) against fishing mortality (Fbar) for Eastern Baltic cod. There is no trigger biomass in the HCR; simulations (Köster *et al.*, 2009) suggest that B_{MSY} at F 0.3-0.4 at low recruitment may be set between 230 000 t to 280 000 t and at high recruitment between 450 000 t to 500 000 t (taking cannibalism into account).

Baltic sprat

For Baltic sprat, the state of the stock, and reference points are shown in table 6.11. and table 6.12, respectively. The spawning stock biomass plotted against fishing mortality is shown in figure 6.10.

Table 6.11. State of the Baltic sprat stock

Baltic sprat				
Spawning biomass in relation to precautionary limits	**Fishing mortality in relation to precautionary limits**	**Fishing mortality in relation to high long-term yield**	**Fishing mortality in relation to agreed target**	**Comment**
Undefined	At risk	Overexploited	NA	

Table 6.12. Baltic sprat – reference points

Baltic sprat			
	Type	**Value**	**Technical basis**
Precautionary approach	B_{lim}	Not defined* (200 000 t until 2008)	
	B_{pa}	Not defined* (275 000 t until 2008)	
	F_{lim}	Not defined	
	F_{pa}	0.40	F_{med} (estimated in 1998), allowing for variable natural mortality
Targets	F_y	Not defined	

*A recent integrated ecosystem assessment (ICES Doc. CM/BCC:04) shows a major shift in food-web composition and in environmental drivers in the Central Baltic. Therefore, the previously defined biomass reference points ((B_{pa}, B_{lim}) are no longer considered appropriate and they were not used in advising on the stock status.

Sprat and herring are mainly taken in pelagic trawl fisheries, which include some fisheries taking both species simultaneously. The actual composition of pelagic catches, and compilation of associated statistics, is poorly known for these fisheries because there is substantial variability in practices between countries, dependent *inter alia* on whether sprat or herring is officially targeted, whether the fishery is for human consumption or industrial purposes and different log-book and inspection routines. This means that the actual composition and catch levels are uncertain, with the consequence of misreporting being that the sprat stock is overestimated, and the herring underestimated as the herring TACs are limiting and hence there is an incentive to declare herring to be sprat.

Since 1998, the sprat stock was managed with respect to a B_{lim} of 200 000 t (former MBAL) from which the B_{pa} of 275 000 t was derived. F_{lim} was not defined and F_{pa} was set as F_{med} = 0.40 in 1998, allowing for variable natural mortality.

The BSFC agreed to implement a LTMP for sprat in the Baltic in September 2000 by Resolution XIII, stating that this plan shall be consistent with the precautionary approach and be designed to ensure a rational exploitation patter and provide stable and high yields. This plan consisted of the following elements:

1. *Every effort shall be made to maintain a level of SSB greater than 200 000 t.*
2. *Annual quotas to be set for the fishery, reflecting a fishing mortality rate of 0.4 for relevant age groups.*
3. *Should the SSB fall below a reference point of 275 000 t, the fishing mortality rate referred to under 2 will be adapted in the light of scientific estimates of the conditions then prevailing, to ensure safe and rapid recovery of the SSB to levels in excess of 275 000 t.*
4. *The IBSFC shall, as appropriate, adjust management measures and elements of the plan on the basis of any new advice provided by ICES.*

ICES considered this agreed management plan to be consistent with the precautionary approach, and until 2006 sprat was managed by means of this LTMP. Since then, ICES scientific advice was given on the basis of precautionary biomass and fishing reference points, until in 2009 the limit biomass reference points were abandoned.

In 2009, the European Commission requested ICES to identify multi-annual management options for each of the Baltic herring stocks and the Baltic sprat stock based on the following form of HCR:

i. *The sum of the regulated catches for the stock of ("the stock") shall be set according to a fishing mortality of [A].*
ii. *Notwithstanding paragraph i above, the sum of the regulated catches shall not be altered by more than [B] % with respect to the sum of the regulated catches for the previous year.*
iii. *Notwithstanding paragraphs i and ii, in the event that the spawning stock size for the stock is estimated at less than [C tonnes / appropriate model-specific units], the sum of the regulated catches for the stock shall be adapted to assure rebuilding of the spawning stock size to above [C] without incurring the restriction referred to in paragraph ii. ICES should propose a TAC-setting calculation in such cases.*

ICES was asked to identify combinations of values for A, B and C that would ensure that management of the stock would conform with the precautionary approach; *i.e.*, a low risk of stock depletion, stable catches and sustained high yield. UNCOVER provided simulations and preliminary recommendations for a management plan with a F proposed to be 0.40, accompanied by a TAC variation for ± 20% above a trigger SSB of 400 000 t. If the SSB falls below this, F shall be linearly reduced to zero at an SSB of 200 000 t. The recommended target F is close to F_{MSY} and F_{pa}. For *status quo* F (0.45) there is higher than 5% probability of SSB falling below 400 000 t in some years at the beginning of simulation periods. The HCR with target F of 0.3 would produce catches lower by *ca.* 10%.

Multispecies evaluations showed that the herring and sprat populations remain within safe limits, provided that cod is fished with the present target F at 0.3 and has recruitment as observed in the past 15 years. If cod recruitment is increased by about 125%, which would still be on a low level as compared to the recruitment in the mid-1980s, the present target fishing mortalities for herring and for sprat would be too high to maintain the spawning stock biomasses of these pelagic stocks above precautionary thresholds with a high probability. Thus, the suggested management plan for Baltic sprat is only precautionary in a low cod recruitment scenario. If reproductive conditions for cod improve, a target F of 0.4 for sprat is too high. Apart from the direct predation effect, the simulations demonstrate that clupeid growth and thus also competition between sprat and herring matters, so indicating that in periods of high growth rates, the stocks sustain a higher target F.

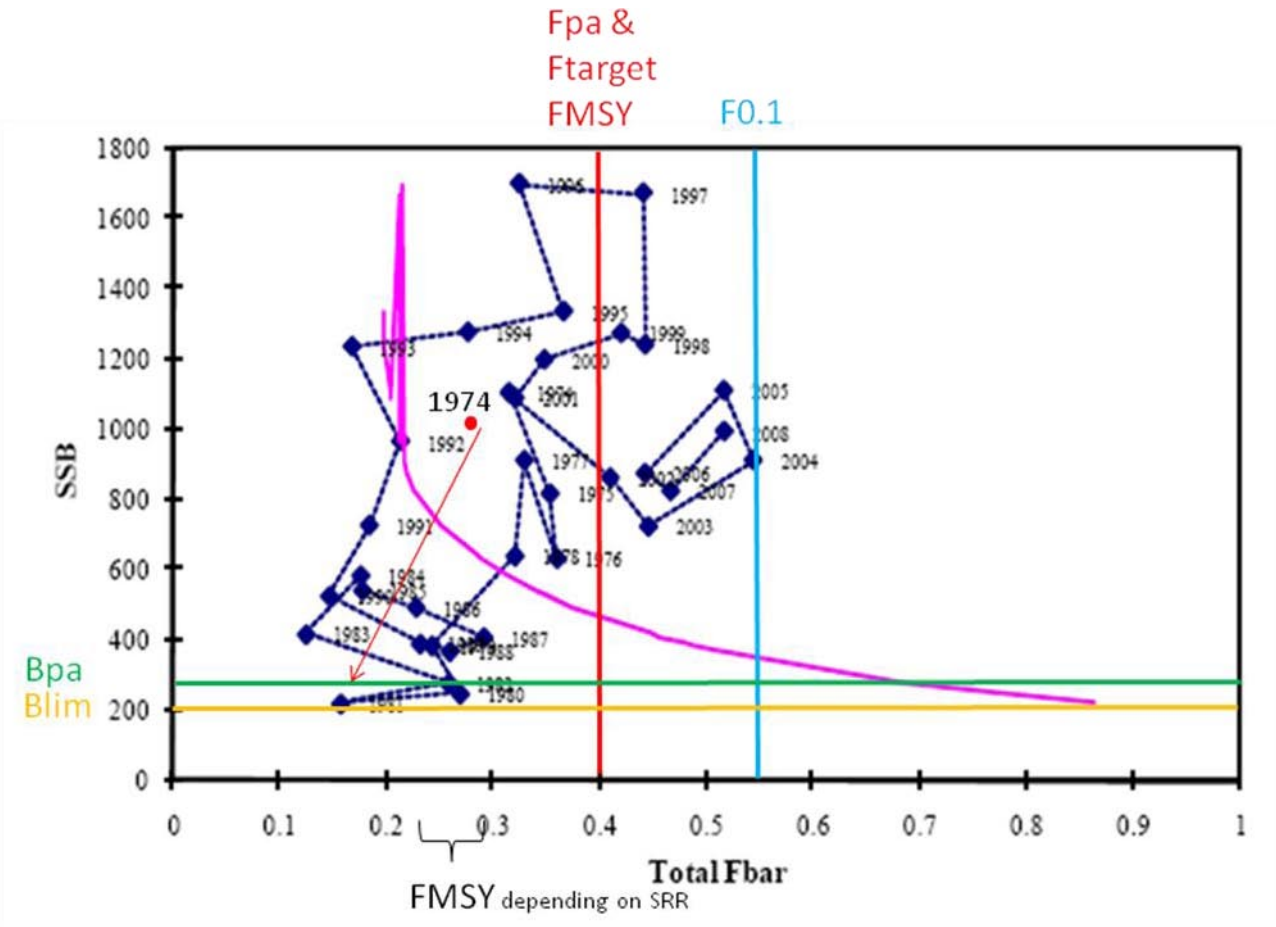

Figure 6.10. Spawning stock biomass (SSB) against fishing mortality (F_{bar}) for Baltic Sea sprat. $B_{trigger}$ is set to 400 000 t and at 200 000 t F is to be 0.

6.3.4 Bay of Biscay and Iberian Peninsula

Northern hake

The current management reference points and their corresponding values for Northern hake are shown in table 6.13.

Table 6.13. Northern hake current management.

Northern hake	
Reference point	**Value**
B_{pa}	140 000 t
F_{pa}	0.25
F_{target}	0.17
Discards permitted	Yes
Other measures	Minimum landing size, temporary closure of areas, landing warning to authorities, mesh sizes. LTMP under discussion

The Northern hake stock has historically been targeted by French and Spanish fisheries in the Bay of Biscay area.

The management of this stock is based on consideration of the corresponding biological reference points. Table 6.14 shows the evolution of these points over time. The last column contains the reference points that are currently on use.

Table 6.14. Northern hake evolution of biological reference points. The last column shows the current reference points.

Northern hake			
	WG[10] 1998	**ACFM 1998**	**Updated values for 2003**
F_{lim}	No proposal	0.28 (= F_{loss}WG 98)	0.35(= F_{loss}WG 03)
F_{pa}	No proposal	0.20 (= F_{lim}*e-1.645*0.2)	0.25(= F_{lim}*e-1.645*0.2)
B_{lim}	No proposal	120 000 t (~ B_{loss}= B94)	101 200 t (~ B_{loss}= B94)
B_{pa}	119 000 t (=B_{loss}= B94)	165 000 t (= B_{lim}*e1.645*0.2)	140 625 t (= B_{lim}*e1.645*0.2)

The historical evolution of this stock can be followed (Figure 6.11 a, b) where the stock level against the fishing mortality has been plotted each year.

Until 2001, there were very few technical measures implemented in the Northern hake fishery management. Although there was clear evidence of the depletion of the stock since the mid-1990s, the Emergency Plan was not implemented until June 2001. After that, some management measures were added to the ones described in the Emergency Plan in 2003. In 2004, the Recovery Plan was developed and implemented, once the stock was above the established F_{pa}

[10] ICES Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk, and Megrim.

and B_{lim}. Since the stock seemed to be above B_{pa} in 2006 and 2007 (not in this plot, which contains data from the assessment of 2009), and following Article 3 of the Recovery Plan, a LTMP was proposed. This LTMP aims to produce a stock which is above its MSY level by 2015, as agreed in the 2002 WSSD's Johannesburg Declaration. In 2007, STECF proposed an $F_{MSY} = F_{max} = 0.17$ for northern hake.

Apparently, both the Emergency Plan (2001) and the Recovery Plan (2004) may have helped the SSB increase (Figure 6.11 b). Currently, the stock is defined as being in full reproductive capacity, and fished sustainably in relation to precautionary limits. Nevertheless, the stock is still overfished according to the F_{MSY}, even if the biomass levels are in the limit of being in a good situation.

a) **b)**

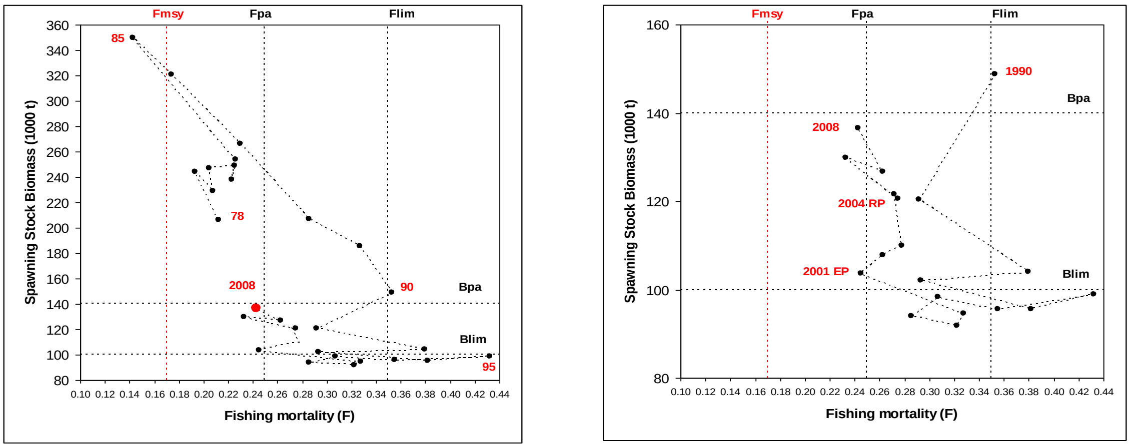

Figure 6.11. Precautionary Approach plots for Northern hake: a) including the whole time series; b) only from 1990.

Southern hake

For Southern hake, the current management reference points and their corresponding values for Southern hake are shown in table 6.15. The SSB/R plot with regard to B_{lim} and B_{pa}, and F/SSB plot with regard to biological reference points are shown in figure 6.12.

Table 6.15. Southern hake current management.

Southern hake	
Reference point	**Value**
B_{pa}	35 000 t
F_{pa}	0.40
F_{target}	0.27
Discards permitted	Yes
Other measures	Minimum landing size, temporary closure of areas, landing warning to authorities, mesh sizes. Recovery-based on effort reduction.

The Southern hake stock has been unsustainably harvested for many years. Based on the most recent (2009) estimates of SSB, ICES classifies the stock as suffering reduced reproductive capacity. Based on the most recent estimate (2008) of fishing mortality, ICES classifies the stock as at risk of being harvested unsustainably. Fishing mortality has increased in recent years and is currently near F_{lim}. SSB and recruitment have increased in recent years.

There is a Recovery Plan for Southern hake under EC Regulation No. 2166/2005, enforced since 2006. The aim of the plan is to recover the stock to a spawning-stock biomass above 35 000 t by 2016 related to reducing fishing mortality to 0.27 (F_{max} in 2004 assessment). The main elements in the plan are a 10% annual reduction in F and a 15% constraint on TAC changes between years. This plan has not yet been evaluated by ICES.

Fishing mortality has been above F_{lim} for most of the time since 1994 and, although the SSB remains below B_{lim}, the last three years have seen an increase in SSB. Recruitment was high in the mid-1980s and then decreased to low levels. Nevertheless, since 2001 recruitment has increased to a level comparable to the mid-1980s as estimated in the most recent assessment.

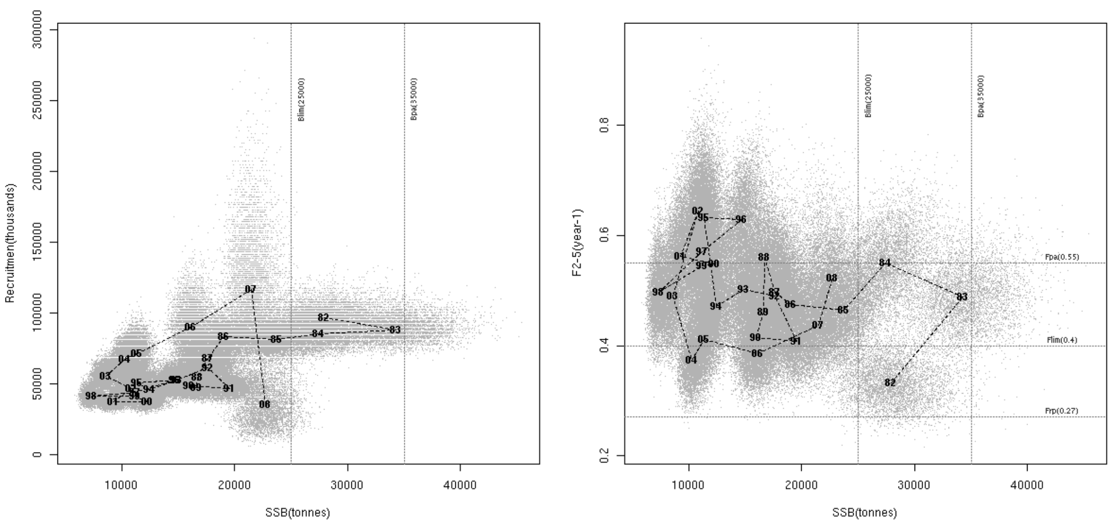

Figure 6.12. Southern hake SSB/R plot with regard to B_{lim} and B_{pa} (left) and F/SSB plot with regard to biological reference points. From last Bayesian assessment (ICES, 2009)

Despite the stock currently being in a relatively good status (the fifth best SSB level ever known), it is far from the recovery target of 35 000 t to be reached by 2015, taking into account that the Recovery Plan was implemented in 2006. Moreover, there is evidence of problems compliance of the Recovery Plan, particularly regarding the high TAC overshooting observed in recent years.

The current Recovery Plan is due to finish in 2016. There is not any agreed proposed for a LTMP for this stock. Although F_{max} estimated in the last ICES assessment is 0.18, this assessment appears to be fraught with uncertainties. The main uncertainties are: lack of discards data for inputting into the assessment model, doubts about the hake's growth rate and predation-related, mainly due to cannibalism.

The UNCOVER project has not analyzed the discards data, but recently published studies (Jardim *et al.*, 2010; Fernandez *et al.*, in press) show that not considering discards, neither in the model nor in the projections may underestimate the probability of reaching the recovery target (35 000 t of SSB by 2016). This is explained by the fact that including discards in the stock assessment increases the recruitment used in the stock-recruitment relationships utilized in the projections.

The analysis developed along UNCOVER focused on growth and cannibalism. Combinations of fast/slow growth with/without cannibalism revealed four scenarios to be included in the long-term simulations conducted with GADGET (Table 6.16). Considering cannibalism and fast growth assumptions add additional levels of biological realism to the current assessment models. Although the current knowledge of these processes is not complete, we know that these processes exist and including them in the models helps us to understand their impact on the state of the stock and its dynamics, the references points for management and the recovery expectations.

Table 6.16. Four models used to examine the interactions between cannibalism, growth rate, and natural mortality.

Southern hake			
Model	**Cannibalism**	**Growth rate K (von Bertalanffy)**	**Natural mortality M**
Model 1	No	0.075	0.2
Model 2	Yes	0.075	0.2
Model 3	No	0.150	0.4
Model 4	Yes	0.150	0.4

Reference points were estimated for the four models. Historic results show that Models 1 and 2 produce similar levels of SSB to the official assessment, so the same SSB target (B_{pa}=35 000 t) was accepted. In contrast, the fast growth models (Models 3 and 4) showed similar historic trends but levels of SSB were about 25% lower. This suggests that the current SSB target should be modified to 25 000 t for Models 3 and 4 (see UNCOVER Deliverable 18). Regarding F reference points, F_{max} was estimated for the four models.

The reference points are summarized (Table 6.17) using the results from long-term projections to 2050 under recruitment equivalent to the historic mean (*i.e.*, 1990-2007).

For Model 1 the value of F_{max} is 0.18, equivalent to the current ICES assessment and well below the recovery target (0.27). For the fast growth models (Models 3 and 4), this figure is about two times larger. This long-term analysis also shows that F_{max} for slow growth models (Models 1 and 2) produce SSBs at equilibrium well above the SSB target, although these SSBs levels were never actually observed in this stock. Nevertheless, fast growth models seem to produce SSB values at F_{max} similar to those expected for recovery.

Table 6.17. Southern hake reference points for the four different models. F_{max} is in the first column; in the second column the level of F_{max} reduction compared with the current F (2008); and in the last column the level of this SSB expected coincide with recovery.

Southern hake			
Model	**F_{max}**	**Multiplier of $F_{(2008)}$ = 0.72**	**SSB recovery (t)**
1	0.18	0.3	35 000
2	0.16	0.2	35 000
3	0.31	0.45	25 000
4	0.36	0.5	25 000

Including cannibalism produces different reference points and projections with, however, larger dependence on the growth models. It is difficult to generalize about these results. Applying a slow growth model results in slow recovery and *vice versa*.

Differences between fast growth models with and without cannibalism are small.
When not considering cannibalism, the related F_{max} to achieve MSY would result in a 70% reduction of F(2008) levels for the slow growth models, compared to a reduction of only 55% for the fast growth models. However, if cannibalism is considered in the models to achieve MSY, the necessary reductions of F(2008) to F_{max} are dissimilar for the different growth rates in the models: While the slow growth models require F_{max} to be reduced by 80%, the fast growth models only require a 50% reduction of F(2008) levels.

This analysis has shown that it is essential to take into account the growth rates of southern hake when recommending any recovery plan. Ignoring higher growth rates and related mortalities may underestimate the recovery possibilities. The same appears to be applicable for discards while the impact of cannibalism appears to be more limited.

Work conducted under the UNCOVER project will contribute directly to the assessment and management of southern hake in the Iberian Peninsula. It was discovered that there were major biases in the age reading of hake in the Bay of Biscay. Thus, an age-length based GADGET model for the Southern hake stock was developed within UNCOVER. This model was extended by considering more data (landings from 1982 to 93, discards and C‡diz landings), after that the model was refitted and finally it has been evaluated by the ICES WKROUND benchmark meeting held in 2010. The model will be used as the basis for management advice from 2010. Furthermore, this model forms the basis for ICES analysis of the Recovery Plan that is being developed about March 2010.

Anchovy

For the Bay of Biscay anchovy, the current management reference points and their corresponding values are shown in table 6.18. The evaluation of the past series of SSB estimates relative to B_{lim} are shown in figure 6.13, while the precautionary approach plot is shown in figure 6.14.

Table 6.18 Anchovy current management.

Anchovy	
Reference point	**Value**
B_{lim}	21 000 t
F_{lim}	Not defined
F_{target}	Not defined
Discards permitted	Yes
Other measures	Fishery closed until spring 2010. LTMP enforced with an HCR.

A TAC-based management system, at an almost constant TAC level around 30 000 to 33 000 t, was in place until the fishery collapsed in 2005 and 2006. The fixed TAC was being set regardless of scientific advice, whereby in some years catches exceeded, and in other years catches did not reach, the fixed TAC level. The fishery has been closed since its collapse. There has not been a recovery plan other than closing the fishery. The crisis was brought about by successive failures of recruitment since 2002, which ultimately led to stock depletion in 2005.

Figure 6.13. Evaluation of past series of SSB estimates relative to B_{lim} for Bay of Biscay Anchovy.

Following the collapse of the anchovy fishery, the EC has pushed ahead the development of a LTMP for anchovy, for which final approval is expected to be given during the first half of 2010. According to the EC regulation, the LTMP is called a Recovery Plan when the biomass is below B_{pa} (<33 000 t) in order to allow for financial support from the EC Fisheries Fund, whereas it is called a LTMP when the biomass exceeds B_{pa}. The LTMP defines a sustainable harvest rate at 30% (as advocated by the EC), or at 40% (as modified in the European Parliament process during the second half of 2009) and it imposes a TAC ceiling of 33 000 t.

As a recovery rule, the plan establishes that, should the stock should fall below 33 000 t, then a fixed constant minimum (or precautionary) TAC of 7 000 t will be allowed for SSBs between 33 000t and 24 000t, whilst below the latter SSB threshold the fishery will be closed.

STECF (2009) proposed two HCRs. The first HCR B considers a variable TAC as long as the SSB is between B_{lim} (21 000 t) and B_{pa} (33 000 t). The TAC will be zero should the SSB falls below B_{lim}. A maximum TAC is set at 33 000 t.

The alternatively suggested HCR E differs from HRC B regarding the threshold values for SSB and by putting limits on the TACS. To maximize the income to the fishery, it implies a fixed minimum TAC of 7 000 t should the SSB be between 24 000 and 33 000 tons. It also applies a TAC ceiling of 33 000 t.

UNCOVER tested the HCR in the suggested management plan (HCR E) and the alternative HCR B (decrease of F between B_{lim} and B_{pa}) using a broader range of scenarios and stock-recruitment models than in STECF simulations.

A stock-recruitment relationship with persistent low recruitment and high recruitment scenarios, depending on the historical series autocorrelation (to incorporate the cyclical periods of recruitment levels, expected to be associated to the currently not understood environmental conditioning) was applied in an FLR-framework. This approach was taken after performing a new revision on the influence of several oceanographic indices on the incoming recruitment, and concluded that there is not a reliable index to improve the knowledge on recruitment by itself (S‡nchez *et al.*, 2009), excepting for the role of the parental stock which seems to be the only factor remaining statistically significant over the series.

Summary of the main results:

- Regarding the sensibility of the HCRS to the uncertainty on recruitment, if one sets a maximum TAC then both HCRs B and E are robust to any uncertainty about the recruitment, except for the case in which one assumes that the incoming recruitment is going to be persistently low. Under the latter assumption, although the fishery remains closed, the biological risks are very high.
- Concerning the management strategy recommended in the proposal of the LTMP for anchovy (HCR E, harvest rate = 0.3 and TAC_{max} = 33 000 t) and the modification suggested in the European Parliament process (HCR E, harvest rate = 0.4 and TAC_{max} = 33 000 t), the sensitivity of the LTMP to the way of estimating the incoming recruitment is noticeable. In the low recruitment scenario, the projected median SSB will remain mostly at levels below B_{pa} and very close to B_{lim} (with a risk of being below of around 33%). In the rest of the recruitment scenarios, the projected median SSB will exceed B_{pa} from the third projected year onwards but with a risk of being still below B_{pa} of about 35%. However, there is little sensitivity of those HCRs to the SSB observation error and, in all cases, the median SSB levels remain well above B_{pa} from the third projected year onwards.

Simulations were also conducted within the ISIS-framework. Results of the so-called hindcast and forecast simulations are detailed in UNCOVER Deliverable No. 25. Only the most significant outcomes are provided here. Consideration of environmental processes is part of the model, and three designs of spatial and seasonal closures and effort reduction rules were evaluated.

As expected, the results appear highly sensitive to larval survival scenarios both in hindcast and forecast scenarios. None of the measures proposed are really robust to recruitment failures and the biomass never reached B_{pa}. In the short-term, HCR B gives generally better results than the classical TAC. But in the longer term, unexpected effects arise due to higher frequencies of fishery openings. It questions the adequacy of the biomass level used as the fishing ban threshold and the exploitation rate allowed. It must be noted that the HCRs are applied based on true biomass, with no observation error being added. Effort reduction and MPA effects are secondary. However, the combination of those measures often improves final biomass, with effort reductions limiting the negative effects of effort reporting. However, in the forecast scenarios, these measures appeared sensitive to uncertainty concerning the modeling of *païta* fishing and effort level. It evidenced the necessity to improve our knowledge on *païta* fishing. Finally, it is likely that— given the high frequency of fishery closures in forecast scenarios—the effects of those measures (generally seen as long-term measures) are underestimated. The highest biomass levels are obtained, on average, with the combination of HCR B, closure of coastal areas during the spawning season (from April to September) and a reduction of total effort by 33%. In any case, the spatial distribution of fish in spawning areas is a determining factor for recruitment and management success.

As the LTMP has not yet been approved, it has not yet been officially tested in practice beyond the simulation level of scientific work carried out by STECF.

The EU Fisheries Council, meeting in December 2009, decided to re-open the fishery for 2010 with a provisional TAC of 7 000 t. This decision was undertaken after the National Governments received indications that a better level of recruitment was entering the population during the autumn 2009. Thus, it has been presumed that the closure of the fishery since 2005 has finally resulted in a good level recruitment, restoring the population to levels above B_{pa}. However, this needs confirmation from the spring surveys in 2010, which form the basis of ICES advice.

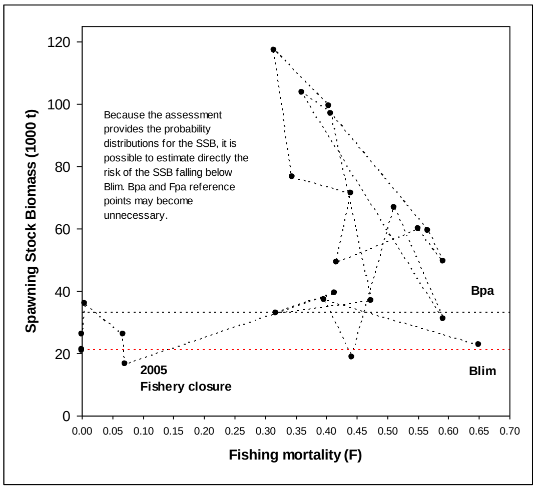

Figure 6.14. PA plot for Bay of Biscay anchovy.

6.3.5 Consideration of socio-economic consequences of existing and alternative recovery plans

Social, cultural, and economic information can be, and indeed has been, taken into account in fisheries management stock recovery and long-term management in many areas of the world, particularly in North America and Australia. There has also been work begun in Europe, such as with the early PESCAFISH work, UNCOVER's own social impact assessments, and a small pilot project in the UK through DEFRA: The UK Ports Project and Socio-Economic Dataframe (Hatchard *et. al.,* 2007). The Dataframe is a unique example of an attempt to provide an information structure within which socio-economic information relating to fisheries and fishing communities can be stored and maintained. It also proposes an interface by which the data can be both presented to and accessed by policy-makers, industry and other stakeholders. Work is also currently underway in the EU planned to highlight regional social and economic impacts of change over the last ten years in (24) fisheries-dependent communities.

Following these accepted methods in other parts of the world, in order to assess the impacts of the Baltic and North Sea cod recovery plans, as well as the Northern Hake recovery plan, baseline studies for identifying the socio-economics of fishing communities in the Baltic and North Seas were the first step taken to understand the likely impacts of fisheries management plans and actions. This information is also a prerequisite to mitigate possible negative consequences on fishing communities. For example, a proposed quota reduction may result in fishers of a certain fisheries segment to go out of business. Just as important are the perceptions and the willingness of community members to support this fisheries segment.

Norwegian Sea and Barents Sea

No UNCOVER social and economic work was carried out in this CS Area. This was built in to the project design because of the remoteness of this case from the social science partners and the need to stay within the proposed budget.

North Sea

In the course of UNCOVER, SIAs of the North Sea Cod Recovery Plan were conducted in three North Sea fishing communities, Thorsminde (Denmark); Urk (the Netherlands); and Peterhead (United Kingdom). As would be expected, the situation varied among communities and fleets considerably over time, though there were some generalities surrounding the issues of regulations, compliance, and fleet specialization, which can impact the success of recovery plans.

Fishing related industries all have a need for regulations, which will enable appropriate planning to take place. There was a great deal of concern, of course, when the CRP was first introduced and fears were high for the impacts it would have on fleets and communities, yet qualitative interviews uncovered a desire among participants in the industry for long-term planning. If long-term planning business planning is possible, cheating for short-term gain can be minimized.

One difficulty fleets and fishers face in adapting to changes recommended in recovery plans is whether fleets and fishers are specialists or generalists. Specialization makes it difficult to switch between species or gears – and even if possible because quotas for other species are held, or the season is appropriate, other regulations may make it difficult to do so. The importance of specialization or generalists was uncovered in not only the North Sea case, but also in the Northern Hake and Baltic cases, and even from the bio-economic modeling.

At the community level, it must be understood that specific impacts of the recovery plans varied spatially and temporally among the communities and groups investigated. Some general, take-home lessons are:

- Impacts felt vary according to the subgroup, and changes through time. The impacts on ancillary, shore-side sector cannot be forgotten (*e.g.,* processors, fish graders, net-repairers, engineers). Also, there may be particular demographic-oriented subgroups which will face hardships more than others: a graying or immigrant population (*e.g.,* in Thorsminde, or workers in processor firms and as crew), or in cultures where wives remain at home and do not have the education for outside work (*e.g.,* in Urk).
- Cumulative effects must be taken into consideration when viewing impacts. Some fleets and communities may be able to adjust to one plan, but when faced with multiple plans and regulations find they cannot adjust successfully.
- Stakeholder acceptance of long-term management plans is quite high; they see the business advantages to be able to plan for the future.

Finally, it should be noted that fishers and community stakeholders do agree with the need for long-term management plans which contain biomass targets expressed in clear precautionary and limit reference levels. What they do not agree with is the speed at which recovery may be emphasized in times of crisis in recovery plans: for example, why two years at zero effort rather than four at half effort?

Consideration of social and economic concerns into recovery plans will help make certain that there is an industry to weather crises, which in turn often helps to ensure not only community survival, but also sees thriving, healthy, heterogeneous communities.

Baltic Sea

In the Baltic, with the needs of UNCOVER in mind, a small-scale fisheries study (Delaney, 2007) investigated the impacts of the management plan for the cod stocks in the Baltic Sea on four fishing communities, Simsrishamn (Sweden); Kuźnica (Poland); Freest and Heiligenhafen (Germany); and Bornholm (Denmark). Cod fishers in these communities are highly dependent on that resource, as they tend to have lower incomes than their colleagues fishing for other stocks. They have limited access to credit, use older vessels, and have difficulty shifting to other species.

The research uncovered a number of similarities in terms of adaptability and vulnerability, community support and alternative activities among these communities. The main issues uncovered surround the topics of:

- Low profitability;
- Lack of employment diversification, including other fisheries as well as outside employment;
- Low recruitment (of fishers – tied intricately with the current management system);
- Inability of fisheries-related businesses to plan for the future.

Most of these communities, and/or the small-scale fishers, are highly dependent on the cod fishery, especially in Kuźnica (PL) where cod is the only stock, which provides them with a profitable fishery. Other segments of the sector are also dependent, however as diversification is extremely low. Also, there is a strong ethnic identity and cultural preference for fishing in the majority of these communities; Kuźnica with its Kashubian ethnic minority is a prime example of this fact. These types of communities can often face greater negative impacts and social stress in the cases of downturns and forced closures.

Overall, in Sweden, Poland, and Germany, local officials appear committed to keeping small-scale fisheries alive, and in many ways the future of these communities are tied closely to the cod fishery. Tourism may be a business for the future (*e.g.,* Simrishamn), and is certainly currently vital for Kuźnica given the lack of alternative employment opportunities. Bornholm (Denmark), in contrast, is seeing the consolidation of quotas into larger boats with fishers pessimistic about the future of fishing on the island.

Even if a local community and EC Member State take a strong position in favour of maintaining a sustainable small-scale fishery, the necessary reforms need to come at the international level. In order for investments to take place and young persons to enter the fishery, this segment must have a predictable regulatory framework to enable them to plan for the future, and they may also require preferential treatment in recognition of their weaker position vis-ˆ-vis larger vessels. But in order for investments to be sustainable, the cod stocks must recover by means of better-targeted control measures and use of efficient management tools.

Indeed, in the Swedish community newer vessels have been sold by cod fishers to pay debts. In fact, most of the Swedish Baltic cod quota is taken by larger fishers from the west coast rather than fishers from the Baltic. Cod fishers are also commonly older people, and many have quite small operations and are using passive gear. They are not well represented within fisheries management institutions.

The communities themselves are also relatively isolated and have limited alternative employment activities, with higher unemployment and lower incomes than is found in other parts of their respective countries. The main employment alternative is tourism, which is increasing in Sweden and Poland but not in Germany and Denmark. The fish-processing sector is also declining except in Poland, which is attracting these companies from other Baltic nations. Dependence on government unemployment benefits is growing in all of these communities. Poland is also seeing an out-migration of fishers, both to land-based jobs in cities and to North Sea fisheries. The Danish community is the only one where local retraining opportunities exist for cod fishers who must leave fishing (Delaney, 2007). In sum the situation for Baltic cod fishers seems to be one of limited ability to continue fishing for any species in the face of the recovery plan, yet they also have very limited non-fishing alternatives.

Bay of Biscay and Iberian Peninsula

In this CS Area, both SIAs of the northern hake recovery plan and bio-economic modeling were undertaken to extract understandings of economic and social impacts of management plans. SIAs were conducted in Spain in Pasajes (*Pasaia*) and Ondarroa. Pasajes is located in the municipality of Gipuzkoa, and Ondarroa in Bizkaia. These are the most important ports for commercial landings in the Basque Country. In France, a regional approach was taken to the SIA, with impacts researched for Guilvinec Maritime district.

Historically, hake has been an important species for these communities. In 2006, the French annual catches of Northern hake in the Bay of Biscay amounted to 9 797 t for a total value of EUR 40.7 million. At national level, Northern hake is one of the major species landed by the French fishing fleet and contributes to around 5% of the fresh total landings in value. While in Spain, hake landings have decreased steadily from 66 500 t in 1989 to 35 000 t in 1998 (except for 1995). Up to 2003, landings fluctuated around 40 000 t. In 2004 and 2005, an important increase in landings has been observed with 46 416 t and 46 550 t of hake landed respectively. In 2006, the total landings decreased to 41 469 t. They increased again in 2007 at 45 093 t and in 2008 at 47 822 t. Researchers found that a strong cultural preference for juvenile hake remains, despite legal minimum size restrictions.

In France, a proposal was tabled imposing a recovery plan for hake in 2004. Although Guilvince fishers already used selective gear, their main concern was how they could protect their juvenile langoustine fishery using a langoustine selective trawl. Fishers were concerned they would be banned from fishing langoustines in order to 'protect' juvenile hake. Serious negotiations with scientists, national and European administration, and with fishers of langoustines themselves were necessary to avoid the prohibition of langoustine fishing within the Bay of Biscay. The road to acceptance of a selective hake trawl, in addition to the langoustine gear, was an extremely long one and took concerted effort by the administration, scientists, as well as they first fishers to experiment with the new gear.

The organization of langoustine fishers at local level and their involvement in fisheries management by formulating proposals is something new within the French fishers' organizations. Usually, only national representation was allowed to defend fishers interests and sometimes without consulting regional and local committees. The organization at local levels of specific groups of langoustines and then hake and langoustines making proposals to the European project of regulations means that local fishers are able to participate to fisheries management by giving their experience and knowledge.

The primary causes of negative impact on these two communities have been an aging workforce and fleet and overall stock depletion due to a variety of both natural and anthropogenic causes.

However, the issue of compliance was raised in Spain with both the SIA as well as the bio-economic modeling. At the MS level, It appears as though there is a disconnect between policy and practice, wherein policy makers seem to be unconcerned with future issues in favor of short-term advances for Spain. The lack of enforcement despite the general knowledge of ubiquitous cheating is one such example.

In conclusion, in Spain we see that these communities face similar issues seen throughout Europe fisheries with an aging workforce and declining stock numbers. In France, though we witness similar challenges, we also see, thanks in part to the Northern hake recovery plan, an innovation in the governance structure with local groups taking on a more active role. As shown from this French example, as well in different aspects of the other SIAs, stakeholders can wield great influence either by participating in the creation of management measures and working as innovators – or by helping or hindering their implementation. Consequently, the importance of civil society, expressed in active social networks, for fisheries management is very clear from the recovery plan experience.

6.3.6 General conclusions from final recovery scenarios

The conclusions arising from the UNCOVER project's final recovery scenarios are placed in a wider perspective in section 8.5.

6.4 Conclusions from the UNCOVER Case Studies

6.4.1 Norwegian and Barents Seas

A wide-ranging review of the three key target fish species (cod, capelin, and herring) was conducted in the Case Study area with respect to their position in the ecosystem and modeling of their behaviour under different management and environmental conditions. The history of each stock, including the periods of depletion or outright collapse, and their subsequent recovery is described and an overview of the Barents Sea ecosystem is presented. The current management rules are described and modeling work to examine the effectiveness of that management is presented. It should be noted that although this project was conducted examining management under the precautionary approach, the conclusions and recommendations presented here are equally applicable to fisheries aimed at achieving MSY.

The modeling studies suggest that the current management rules are precautionary under current environmental conditions. Different modeling approaches using GADGET and STOCOBAR both suggest also that under moderate environmental change the management plans will continue to be precautionary. By using two different models, and two different approaches to modeling likely environmental impacts, we have reduced the model-formulation related uncertainty in these conclusions. The comparison of the two different models has also highlighted areas where underlying structural uncertainties (concerning growth and recruitment) present difficulties in giving precise predictions on future stock behaviour.

As a key conclusion it can be stated that the success of a recovery plan depends on the implementation of the total suite of management measures. The fishing mortality imposed on the stocks in the target fisheries, although important, is not the sole factor determining the success or otherwise of the plan. Methods of reducing unwanted mortality (enforced minimum landing size, discarding ban, closure of areas with high percentage of undersized catch, gear changes in other fleets to minimize bycatch) should be considered. For example for herring, the introduction of a strictly enforced minimum landing size near the size of maturation played a key part in creating the conditions in which a recovery was possible. For cod, action to reduce IUU fishing and reduce cod bycatch mortality in the shrimp fishery made management based on F in the targeted fishery more effective. For capelin, an escapement management strategy aims to ensure that, where possible, sufficient recruitment occurs regardless of the highly varying stock size.

It is important to evaluate management plans (including recovery strategies) in a multispecies context, *i.e.* predation, competition, and mixed-fisheries interactions needs to be considered. The interactions run in both directions, fisheries on a target species will affect other species, and the abundance of prey or competing species will influence the success of a recovery plan. The GADGET modeling highlights the important indirect effects that fisheries can have on other species through multispecies interactions. The multispecies interactions within the model have been strengthened by including herring predation on juvenile capelin reducing the reliance on external proxies as driving factors, and allowing more of the critical dynamics relevant to stock reproduction and recovery to be explicitly modeled. The STOCOBAR modeling shows the important effect capelin biomass has on the ability of a depleted cod stock to recover. None of the species considered in the CS Area have significant technical mixed-fisheries interactions with each other. There are technical interactions with other non- modeled species (*e.g.*, mixed cod/haddock/saithe trawl fishery, bycatch of juvenile fish in the shrimp fishery). These were not considered to be within the scope of this study. However, where mixed-fisheries exist then bycatch mortalities must be an integral part of evaluating the management strategy, and misreporting of species in mixed-fisheries may also be important (alongside IUU fishing) in giving a misleading picture of total fisheries-induced mortality.

Evaluation of a management plan should include testing its robustness to different environmental conditions (or proxies for environmental conditions). A management plan should be robust to changes in recruitment or growth caused by varying environmental conditions. This can be modeled using a direct link from the environmental driver, or by identifying the likely range of variation in the biological process. In either case, a management rule that does not produce viable long-term populations and fisheries under the likely range of conditions cannot be considered precautionary. Modeling with GADGET under a range of different recruitment levels suggests that the current cod management is precautionary to moderate changes in recruitment level. Such changes in recruitment could be due to changes in temperature, ocean currents or food availability.

It is necessary to evaluate the HCR against a wide range of sources of uncertainty. Such uncertainties should include multispecies, environmental, recruitment, and model formulation. Furthermore, even where management plans are for a single species, the impacts of the plan should be evaluated on a multispecies or ecosystem basis. Constructing a tool that can examine these uncertainties in a multispecies context is a significant advance in testing the precautionary nature of existing management rules, and provides a step towards eventual ecosystem-based management. Such analysis would be at least as important under MSY-based fishing. Given that calculating B_{MSY}, and especially F_{MSY}, is likely to have greater uncertainty than calculating B_{lim}, tools that can evaluate as many of the sources of uncertainties as possible will remain critical. The linked model produced, combining a multispecies GADGET operating model to FLR-based assessment routines, provides such a tool.

The work on combining a multispecies GADGET model with FLR assessment model provides a valuable modeling tool for evaluating management plans, especially in the context of steps towards an ecosystem-based approach to fisheries management. It is currently a stated goal of a number of fisheries research institutes, including the Norwegian Institute of Marine Research, to move towards an ecosystem-based approach to fisheries management. Having a tool that is capable of assessing the impact of a single species HCR on a multispecies system, or of evaluating possible future multispecies HCRs, provides one part of the work required to implement such a goal. Within this project the model framework was tested on existing and alternative single species management rules to identify their effects on the multi-species system. It was also examined how changes in environmentally driven recruitment, growth and maturation interact with the management rule.

The current management plans for the cod, capelin and herring in the Barents Sea should be considered to be precautionary. It is important to note that this conclusion is based on an assumption of no major environmental shift, and that the management plans continue to be implemented. We have not taken implementation error into account in assessing these rules, as we believe that currently compliance is relatively good. We also assume that the current conditions of good food availability and relatively few competing species will continue.

Further work is needed to include knowledge and/or data from earlier periods into the model fitting. There is a long times series of data (covering catches, abundance, recruitment, growth, maturation and fecundity) from the Barents Sea fish stocks. However these datasets are often not at the same level of detail as the data employed in tuning the models presented here. It would be advantageous to use the longer time span, and more varied set of conditions, covered by this data. However, this data in the models presents difficulties. Thus, work should be conducted to either include the data directly or to use it to draw conclusions about the likely behaviour of the stocks under a wider range of conditions than that covered by the more detailed datasets.

More knowledge on the biological processes affecting the reproductive potential of fish stocks including the effect of stock structure is required. An example of the complexity of processes acting is the established relationship between temperature and gonadal maturation, which may decouple the match of spawning time and spring peak primary production (light-based regulation). Apart from evidence that older, larger cod are more efficient at producing viable eggs and larvae, retaining older fish in the population by low or moderate fishing pressure improves the resilience of the stock against environmental change/variability, thereby enhancing the probability for stock recovery.

Further investigations are needed into the relationship between environmental factors and fish populations, and how these relationships might change in the future. Many of the biological processes governing the life cycle of the fish are driven by environmental factors. To some extent temperature has been used as a proxy for a range of these factors (actual experienced temperature, ocean currents, food availability). However, the correlation between good recruitment of cod, herring and haddock and high temperature seen in earlier decades, did not hold in the 2000s. Some hypotheses for explaining this change have been proposed, and could be tested out in future model studies. However, further work is needed to produce a better understanding of the way these external drivers interact with each other and with the commercial fish species.

6.4.2 North Sea

The North Sea Case Study has investigated biological, ecological and environmental factors impacting on the recovery potential of North Sea cod and plaice and Autumn spawning herring. Many of these factors have been included in full feedback management strategy evaluation simulations, where the management plan has been tested against a range of plausible hypothesis. These simulations have been complemented with multispecies simulations exploring the impact of biological interactions on stock recovery. Additionally, mixed-fisheries technical interactions were considered and socio-economic factors and the importance of stakeholder participation to management plans addressed.

<u>Recovery and management plans</u>

There exist recovery plans/LTMPs for all three target stocks and all of them have been evaluated by ICES or STECF with substantial contributions from UNCOVER, *i.e.*, 2009 for cod and herring, 2008 for plaice, but the latter with no conclusion.

Table 6.19. Status of North Sea stock and corresponding management plan

Stock	***Previous status***	***Precautionary plan?***	***What happened?***
Cod	Collapsed	Yes	No recovery
Plaice	Collapsed	?	Recovered
Herring	Healthy	Yes	Risk of collapse

Cod spawning stock size has declined since the early 1970s, but with a stabilization period in the 1990s. The 1996 year-class was the last relatively large one. Fishing mortality has declined since 2000, but increase in 2008, predominantly due to increased discarding. Discard mortality is now greater than the fishing mortality for human consumption. The failure of the cod recovery has been attributed to poor recruitment (which is set to continue), a damaged stock structure, and high fishing mortality with increasing discarding. The former recovery plan (implemented in 2004) was not considered to be precautionary, the reason being that the cuts in quota were not matched by reduction in effort (days at sea). In 2008, two proposed management plans (from Norway and the EU) were evaluated for ICES, using tools developed by the Case Study. However, there was no advice on the suitability of the plans in relation to the precautionary approach because generally agreed criteria were lacking. It was recommended that future plans should state their objective about the target date for recovery and the acceptable level of risk that recovery does not occur. The current plan was adopted in 2009 and is considered by ICES to be precautionary viewed against the precautionary reference points, providing it is implemented and enforced adequately. Effort management, based on mŽtier and gear, was changed to a kW day^{-1} system. The current plan is based on single species considerations and was evaluated using single species models. Multispecies evaluations of the North Sea cod management plan conducted by the Case Study showed that earlier conducted single species evaluations overestimate the recovery potential of the stock considerably, as they ignore density dependent processes and changes in large-scale spatial predator- prey overlap. A growing cod population first has to outgrow the abundance range with rapidly increasing predation mortalities before it reaches spawning stock sizes that will have a positive effect on year-class strength. The spatial overlap between cod and its predators was found to increase with increasing temperature. However, more information on processes responsible for distribution changes of predator and prey populations are needed to enable more accurate forecasts of the cod population dynamics under climate change.

STECF first proposed a recovery plan for plaice in 2003. However, it wasn’t until 2005 that ICES actually tabled a proposal for a multi-annual plan, and not until 2007 that a plan was agreed. The plan has two stages (recovery, followed by long-term management) and operates through a combination of TAC and effort control. The LTMP was evaluated in 2008. However, it has not yet been concluded that it is consistent with the precautionary approach regarding plaice. This is due to a lack of robustness to the starting values of the population abundances, a systematic over-estimation of historic landings, and under-estimation of bias and variance in the assessment model. For two successive years, ICES has classified the stock to be within safe precautionary boundaries, fulfilling the first phase of the management plan. This is largely due to a reduction in fishing mortality. It is not yet possible to attribute the recovery of the stock to the plan. Other contributing factors to the reduction in fishing mortality include capacity reduction and an increase in the price of fuel. The stock increase occurred under average recruitment conditions and is not thought to be caused by higher productivity. In 2009, STECF reviewed the plaice management plan in terms of its success. The final report is not yet available. But, as the review was carried out before all the appropriate data was available, it was deemed too soon to evaluate the medium-term consequences (economic, environmental, *etc.*). This raises the question of how soon can the impacts of a recovery or management plan be detected, and at what point can successful recovery be attributed to the plan?

A management plan for herring was implemented in 1996, and has been reviewed and adapted every few years. Precautionary reference points were adopted in 1998. Even though the current and previous plans were thought to be precautionary, the stock declined below biomass targets in the mid-2000s. The decline of herring has been attributed to changes in productivity, exacerbated by the failure of the managers and industry to adhere to the existing management plan. It can be argued that the plan should have been precautionary to both of these drivers. Large deviations from adherence to the management plan (also known as implementation error) were not included in evaluations (only a 10% implementation error basis was considered). This strongly suggests that implementation error, as well as a range of biological scenarios, needs to be fully considered before a plan can be considered as precautionary—particularly considering that the cod plan is also only precautionary if enforced adequately.

<u>Environmental processes</u>

Increasing temperatures and low zooplankton abundance have been involved in the decline and lack of recovery of cod. Higher temperature is linked to faster gonadal maturation dynamics and earlier onset of spawning. There is evidence of a possible mismatch between the start of spawning and primary production (light based regulation).

Also in plaice, changes in temperature were found to be a significant driver of recruitment variability. Furthermore, warming is driving adult plaice further north and into deeper water.

The main driver of productivity of herring is recruitment. Although growth does vary with temperature and stock density, it does not impact greatly on the variability of the overall harvestable biomass of the stock. Past overexploitation events have been associated with declines in productivity, *i.e.*, recruitment. There is an indication that recruitment is directly linked to the Atlantic Multidecadal Oscillation (AMO) and the North Atlantic Oscillation (NAO) but no explanatory mechanism is proposed (study conducted independently of UNCOVER).

Studies within UNCOVER, suggest that year-class strength is determined in the larval stage. There is also evidence from the southern North Sea that years where the larvae are retained (*i.e.*, low transport) are associated with stronger year-classes. In addition, recent modeling exercises outside UNCOVER suggest that there has been a shift in larval prey requirements, principally as a result of higher temperatures, which is concomitant with the poor recruitment events.

Compensation in recruitment has occurred in North Sea herring, and it was stronger after the collapse of the stock. The compensation appears to be a product of both increased production of larvae per spawner and increased survival to the juvenile stage. There is only slight evidence for depensation and the point at which North Sea herring has zero recruitment appears close to the origin.

There is more variability in recruits per unit spawning stock size when the stock is smaller. This is probably a result of the potential larger diversity in contributions from spawning components in an unexploited stock compared to an overexploited stock. This should be included in future management plan evaluations.

Stock structure and reproductive potential

The presence of sub-populations is also an important consideration for the development of recovery and management plans. It has been shown that North Sea cod and herring are composed of sub-populations. But, both of these are managed as single stocks units. However, different spawning components of North Sea herring have different recruitment patterns and dynamics, leading to spatial and temporal variability in production. This potentially has implications for the success of management plans.

It is known that for all three species fishing affects the size structure of a stock through selective removals and can also affect the age structure. In the case of cod and plaice there is also the issue of selective removals of females. For plaice there is evidence of shifts in sex ratio as a result, but it has not been investigated for cod. In herring there is no sexual dimorphism.

For plaice it was found that stock age-diversity did not impact on recruitment. This allowed the stock to recover from the depleted levels seen in 2000, in conjunction with an overall decrease in fishing mortality. However, for cod there is a strong maternal effect and stock age-diversity plays a role in reproductive potential. The low average age of the cod spawning stock has reduced the reproductive capacity of the stock. as first time spawners reproduce less successfully than older fish. This is considered to be a contributory factor to the continued low recruitment of the stock that has resulted in non-recovery of the cod stock. More careful modeling will be required to explore the impacts on potential recovery.

Regarding stock recruitment potential, it was found for herring that SSB is a robust measure. For cod, the relative SSB and total egg production (TEP) were in agreement apart from the 1980s and early 1990s when the ICES working group considerably over-estimated the relative SSB by not taking improved biological information into account. However, for plaice, using TEP estimates led to a different perception of the changes in spawning population than using SSB. The most biologically realistic TEP estimate suggests that the stock status was poorer than perceived from the ICES working group assessment. For plaice, it was found that more than half of the inter-annual variations in the fecundity – size relationship can be explained by inter-annual variations in body condition and the proportion of recruit spawners. Further studies are needed to explain the remaining inter-annual variations. Phenotypic plasticity response to variations in the environment and fisheries-induced evolution has been suggested as a potential driver. In case of the latter, the recovery rate from an evolutionary change will be much slower than of a phenotypic plasticity change.

A loss of genetic diversity in North Sea herring has not been detected, despite the two recent periods of intense fishing pressure (1970s and 1990s). Although the population declined by several orders of magnitude, final population size was potentially still of sufficient size that any minor genetic losses were largely undetectable.

There is no clear indication to support or reject the hypothesis of a fisheries-induced impact on the maturation schedule of North Sea herring. It should be noted that a large proportion of the fishery takes place on spawning individuals and this may also reduce the impact of fisheries on the evolution of North Sea herring. However, fisheries do impact the spatial distribution of North Sea herring. This influences the reproductive potential as different spawner types of herring have different fecundities and spawn in different areas. This is an area of interesting potential future work.

North Sea herring has a different stock structure post-collapse. This raises the question: are we rebuilding or recovering the stock? Also, what are we recovering to? The biomass may reach the same levels but the stock structure, and therefore vulnerability to collapse, may be quite different.

Results from the Case Study suggests, at least for two of three stocks, that including additional biological information may result in alternative estimates of stock reproductive potential. Management plans should be tested against these alternative calculations of SRP to ensure that they are robust to alternative, plausible biological hypotheses. This is future area for research.

Multispecies considerations

In the North Sea, spatial predator-prey overlap is a key process driving trophic interactions in the upper level of the food-web, depending on the hydrographic conditions as well as the sizes and structures of the stocks. Predation on pre-recruiting fish has a high influence on recruitment success and hence recovery potential. Small-scale hot spots of predation on juvenile fish can reach magnitudes of ecosystem-, and population-wide impacts.

The importance of herring and other planktivorous fish in multispecies models has not yet been fully explored. As mentioned above, the level of variability in herring biomass substantially influences the North Sea ecosystem complex. As both prey and predator, the high variability and potential large abundance ensures that herring will impact many other organisms in the system. For example, up to 10% of cod egg production can be consumed by herring in some years. The planktonic impact is not accounted for in any management or recovery advice for stocks in the North Sea. However, is questionable whether these interactions and their outcomes can be predicted, particularly in a collapse or recovery phase of a population.

Simulations with a multispecies model confirmed that reducing effort on predators leads to lower yields in many fisheries if species interactions are taken into account. This also implies that growth overfishing is far less important than previously thought. A recovery of a predator stock has demonstrated consequences on the trajectories of other stocks interacting with this predator, either directly via predation or indirectly (competition). The currently available data are poor for several key species and processes, which severely hampers the reduction of uncertainties in multispecies model predictions.

For the first time, a comparison between a North Sea multispecies stock assessment model (SMS) and an ecosystem model (Ecopath/Ecosim) were conducted. Predictions from 2006 to 2030 were carried out with both models assuming a constant fishing mortality on precautionary level for all stocks. SMS and Ecosim came to different results in stock predictions especially in short to mid-term forecasts. In contrast, the long-term equilibria estimated for the different stocks were quite similar, with the exception of herring for which results were substantially different. In general, Ecopath with Ecosim (EwE) dynamics tended to be more dampened and tended to reach equilibria faster.

The differences between the short- and mid-term outputs of the EwE and the SMS models underline the fact that results from multispecies models need to be treated with caution, particularly regarding potential recovery trajectories. However, as their results are generally different to single species models (multispecies models often give lower probabilities of recovery to single species models), their continued development is essential in gaining a more comprehensive understanding of ecosystems and fishery dynamics. Multispecies models are generally not consistent enough to be able to provide advice in complex ecosystems such as the North Sea, but they should be used to test proposed management plans.

<u>Socio-economics, stakeholder involvement and recovery</u>

No socio-economic consequences were considered by the models used in the Case Study. It is worth noting that ICES did not consider socio-economic consequences during the evaluation of the recovery and long-term management plans of cod or herring. Some economic consequences were evaluated by the STECF for plaice. In all cases, ICES recommended that they be considered for future evaluations.

The work performed under UNCOVER found that the specific impacts of recovery and management plans vary both spatially and temporally. However, it is still possible to draw some general conclusions. Implementation error can have a significant impact on the success of a management plan. If long-term business planning is possible, cheating for short-term gain can be minimized and management implementation is more likely to be successful. Stakeholder acceptance of LTMPs is generally high due to the perceived business advantages.

As a part of the long-term planning, industry and community stakeholders voiced a desire for having some say in the process. Experience has shown that having buy-in and avenues for stakeholder input often substantially impacts industry attitudes and increases compliance. Not having a say increases stress and anomie in communities and among the industry. An active fisheries-oriented civil society, along with ability to diversify, showed the highest potential for innovative engagement in fisheries management. The North Sea RAC functions as the main conduit for stakeholder participation creating fisheries policy in the North Sea. Its work on recovery plans led to a general consensus of not only support for the plans, but also active support.

<u>Implications for management and recovery</u>

The above has shown that biological, ecological and environmental factors all affect the potential for stock recovery. However, it is not possible to accurately predict their impact due to the high levels of uncertainty. Thus, proposed management plans should be tested against a broad range of plausible hypothesis to ensure that they are robust to all such uncertainty. The MSE framework is an ideal tool for this as it allows managers to explore the precautionary nature and risks involved in the proposed plans.

Consideration of the biological, ecological and environmental factors is not enough. There is no point in devising a plan that is robust to all this uncertainty if it is not implemented correctly. Both cod and herring have management plans that, following evaluation, were considered to be precautionary. Besides suffering from poor recruitment, implementation error (continued high discards for cod; compliance deficiencies for herring) has been identified as a key problem with the lack of success of the management plan. In the case of herring, implementation error was included in the evaluation, but only at a low level (10% bias).

In the case of cod, correct implementation of a single species plan will be extremely difficult in a mixed-fishery. The additional measures that were introduced as part of the cod recovery program during 2009 should help to restrict fishing effort on the stock, but there remained a risk that technical interactions may inhibit the rate of recovery of the cod stock. Mixed-fishery interactions must be considered when evaluating a proposed management plan.

No conclusion about the precautionary nature of the management plan for plaice was reached. However, out of the three stocks it is the one that can be regarded as a 'success'. This is largely due to a decrease in fishing mortality, which can be attributed to a combination of the management plan, reduction in capacity and an increase in the cost of fuel, while productivity of the stock remained on the same level. Although it is too early to say, it is likely that the plan succeeded because of the reduction in capacity and an increase in the cost of fuel meant that it was implemented correctly.

This suggests that future evaluations of proposed management plans must consider fully implementation and compliance, which is closely linked to socio-economic concerns. More stakeholder involvement through their active participation in the generation of proposed plans is likely to lead to greater compliance, and hence increase the probability of recovery and the long-term stability of the fish stock.

6.4.3 Baltic Sea

The Case Study has made a major contribution to the further development of the ecosystem approach to fisheries management in the Baltic, by: i) design and evaluation of multiannual management and recovery plans for commercially important fish stocks/fisheries; ii) including the effects of environmental changes in stock predictions; and iii) addressing areal and seasonal closures as management measures, and assessing the impact of redistribution of fisheries effort. Furthermore, the Case Study has opened up for the extension of the MSY concept (*i.e.*, setting propitious F_{target} levels, or MSY proxy equivalents) which will facilitate meeting the aims of the 2002 WSSD. The project results are, furthermore, expected to contribute towards the MSFD's fishery-related indicator goals of maintaining stocks '*within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock*'.

For the management and recovery plans to be successful a number of factors play a key role. These include issues such as improving scientific research and knowledge synthesis, as well as the quality of data and statistics concerning catch, bycatch and discards of both target and non-target species. This information needs to be made available at appropriate temporal and spatial scales, by vessels/fleet and country, in order to determine where and when fishing mortality/effort occurs, and what and how much is being caught, landed, discarded or 'vanishes' from IUU fishing.

The EU and Member States have multiple roles in recovery plans, while broad stakeholder input in defining the scope of the problem, directions, targets and requirements, have to be set to avoid endless discussions. In the Baltic, this appears to be especially important as restrictive management measures have clear socio-economic consequences for local communities. Baltic cod fishers, for example, have only limited ability to continue fishing for any species, yet they also have very limited non-fishing alternatives. The importance of civil society, expressed in active social networks, for successful implementation of management/recovery plans was evidenced by a review study. Fishing communities that did not have active fisheries-oriented networks did not contribute actively to the plans. Engagement was most directly expressed at the regional level and involved fishermen's organizations. At the shared-seas level these organizations began to work with conservation NGOs and other stakeholders. Thus, definition of social and economic objectives, in addition to ecological objectives, for the management/recovery plan appears to be a prerequisite for successful implementation. Once this is done the main role of government is to facilitate the multi-scale, multi-stakeholder and multi-disciplinary networks that actually change fishing practices to enable recovery.

An ecosystem-based approach to fisheries management requires a holistic framework capable of integrating over a wider knowledge-base than previously considered within single-species management practices. Communicating the complexities and interactions of ecological-social systems to a wide range of stakeholders is becoming increasingly important. Indicators and knowledge-based systems can assist in advancing these processes by combining widely different types of information into a single coherent framework. The Case Study provided a first step towards promoting the **development and implementation of an indicator-based framework for the Baltic Sea, using the methodology of knowledge-based systems.** An ecosystem-based framework to combine ecological/biological, environmental and fisheries indicators was created related to the recruitment, growth and survival of the three main commercially exploited fish species in the central Baltic Sea and demonstrated the benefits of this approach, which include: i) tracking and visualizing the performance of underlying forcing factors of developments in fish stocks; and ii) demonstrating the potential and limitations of fisheries management to regulate fish stocks under different ecological/environmental conditions.

<u>Management plans and their performance</u>

The performance and robustness of the Eastern Baltic cod management plan was tested with a MSE framework, applying different scenarios of recruitment and sources of uncertainties. Under the different magnitudes of errors investigated, the plan is likely to reach its objectives by 2015. It is more sensitive to implementation errors (*e.g.*, catch misreporting) than to observation errors (*e.g.*, data collection). The plan is already at risk if 10% of systematic under-reporting occur in the fishery. Recovery is not only delayed, but some very unsuccessful trajectories could happen, if combined with the other uncertainties coming from the whole management procedure. Additional sources of uncertainties from fishery adaptation to the plan were tested using fleet-based and spatially explicit evaluations covering two cod recruitment regimes. The tested management options included TAC control, direct effort control, and closed areas and seasons. The modeled fleet responded to management by misreporting, improving catching power, adapting capacity, and reallocating fishing effort. The simulations revealed that **the cod management plan is robust and likely to rebuild the Eastern Baltic cod stock in the medium term even under low recruitment.** Direct effort reduction limited underreporting of catches, but the overall effect was impaired by the increased catching power or spatio-temporal effort reallocation.

Closed seasons and areas, being part of the management plan, have a positive effect, protecting part of the population from being caught, but the effect was impaired if there was seasonal effort reallocation. Simulations, with another spatially explicit model (ISIS), revealed that reduction of effort and thus fishing mortality, as imposed by closed seasons, is more efficient than reduction of spawner disturbances through the implementation of spatially restricted spawning closures. Even a large spawning closure scenario, affecting year-around about one fifth of the entire fishing area, performed remarkably worse than the tested seasonal closures. Although this scenario effectively removed all effort from dense pre-spawning and spawning concentrations, the capacity of the cod fleets was high enough to compensate the closure effect to a large degree by reallocating the effort into open areas maintaining high catch levels. Under unfavourable environmental conditions, none of the proposed or implemented closure scenarios was able to recover the stock even to B_{lim}.

The case study provided also **simulations and preliminary recommendations for a Baltic sprat management plan.** The recommended target F is close to F_{MSY} and F_{pa}. Multispecies evaluations showed that the herring and sprat populations remain within safe limits, if cod is fished with the fishing mortality prescribed in the management plan and having a recruitment as observed in the past 15 years. If cod recruitment is increased by about 125 %, which would still be on a low level as compared to the recruitment in the mid-1980s, the present target fishing mortalities for herring and for sprat were, however, too high to maintain the spawning stock biomasses of these pelagic stocks above precautionary thresholds with a high probability. Thus, the suggested management plan for Baltic sprat is only precautionary in a low cod recruitment scenario. Apart from the direct predation effect, the simulations demonstrate that clupeid growth, and thus also competition between sprat and herring, matters thereby indicating that in periods of high growth rates the stocks sustain a higher target fishing mortality.

<u>Drivers of stock dynamics and impact on management</u>

For any stock projections beyond a short time scale, assumptions about stock recruitment relationships are of fundamental importance and will determine largely the stock trajectory under different fisheries scenarios. For the Eastern Baltic cod, the dependence of recruitment on environmental conditions and fluctuation of recruitment at a low level—apparently independent of the size of the spawning stock or the magnitude of egg production since late 1980s and early 1990s respectively— does not imply, however, that the SSB has no significant impact on recruitment. All statistical analysis considered environmental factors, include SSB or potential egg production as significant variables.

A study was conducted on how climate variability and multiple human impacts (fishing, marine mammal hunting, eutrophication) have affected multi-decadal scale dynamics of the Eastern Baltic cod during the 20th century. Climate-driven variations in cod recruitment had major impacts on population dynamics and the yields to commercial fisheries. Applying simulation techniques, the roles of marine mammal predation, eutrophication and exploitation on the development of the cod population were found to differ in intensity over time. In the early decades of the 20th century, marine mammal predation and nutrient availability were the main limiting factors; exploitation of cod was still relatively low. During the 1940s and subsequent decades, exploitation increased and became a dominant force affecting the cod population. Eutrophication had a relatively minor, positive influence on cod biomass until the 1980s. The largest increase in cod biomass occurred during the late 1970s, following a long period of hydrographically-related above-average cod productivity coupled to a temporary reduction in fishing pressure. The Baltic cod example demonstrates how combinations of different forcing factors can have synergistic effects and consequently dramatic impacts on fish population dynamics.

For Eastern Baltic cod, simulations suggest that fishing at F_{pa} may not rebuild the cod stock in a period of unfavourable environmental conditions and low reproductive success. In contrast, the present F_{pa} may be sustainable in a high productivity system. Including cannibalism results in somewhat less optimistic trajectories. At higher fishing mortalities, the risk of the stock being below B_{pa} is increasing faster with increasing fishing mortality in singles species simulations, *i.e.*, the compensatory mechanism of cannibalism gives more stability against high fishing mortality, but it requires lower fishing mortalities to reduce the risk of being below B_{pa}. Simulated SSB and yield at equilibrium depend mostly on the time span used to fit the recruitment model, while choosing different stomach content data, representing periods of high and low cannibalism has only limited impact on the simulation results. Any longer-term projection of biomass and yield trajectories requires quantification of the impact of stock size on recruitment. Simulations without having this information may be highly misleading, both on an absolute scale, *i.e.*, biomass and yield, but to a lesser extent also on a relative scale, *i.e.*, the fishing mortality at which high long-term yield and stable stock size are sustained. The present target F is at the lower end of potential candidates and so can be assumed to be robust against these uncertainties, as well as limited assessment errors and bias. To optimize fisheries, changes in stock productivity need to be considered when defining HCRs, either by constructing time series reflecting similar productive states or by direct inclusion of environmentally sensitive stock-recruitment relationships. The latter would relieve the scientific community and managers from discussing how to adapt our management procedures and goals to shifting regimes, but at present no methodology exists to be applied for the determination of limit and target reference points under shifting environmental conditions.

Long-term simulations with a new statistical food-web model for the Central Baltic indicates that the probability of cod stock collapse increases steeply and non-linearly with F and decreasing salinities. The presently adopted target F may allow for sustainable exploitation of the cod stock, but only given moderately declining salinities. The degree to which species interactions may either buffer or accentuate the cod stock response to climate change depends on the nature of both positive and negative feedback loops within the food-web. It is evident that a sustainable strategy for managing exploitation of the cod stock and its prey must be adapted to several aspects of climate change. Based on the conducted simulations, it can be concluded that an ocean-scale biomanipulation of the Baltic of fishing down the sprat stock with the main focus of reinstating the dominance of Eastern Baltic cod is likely to be: i) ecologically ineffective; ii) operationally difficult; and iii) economically not the preferable management approach. The work conducted during the Case Study demonstrates the utility of using multispecies modeling tools to evaluate HCRs in a multispecies context. This represents an alternative to single species evaluations, and provides a tool enabling the assessment of whether fisheries management is being conducted in a precautionary manner for interacting fish species as well as for individual species.

The occurrence of the ctenophore *Mnemiopsis leidyi* as a new invasive species in the Baltic Sea and the potential consequences for Central Baltic fish stock recruitment was investigated, as *M. leidyi* has been shown to be an important predator on early life stages of fishes in other regions. The overall impact of *M. leidyi* was found to be low. Despite a vertical overlap with cod eggs, the seasonal abundance pattern does not indicate a substantial predation pressure on cod or sprat early life stages.

An analysis of the spatial and temporal variability in predation of cod eggs by sprat showed both a pronounced spatial (*i.e.*, vertical and horizontal) and seasonal overlap between sprat and cod eggs existed in the early 1990s. Currently, however, the seasonal overlap is limited, as cod spawning time has shifted to summer month during mid 1990s, while sprat still spawns still in spring, leaving after spawning the deep Baltic basins. The horizontal overlap is in general lower compared to the mid-1990s, because sprat is more easterly and northerly distributed with highest concentrations in the Gotland Basin, while cod spawning activity is centered in the Bornholm Basin. Thus, **the importance of egg predation by sprat has declined throughout the last two decades, while the importance of herring as a predator has increased**, as the seasonal overlap is enhanced, with herring having returned in summer from their spawning in coastal areas to the deep basins.

All the above model-based predictions do not account for changes in climatically driven predator-prey overlaps, the dependence of growth and recruitment on food competition, and the impact of trophic cascades on regime shifts. Thus, the **findings from the Case Study will be used to develop the next generation of ecosystem models** so as to include the effects of climatically driven predator-prey overlaps, the dependence of growth and recruitment on food competition, and the impact of trophic cascades on regime shifts. Increasing complexity is not a goal in itself for this kind of modeling. However, the results from the Case Study indicate that there is a substantial structural uncertainty in the present approach to model the demography of Baltic target species. Including the key processes thus appears necessary as a step towards an integrated ecosystem-based fisheries management.

A new generation of integrated models, generally described as end-to-end models, is currently being developed in various projects, *e.g.*, the FP7 project MEECE. This approach is also pursued for the Baltic Sea. Although these models vary in structure and objectives, they share a common approach in which the relation between key elements of different parts of the ecosystem and the main variables affecting them is described in a mechanistic way, and the different parts of the ecosystem are sequentially and intimately coupled in an interactive, two-way, fashion. **These models are expected to allow to test different ecological hypothesis, and to provide insight into potential interacting effects of eutrophication, fisheries and climate change in the ecosystem and so will be of great assistance in an ecosystem-based approach to management**.

<u>Ecosystem-based fisheries management</u>

In contrast to the traditional stock assessment and management methodology, numerous target species need to be assessed simultaneously and interdependently. Therefore, the idea of MSY has to be revised. The MSY of a prey species might be much too high when it comes to the food basis and growth of their predators. Furthermore, these then multiple optima are not static, because recruitment and spatial superposition of predators and their prey, and consequently population encounters, vary with climatic changes. In conclusion, **the traditional one-optimum approach for fish stock management needs to be replaced by multiple, dynamic optima, and the question arises about management objectives and what a ‘healthy’ ecosystem really means.**

In this context, **integrating available knowledge of past developments in an ecosystem into decision-making advice is increasingly recognized as being essential for setting meaningful targets for management, restoration and recovery**. The internationally-agreed Baltic Sea Action Plan (BSAP) for ecosystem-based management and protection has defined management goals for the Baltic Sea which include amongst others reduction in nutrient concentrations and recovery of populations of marine mammals (HELCOM, 2007). The ecosystem structure and food-web present in the early decades of the 20th century correspond roughly to the type of ecosystem that the BSAP is aiming to achieve during the 21st century (c.f., HELCOM, 2007). Thus, knowledge of historically observed effects of respective drivers and their interactions with each other and with climate variability is useful for developing and implementing restorative ecological polices such as the BSAP.

As with other European Regional Seas, priority is devoted to the MSFD's fisheries-related indicator aiming for '*Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock*'. Regarding the goal of maintaining stocks within safe biological limits (SBL), UNCOVER has clearly made a major contribution. With respect to the '*age and size distribution indicative of a healthy stock*', SBL does not explicitly take size or age distributions into account, but as these distributions dominate assessments they indirectly underpin the selection of limit and target reference points for the particular stock. Although age or size composition is not taken into account in defining B_{lim}, F_{lim} should be set at a level to ensure that, on average, sufficient older, larger fish are able to survive to spawn. Distinctions can be set in positioning B_{lim} and F_{lim}, for example, concerning the desired proportions or amounts of recruit and repeat spawners.

6.4.4 Bay of Biscay and Iberian Peninsula

The Case Study elaborated new biological knowledge on the reproductive potential of Northern hake, which have been used in: i) evaluation of the management plan performance; and ii) the latest hake benchmark assessment. For Southern hake, a multispecies model was implemented allowing the evaluation of the management plan with cannibalism and new growth information derived within the project. The GADGET modeling toolbox was used to simulate (hindcast and forecast) the dynamics of both the Northern stock and the Southern stock of hake. For anchovy, environmental conditions are crucial for the recovery of the stock and different recruitment/environmental scenarios have been deployed when evaluating management scenarios, using two other modeling frameworks. Firstly, a non-spatial FLR model was run in a medium-term forecasting procedure, using scenarios for the productivity of the stock linked explicitly or implicitly with the environment. Secondly, the spatially explicit ISIS-Fish model was deployed, including several fisheries for testing management procedures both in hindcast and forecast. The hindcast covers the recent period of dramatic reduction in stock size, based on the environment affecting the spatial distribution of fish in spawning areas and larval potential survival based on a biophysical model. Forecasting allowed testing of different harvest/management rules and relative fisher's reactions under different environment scenarios.

<u>Northern hake</u>

In support of STECF, **simulation of different management advice for Northern hake was conducted testing the robustness of the management strategy to variability in the stock recruitment relationship.** The results showed that the management strategy was robust to generated recruitment patterns and that the most conservative approach was the one using the Ockham SR relationship. Utilizing this stock recruitment relationship, different target Fs were tested for being precautionary, with the result that F_{pa} was not considered as sustainable. Taking these results into account, STECF in 2007 noted that there is little difference, in terms of long-term yields, between F_{max} and F_{pa}/F_{sq} scenarios. Reducing F to F_{MSY} as opposed to F_{pa} would lead to higher SSB, and thus give the stock more stability, reducing the risk of getting back to an unsafe situation. STECF choose F_{max} as the long-term target fishing mortality since F_{max} is well defined for Northern hake, is quite stable between years, and does not depend on the S-R relationship assumed. Furthermore, with a HCR based on 0.17, SSB will increase above B_{pa} and remains stable regardless of the S-R relationship assumed.

Uncertainties in growth pattern were also tested, resulting in some differences in the absolute values of stock biomasses and fishing mortality depending on the growth rate, but maintaining the same trends. Inclusion of discard estimates in the analysis creates a stronger positive effect on yield and SSB when F is reduced. Furthermore, inclusion of discards in simulations where the selection pattern is changed to reduce F on younger ages produces positive benefits of similar magnitude to reductions in overall F. These analyses are based on preliminary and incomplete estimates of discard quantities. Based on these results, STECF recommended that in any management plan involving a move towards an F_{max} target, measures which improve the selection pattern should be included. Based on recommendations given by STECF in 2007, the European Commission has formulated a LTMP proposal for Northern hake, which is currently being discussed by the corresponding RACs.

The biological parameters (weight-at-age, sex-ratio, and maturity-at-age) of the Northern Hake population are fixed constant for the whole time series in the currently accepted ICES assessment. **Incorporation of the best available reproductive potential indicator** (constant or annual Female Spawning Biomass, FSB) **into the management strategy evaluation indicates that the HCR is robust against uncertainty in parameterizing the reproductive potential, but biomass limit reference points change substantially.** The compiled data has been used as well in the most recent ICES assessment.

<u>Southern hake</u>

The Case Study conducted an evaluation of the Southern hake management plan with a multispecies model (GADGET) including cannibalism. Southern hake is a depleted stock which has been managed with a recovery plan since 2006. Uncertainty about hake growth is also taken into account. Combinations of fast/slow growth and with/without cannibalism revealed four scenarios to be included in long-term simulations. Assuming fast growth, the impact of cannibalism is limited, but higher in the slow growth scenario. In general, the choice of the growth model has more impact on the plan performance, than cannibalism.

Deploying a high and a low recruitment scenario to the growth/cannibalism options described above revealed, as expected, that the recovery is slower in the low recruitment scenario. Differences between slow and fast growth are higher at high recruitment levels. Differences between models (with and without cannibalism) are conditioned by growth rate (fast or slow growth models). In fast growth models cannibalism produces a faster recovery, while slow growth models show the opposite result. The recovery target is not achieved by 2016 in either slow growth models. In fast growth models this target is close to being achieved in the low recruitment regime, meanwhile in the high recruitment regime the target is clearly surpassed. The expected yield changes for the different models and scenarios, though in all the cases the yield decreases with the 10% reduction in F. The losses in yield are lower for fast growth models and these differences are lower for low recruitment regime. Differences between fast growth models with and without cannibalism are small and trends go parallel in both cases. On the other hand, differences between slow growth models, with and without cannibalism, are more important. Apart from problems in estimating growth rates, there is high uncertainty with respect to future recruitment and the results of the scenarios (high and low recruitment) simulations show that these predictions are sensitive to the assumption. An analysis of the stability of management reference points against changes in the perception of growth, including or excluding cannibalism and discarding, showed that—besides biomass reference points—also fishing mortality reference points are affected, *i.e.*, target F used in the HCR may need adjustment.

Multispecies modeling show that management reference points change—the direction depending on the growth scenario. In terms of biological realism, the faster growth is more consistent with current knowledge and inclusion of cannibalism also increases the model realism. In this situation we may consider this model the more realistic projection to achieve the SSB target by 2016 with both high and low recruitment.

Another factor which may compromise the success of the management plan is the fact that discards are not yet included in the assessments. Evidence exists that not considering discards may underestimate the probability of achieving the SSB target by 2016. Taking into account misreporting in the MSE, the overall result is that the recovery objectives are not fulfilled. For doing so, enforcement/compliance should be increased considerably.

Hake is a species of great value, in particular for Spain and France. Even if caught in a mixed-fishery, several fleets depend on hake, and some kind of specialization exists not only in the fleet but also in ports (*e.g.*, processing) and the regions (*e.g.*, retailers). In conclusion, any managerial decision has direct impact on fisher communities.

<u>Anchovy in the Bay of Biscay</u>

For anchovy in the Bay of Biscay, a sensitivity analysis to the uncertainty on recruitment of the proposed HCR performance has been conducted within FRL, in order to represent different environmental conditions. This has included the stock recruitment relationship (average environmental conditions), persistent low recruitment scenario (adverse environmental conditions), recruitment depending on the historical series and its autocorrelation (to incorporate the cycling periods of recruitment levels, expected to be associated with the currently not understood environmental conditioning). This approach was taken after performing a new revision of the influence of several oceanographic indices on the incoming recruitment, concluding that there is not a reliable index to improve the knowledge on recruitment by itself, excepting for the role of the parental stock which seems to be the only factor remaining statistically significant over the series.

Currently, there is no definition of recovery for the stock of anchovy, so the criteria adopted here has been to get a modeled population at a SSB level above B_{pa} for two consecutive years. Results of the FLR simulations indicate, that: i) the higher the exploitation rate, the higher the catch, its variability and the associated biological risks; and ii) **the proposed HCR is robust to uncertainty about the recruitment, except for persistently low recruitment—under that**

assumption the fishery remains closed; and iii) the proposed HCR (with harvest rate = 0.3 and TAC_{max} = 33 000 t) and the modification suggested by the parliament process (harvest rate = 0.4 and TAC_{max} = 33 000 t) result at the low recruitment scenario in median SSB mostly below B_{pa} and very close to B_{lim}, respectively, while at other recruitment scenarios, the projected median SSB exceeded B_{pa}.

Results of the ISIS hindcast and forecast simulations testing the HCR with an exploitation rate of 40% were conducted in combinations with different spatial and seasonal closures and effort reduction rules. Environmental and spatial processes were considered and incorporated in the population dynamics model. **A statistical modeling of recruitment evidenced factors potentially responsible for the variations: factors limiting recruitment changed with time, which explained the series of years with low recruitment.** This helped design scenarios of recruitment levels. Advection off the shelf in summer has repeatedly been a limiting factor throughout the recruitment series. In addition, in recent years, spring and autumn environmental conditions have also been limiting as well as the aggregation index of the spawning adults. The analysis confirmed that series of years with low recruitment can be explained and therefore were considered in the rebuilding scenarios. A sensitivity analysis of the model pointed out the major drivers of fishery dynamics, in particular processes involved in recruitment such as natural mortality from spawning to recruitment and spatial distribution. Variability in the distribution of the population and migration scheme throughout the year adds another source of uncertainty in the evaluation of management plans. Uncertainties on these processes are able to interfere with management measures evaluation preventing from establishing a quantitative diagnostic on their performance.

In line with this, **none of the measures proposed are really robust to recruitment failures and the biomass never reached B_{pa} under environmental conditions as experienced since 2000, but the HCR gives generally better results than classical TAC in the short-term**. But in the longer-term unexpected effects arise due to higher frequencies of fishery openings. This questions the adequacy of the biomass level used as the fishing ban threshold and the exploitation rate allowed. Effort reduction and MPA effects are secondary. However, the combination of those measures often improves final biomass, effort reductions limiting the negative effects of effort misreporting. In forecast scenarios, however, these measures appeared sensitive to uncertainty concerning the modeling of pa•ta fishing and effort level. Finally it is likely that, given the high frequency of fishery closures in forecast scenarios, the effects of those measures, generally seen as long-term measures, are underestimated. The highest biomass levels are obtained generally with the combination of the HCR, closure of coastal areas during the spawning season and a reduction of total effort by 33%. In any case, the spatial distribution of fish in spawning areas is a determining factor for recruitment and management success.

Preliminary results of a **multispecies model** suggest that northern hake has an effect on the anchovy dynamics, since the structure of the stock changes if a single-species or a multispecies model (GADGET) is used.

7 GOVERNANCE RESEARCH WITH RESPECT TO RECOVERY PLANS

7.1 Governance issues

Recovery plans in Europe have not simply been clusters of management measures designed to bring about the recovery of particular species. UNCOVER's research on governance found that they have acted as focal points for collective action around reforming fisheries management at various scale levels. They have help set the stage for the institutional that need to be incorporated in the current reform of the CFP. While the plans have included many specific measures, the 'recovery plans' themselves have not been rigidly defined and this has allowed a general stakeholder consensus. This consensus has been that these species need recovery, that recovery efforts should lead to long-term management plans (LTMPs), and that somewhat greater emphasis should be placed on limiting fishing mortality and discards than on the setting of biomass targets.

The major challenges to the legitimacy of recovery plan have stemmed from their focus on single species. The conservation NGOs, in particular, raise questions about how the recovery plans should fit into an ecosystem approach to management. For the fishing industry and managers, the worst problems arise in mixed-fisheries. Initial recovery plans were accused of 'ignoring' mixed-fisheries. The advantages of effort management in mixed-fishery recovery plans have led to hybrid effort and quota management schemes with greatly increased bureaucracy. The general consensus comes apart when mixed-fishery stocks begin to recover. Fishers associate a depleted stock with a lack of fish, while other stakeholders are looking for a recovered age structure. When the stock begins to recover, fishers see many young fish that, under strict recovery regulations, are interfering with their fishing for other fish. This leads to regulatory discards: the idea that managers are '*making fishermen throw good fish back dead*'.

Recovery plans for depleted species provide an opportunity for real reform. Indeed, very few meaningful changes in fisheries management have not been preceded by some sort of crisis. Both the Ecosystem Approach to Fisheries Management (EAFM) and the development of the RAC system, each in their own ways, are providing opportunities for more effective communication and reflection, and hence both better science and better governance.

One area where stakeholders see European recovery plans as potentially helping to focus and move reform forward is in developing institutions for the ecosystem approach to fisheries management (EAFM). This is the main priority of the conservation NGOs beyond simply the rebuilding of the stocks involved. The EAFM is a major governance challenge. The FAO 2003 technical paper mentioned above (Garcia *et al.*, 2003) contains an early discussion of the governance needs of the EAFM. The EAFM involves a critical tension. It requires strong legislation and a comprehensive, inter-agency, decision-making, and these two aspects do not fit easily with cooperation from more groups in society operating at multiple scales. The latter requires decentralized decision-making, greater participation, and increased transparency. This is a major governance challenge, and recovery plans moving towards LTMPS are one place where it is being recognized.

One way of moving forward here is to pitch fisheries management at appropriate scales. As one RAC Member from a conservation NGO told UNCOVER, '*Ideally, recovery plans should be incorporated into a strategic approach which looks at recovery of stocks within regional seas, or at larger scales if this is more appropriate.*' This is also reflected in the advances made at the

Cod Symposium, an inter-RAC meeting on cod recovery that played an important role in the early development of the RACs' roles. A RAC staff member told UNCOVER that a main message of that symposium was that 'one size does not fit all'.

Another priority is to develop more responsive and flexible management systems. The urgency of recovery plans may provide an opportunity for moving in this direction: Another RAC staff member told UNCOVER that '*The problem at the moment is that the EU decision system is much too 'heavy' and lacks responsiveness to decide quickly on the most effective technical measures....Potentially, RACs might take this sort of responsibility, but they also should be structured to make decisions very quickly, close to real-time.*' A good example of this is the fishing industry's implementation of voluntary 'real time closures'. Where fishing boats encounter spawning events, cod concentrations, or other areas where there is a high danger of bycatch, they call for a temporary closure of that area. For the current cod recovery plan, the system in Scotland is the most advanced. Implementation is being facilitated by the Scottish Government and the Fisheries Research Service.

The interaction between the two reform trends of recovery plans and the RAC has been an important force for change in European fisheries governance. Inter-RAC conferences and symposia were not something that was originally envisioned when the RAC idea was being developed. Indeed, the idea of RACs was precisely to move away from the European level and get systematic input at the regional level. Nevertheless, these events have proven important in focusing a reform agenda. The NSRAC, in particular, put itself on the map through the key role they played in the cod symposium. The RACs have created an important role for themselves and recovery plans have been an important part of this story.

As a fisheries management institution, RACs take an atrophied form. Their budgets are strictly limited. How representative they really are of stakeholders is questionable and unexamined. They are purely advisory forums, and DG MARE, which they formally advise, has no requirement, to take their advice. The RACs are commonly treated within fisheries discourse as if they were just one more stakeholder rather than a stakeholder forum. They are commonly referred to, even now, by ICES scientists, as 'industry bodies'. RACs are made up of many people who have not been socialized into a bureaucratic culture. They experience a great deal of frustration with the process.

RACs, seen as part of the ongoing history of European fisheries management, are playing the critical role of what Niels Röling has called 'learning platforms' (Leeuwis and Pyburn, 2002). This applies to the NSRAC, in particular, as it is both the oldest RAC and one of the few RACs that has, at this early point, developed the organizational capacity to work together effectively. Its history reaches back to the North Sea Commission Fisheries Partnership in which fishers and ICES scientists met on a regular basis. As a learning platform, this group has constantly expanded. Becoming a RAC meant bringing in other stakeholders, notably the conservation NGOS and recreational fishers. Recovery plans, especially understood as precursors to LTMPs, have emerged as a key agenda for that stakeholder-based learning process. They have been the key content of the growth of inter-RAC cooperation.

7.2 Socio-economic issues

The importance of the broader civil society, expressed in active social networks, for fisheries management is very clear from the recovery plan experience. Engagement was most directly expressed at the regional level and involved fishermen's organizations. At the shared-seas level these organizations began to work with conservation NGOs and other stakeholders. Governments at all levels facilitated these efforts. A central example was the work of the North Sea Commission, a network of regional governments that was critical in the formation of the North Sea RAC. Member States were able to work with fishers and scientists to use distribution of fisheries resources in ways that improved resource use, as in the Scottish Conservation Credit Scheme where fishing effort was used as an incentive for intensified conservation practices. At the EU level, the European Commission played the central role of facilitating and legitimating the RACs.

One critical outcome of this intergovernmental cooperation is in compliance. In general, in order for effects of the recovery plans to be felt, fleets and fishers must actually change their behavior. If the short-term costs are viewed as being too high and if the plan does not have 'buy-in' then fleets and fishers may not alter their actions and 'comply' as desired by scientists and managers for rebuilding. After all, incentives exist to 'cheat' when catches are lower due to their need to operate as businesses; they must compensate for revenue losses. The importance of governmental cooperation stems from the fact that compliance and enforcement are closely related, even if a rule is seen by the industry as highly legitimate and broadly accepted, if it is costly fishers cannot comply with that rule unless they have some expectation that other fishers will comply as well, and that expectation comes from enforcement mechanisms. One contradiction uncovered by UNCOVER was that that the bio-economic modeling found that overlapping restrictions may be more effective than a single regulation, while the governance interviews found that such overlaps are not welcome to managers, and the SIAs found that cumulative, overlapping regulations can potentially serve to increase frustration and confusion, and with it *anomie* and negative impacts on quality of life.

One somewhat rare, but critically important, socio-economic factor has been the emergence of *active* support for recovery plans by fishing fleets and communities. This active support has a significant number of cooperative activities addressing improved stock assessment and data collection, increased compliance with measures, the avoidance of recovery species, and the reduction of discards. All of these actions have required support from both science and government, and how to structure this support has emerged as a key institutional challenge within recovery plans.

Fishing communities play a critical role in developing active support. UNCOVER did an in-depth analysis of 10 fishing communities and performed economic analyses on fishing fleets in three of the case studies. Recovery plans involve a reduction of fishing effort, and the basic question is how well a community is able to deal with this reduction. The bio-economic TEMAS model focusing on North Sea Cod found that in response to decommissioning management measures, effort, profitability, and discards (in most cases) decreased. Decommissioning had a strong overall effect in reducing fishing mortality across fleets and fisheries, though effort reduction was uneven across the fisheries. It was found that reducing the number of vessels by 10% reduces the profit within 5-20%. The impact is stronger for smaller vessels.

Both the economic and social analysis found that those communities and fleets that could not diversify their fishing suffered the most (Table 7.1). Hence, the SIAs examined the alternatives available for the communities in terms of both other fisheries and other economic opportunities, as well as the support available for unemployed fishers (Table 7.1).

Table 7.1. Summary of Social Impact Assessments

Member State	Summary of Community Social Impact Assessments				
	Case	Community	Categories of Vulnerability to Impacts		
			Ability to Diversify Fishing	Alternative Activities	Level of Community Support
Sweden	Baltic cod	Simrishamn	Low	Medium: Growing Tourism	Government social services
Poland	Baltic cod	Kuznica	Low	Medium: Growing Tourism	Strong kinship networks
Germany	Baltic cod	Freest and Heiligenhafen	Medium	Low: Limited Tourism	Government social services
Denmark	Baltic cod	Bornholm	Low	Low: Limited Tourism	Government social services
	NS Cod	Thorsminde	Low	Low: Limited Tourism	Active civil society; Government social services
Netherlands	NS Cod	Urk	Low	Low: Limited non-fishing employment	Active fisheries-oriented civil society
Scotland	NS cod	Peterhead	High	High: Substantial non-fishing alternatives	Active fisheries-oriented civil society
France	Northern Hake	Guilvinec	High	Low: Limited non-fishing employment	Active fisheries-oriented civil society
Spain	Northern Hake	Ondarroa	Medium	High: Substantial non-fishing alternatives	Government social services
	Northern Hake	Pasaia	Low	High: Substantial non-fishing alternatives	Government social services

The social analysis revealed that a combination of the ability to diversity and an active fisheries-oriented civil society showed the highest potential for innovative engagement in fisheries management. Fishing communities that did not have active fisheries-oriented networks did not contribute actively to the plans. Even communities with extensive civil society activities, which were for reasons of economics or ecology unable to diversify their fishing, seemed to display less active support. Overall dependency on fishing for employment, on the other hand, proved to be a less important variable than either the ability to diversify or the existence of active networks.

8 ASSESSING THE REQUIREMENTS FOR IMPLEMENTATION OF SUCCESSFUL RECOVERY PLANS

8.1 Problem recognition, defining objectives and stakeholder inclusion

When stating the requirements for implementation of successful recovery plans, the list of actions to be considered should include not only the best scientific knowledge (or lack of knowledge/inherent uncertainty), but also how the whole process has to be developed regarding stating clear objectives, participation and commitment of the stakeholders, and control and compliance of the plan. A summary of the main steps of this process is presented below:

1) **Timely recognition of the problem:** (*preferably do not let it become a problem*…). Delaying definition of a recovery plan and obviously implementation of it, furthers deterioration of the stock and increases likelihood for the stock to take longer to recover (Powers, 1996) (UNCOVER outcome: time between identification of the problem and actions taken (definition of a recovery plan and its implementation, generally, is too long). Ideally, the recovery plan should already be integrated into the established management plan and prepared for potential future use before the need to use it.
2) **Get together to define objectives:** Collaboration between scientists and other stakeholders. The objectives should be appropriate to ensure sustainable management (2015 MSY objective from 2002 WSSD; MSFD aim for good environmental status of marine ecosystems, including the fish component, by 2020) fleets and activity (social sustainability).
3) **Active involvement of all stakeholders:** Such inclusion (*e.g.,* managers, administrators, scientists, fishers, processors and environmental NGOs) is essential in the entire process from defining the scope until finalizing the recovery plan or Long-Term Management Plan (LTMP). For example, an active dialogue with/between stakeholders provides valuable input to the selection of feasible options and scenarios to be evaluated. Also they are important in the discussion of the results of the evaluations. Therefore, the best way to integrate stakeholders' opinions in the recovery plan process is by active involvement of stakeholders ***throughout the whole process***. **The role of each stakeholder party should be stated/clarified and openly recognized:** Stakeholders propose feasible options/scenarios to be evaluated. Scientists should develop the tools and include their best (lack of) knowledge in those tools. Managers should define the risk to be assumed based upon the results (with uncertainty) included in the evaluation framework.

8.2 Evolution and key aspects of recovery plans

UNCOVER originally started to focus on recovery plans, but it was only at the end of the project that also LTMPs were taken into account. While recovery plans are designed to recover depleted stocks and prevent them from collapsing, management plans aim to maintain stocks at safe biological levels. Since the beginning of UNCOVER, the European Commission has further advanced its approach in fisheries management: Based on the 2002 CFP reform, where multiannual management plans or LTMPs were initially introduced for stocks which had been depleted to dangerously low levels ('recovery plans'), they are now being standardized as the method of choice for managing the EU's major commercial fish stocks. Thus, the Commission intends progressively to leave the previous year-to-year management of fish stocks, including the need to have specific recovery plans for overfished stocks, and to move towards developing LTMPs for all major commercial fish stocks which lend themselves to this approach.

These LTMPs should ensure that fisheries are managed sustainably for the long-term, thus, according to the Commission, avoiding the need for an artificial distinction between stocks 'in

danger' and those which are 'safe'
(http://ec.europa.eu/fisheries/press_corner/press_releases/2009/com09_41_en.htm).

A central part of most LTMPs are Harvest Control Rules (HCRs), that define thresholds of stock size (limits) and related measures (*e.g.*, adaptation of TACs or fishing effort) for not exceeding those limits. There is now essentially no difference between LTMPs and recovery plans (Figure 8.1). In practice, recovery plans are a vital component of LTMPs, especially if LTMPs are to be applied for fish stocks that are already dangerously depleted. Therefore many, but not all, LTMPs also contain specific measures (emergency measures) if a stock is at risk – or even experiencing – to decline below limits, that would risk the recruitment success of the stock. In case a stock already has fallen below those limits, these measures might be formulated in such a way as to become a 'recovery plan' (Figure 8.1). An example for this kind of LTMP is the EC's 'Multiannual Plan for the Cod Stocks in the Baltic Sea' (EC, 2007), where the SSB of the Eastern Baltic cod stock at the time of its implementation has been at an historically low level. Thus, this plan contains effective measures regarding how to manage the fishery on this stock under these conditions.

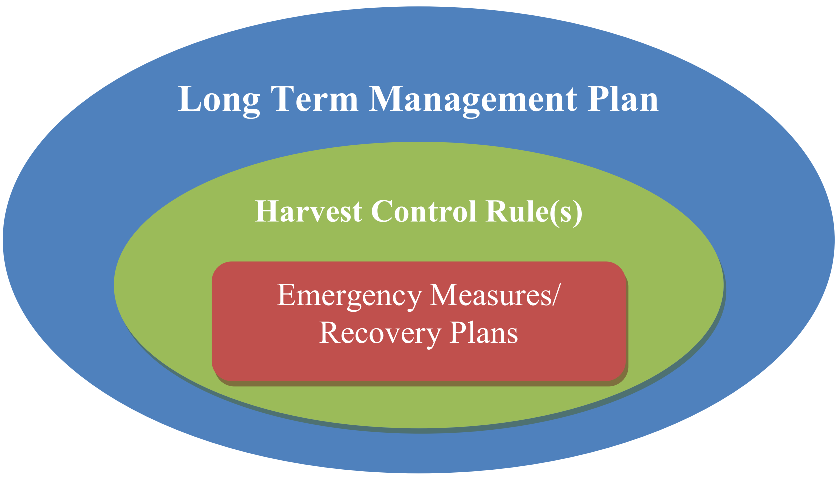

Figure 8.1. The relationship between a LTMP, an HCR, and a recovery plan.

According to Degnbol (2004), a *management strategy* includes:

- A decision (explicit or implicit) on longer term management objectives and performance criteria;
- A decision on the relevant knowledge-base for tactical management decisions;
- Rules for tactical management decisions regarding the fisheries in the current or coming fishing season (harvest control rules);
- A decision on an implementation framework (mainly input or output control, *etc*.).

According to Powers (1999; 2003) '*a recovery plan is a strategy of selecting fishing mortality rates that will increase the biomass above some minimum standard threshold within a specified period of time*'. The author suggested four essential components as being necessary for a recovery plan:

1) A **threshold measure** (or measures) of the overfished state and periodic monitoring of the fishery resource relative to that measure;
2) A **recovery period**;
3) A **recovery trajectory** for the interim stock status relative to the overfished state; and
4) **Transition** from a recovery strategy to an 'optimal yield' or target strategy.

When putting these components in the context of the ICES advisory system, and the fishery management systems applied by the EC, Norway and Russia in the UNCOVER Case Study areas, the terms used by Powers (1999; 2003) may be explained as follows:

1) B_{lim} and B_{pa} are the **threshold measures** of the overfished state; the yearly assessment cycles function as the periodic monitoring of the fishery resource relative to that measure;
2) A **recovery period**, *i.e.*, the time taken to raise the depleted stocks above that threshold level, is normally not implicitly stated in the EC's recovery plans. However, at the 2002 World Summit on Sustainable Development, the EU Member States signed up to limiting fishing to sustainable levels by maintaining or restoring stocks to levels that can produce the maximum sustainable yield (MSY). For depleted stocks, this should be achieved urgently, and where possible not later than 2015.
3) Identification and agreement on following a specified **recovery trajectory**, and what to do when deviation occurs from such a 'path' is essential for promoting appropriate adaptive management. But, a specific recovery trajectory for the interim stock status relative to the overfished state is not currently implemented in most of the recovery plans or LTMPs in the EC.
4) To ensure a **transition** from a recovery strategy to an 'optimal yield' or target strategy by specific rules is not necessary in cases, concerning overfished stocks, whereby specific measures or even a full recovery plan are included as part of a LTMP. This is, for example, the case for the LTMP for the Baltic cod stocks (EC, 2007). In addition, the ongoing inclusion of the MSY concept into EC fishery policies (see above) provides a target level of fishing mortality that is intended to ensure an 'optimal yield'.

For both, recovery plans as well LTMPs, the Common Fisheries Policy (CFP) requires that they 'shall take due account of interactions between stocks and fisheries' (EC, 2002). Also, they may, in particular, include measures for each stock or group of stocks to limit fishing mortality and the environmental impact of fishing activities. However, all these measures shall be decided by the Council, having regard—among others—to the economic impact of the measures on the fisheries concerned. Thus, managers have to find the complicated balance between safeguarding fish stocks, on the one hand, and the marine environment, on the other hand, whilst at the same time ensuring viable fisheries.

UNCOVER aimed to evaluate existent recovery strategies and to contribute to the development of new recovery strategies. Thereby, a central task was to assess the requirements for implementation of successful recovery plans. The main requirement in this context is to set 'realistic' management objectives and strategies for achieving stock recovery.

In this respect, to be 'realistic' and improve the chances to implement a successful plan, the UNCOVER project recommends, based on its work, which the plans should ideally include:

1) Consideration of stock-regulating environmental processes;
2) Incorporation of fisheries effects on stock structure and reproductive potential;
3) Consideration of changes in habitat dynamics due to global change;
4) Incorporation of biological multispecies interactions;
5) Incorporation of technical multispecies interactions and mixed-fisheries issues;
6) Integration of economically optimized harvesting and fleet planning;
7) Address the socio-economic implications and political constraints from the implementation of existing and alternative recovery plans;
8) Broad acceptance of the plans by stakeholders and specifically incentives for compliance by the fishery;
9) Agreements with and among stakeholders.

Points 1) to 4) are covering the biological attributes and condition ('health') of fish stocks and their dependent ecosystem, including multispecies aspects, as well as influences on the stocks and the environment by external factors like climate change and variability. In contrast, points 5) to 9) are reflecting the human component of management plans, concentrating on social and economic aspects, as well as the recognition that only very few fisheries operate in a highly selective manner (*i.e.,* exclusively catch specific sizes/ages of a particular, desired target species) and thus a stock to be protected against a targeted fishery by a management plan frequently is taken as bycatch by another fishery whose main target is another species. Points 1) to 5) are dealt with in specific sections of the Case Study sections found in section 7 of this report.

It is not possible here to consider all the elements mentioned above in the context of a recovery plan. However, one should at least be aware of potential shortcomings with respect to the necessary considerations, and subsequently take account of the lack of knowledge and higher levels of uncertainties when setting thresholds, targets and time lines in the plan. When setting up a recovery plan or LTMP, if it is known that information is lacking or could not be integrated, more emphasis should be directed to avoiding high risks of failure.

Once the plan has been agreed, there is also uncertainty regarding implementation error, for example poor or misleading catch/landing data, IUU fishing, *etc.*, that must be taken into account. Experience from the UNCOVER project indicates that the single most important factor in determining the success or failure of a recovery plan or LTMP is the degree to which it is successfully implemented. A plan that is not precautionary to likely implementation errors is not precautionary. These implementation errors include setting quotas in accordance with the plan, and particularly resisting the temptation to increase catches above the plan as soon as recovery starts. They also include the degree to which total fisheries induced mortality can be constrained to fall within the range specified within the plan. Examples from the UNCOVER project where measures taken to reduce the excess mortality have aided successful recovery include the recovery of Norwegian spring spawning herring after a high minimum landing size was introduced and enforced (c.f., Barents Sea Case Study); the reduction of bycatch in the shrimp fishery via gear changes and the reduction in unreported landings in the Barents Sea cod (c.f., Barents Sea Case Study); or the capacity reduction in the North Sea plaice fishery reducing the unreported mortality and leading to stock recovery (c.f., North Sea Case Study). Conversely, examples where the management plan has not been successfully implemented are often ones which show a failure of the stock to recover as expected. A clear example here is the North Sea cod (c.f., North Sea Case Study), where the plan calls for a cod bycatch lower than that currently taken, but no action was taken to reduce such bycatch. As a result the total mortality is well above that called for in the plan, and cod recovery has been limited. In addition, when the biomass of immature fish began to increase, the quotas were raised, thereby impairing the ability of the stock to sustain the recovery. Any management plan must be formulated to take account of the ability to actually implement that plan, and should include management actions to control the entire suite of fisheries induced mortalities. Any evaluation of the plan must consider the likelihood of successful implementation. A plan that is not precautionary to implementation errors is not precautionary.

8.3 The importance of implementation, compliance and monitoring

For the recovery plan to be successful, the agreed measures must be effectively implemented and complied with. Importantly, the political will to support the recovery plan must not waver. Recovery plans have been shown to be sensitive to implementation error, which must not exceed bounds examined in the Management System Evaluation process. Important implementation errors include discrepancies in catches/landings relative to TACs, including IUU fishing, discarding, and regulation and control of fishing effort (*e.g.,* fishing vessel 'tie-up' in port, days at sea) and gear compliance. **For assessing implementation and compliance, appropriate inspection and monitoring schemes must be operationalized and the collected data quality-assured. Such data must be appropriately analyzed and informative conclusions drawn, without undue delay, regarding status and trends**.

8.4 The human dimension

Social and economic factors play an important role in determining the success or failure of LTMPs. A successful LTMP is one which ensures the sustainability of not only fish stocks in their associated ecosystems, but also for sustaining fishing communities and fleets. We know that in order to recover depleted fish stocks successful recovery plans often require a rapid reduction of fishing mortality. But social constraints often prevent us from doing so. Reducing fishing effort strongly impacts on fishing communities: fishers may become unemployed or may exit the fishery sector completely, with impacts rippling out to the wider community.

Compliance with existing management rules also impacts the success of management plans. Thereby, **compliance is not only affected by the level of enforcement but to a greater extent by the level of buy-in and support of the management rules by the fishing communities.**

The sustainability of fisheries and fishing communities is determined not only by the biological and environmental conditions in a particular area, but also by social and economic factors surrounding the dynamic and adaptable nature of a community. Such a community contains, for example, community members with strong social connections and varied employment opportunities. UNCOVER's social analysis revealed that a combination of the ability to diversify and an active fisheries-oriented civil society showed the highest potential for innovative engagement in fisheries management. Such engagement increases the likelihood of co-ownership of the plan, and with it, potentially increases the level of compliance.

Easily accessible and relevant socio-economic information is critical for the development of sound management plans in support of sustainable fisheries. Two tools/methods available to scientists include:

1) **Community or fleet profiling** is a well-established tool for incorporating such social and economic data into management plans. From such profiles, SIAs and Economic Impact Assessments (EIAs) are more easily conducted.
2) A **Social Impact Analysis (SIA)** is a methodical assessment of the quality of life of persons and communities whose social, cultural, and natural environment is affected by fisheries management and recovery plans. Social impacts refer to changes to individuals and communities due to management actions that alter the day-to-day way in which people live, work, relate to one another, organize to meet their needs, and generally cope as members of a fisheries society. SIAs provide an appraisal of possible social ramifications and proposals for management alternatives, often with possible mitigation measures.

UNCOVER conducted profiles and SIAs in ten fishing communities around the Baltic Sea, North Sea, and the Bay of Biscay. Both the economic and social analysis found that those communities and fleets that could not diversify their fishing suffered the most. Subgroups at risk from negative impacts of the plans varied over time and such impacts increased cumulatively. In some cases, communities, for reasons of economics or ecology, were unable to diversify their fishing, and consequently also displayed less active support for the recovery plans.

SIAs have been valuable in developing sound management plans worldwide. In the context of UNCOVER's socio-economic research identified patterns across recovery plans. The first was the importance of whether or not fishing fleets and communities are relatively specialized or seek to remain generalists; in other words how vulnerable or adaptable are they? Specialization makes it difficult to switch between target species and/or deployed gears. The issue of specialization emerged in both recovery plans and was an important component in both the bio-economic and anthropological analyses.

Vulnerability is a measure of exposure and susceptibility to hardship with change in the environment – such as through overfishing and catch limitations. Communities and companies are vulnerable if they are limited in their ability to adapt to change and are not resilient. In analyzing reliance and resilience one analyzes the community's and fishery's capacity to change. Vulnerability affects which options and choices are available to individuals and companies – for example alternative fishing methods, species or alternative employment. Have companies and individuals the flexibility to change when faced with adjustments to the resource, management, and the market? Once markets are lost, for example, will they return if the stock recovers?

Fishing communities and fleets represent heterogeneous groups of stakeholders. As such, different policy options and related management measures have different impacts on the individual resource users and raise the question of equity. Some individuals or community groups may be affected more than others and changes may also be subtle and difficult to quantify. One should note that the interests of various stakeholder groups differ widely and that while some interest groups make themselves heard others may be less vocal. UNCOVER research revealed that some small-scale fishers perceived decision-making processes as being dominated by large-scale fishers with high annual turnovers. Ultimately multi-level governance, as well as intense communication is needed to address the socio-ecological system. In this context, it is very important to note that SIA is not synonymous with public participation or public involvement, although public participation is an important data collection tool in the conduct of an SIA.

For UNCOVER, economic impacts were also estimated through bio-economic modeling, with the results analyzed in conjunction with the social impact assessments. As would be expected, the situations found in both fishing communities and fishing fleets that have been affected by recovery plans vary considerably. In general, in order for effects of the recovery plans to be felt, fleets and fishers must actually change their behaviour. If the short-term costs are viewed as being too high and if the plan does not have ‘buy-in’ then fleets and fishers may not alter their actions and comply as desired by managers. Reduced catches and the need to operate as businesses increase the incentive to cheat in order to compensate for revenue losses leading to IUU fishing.

Building on the stock simulations for recovering fish stocks, economic modeling explores the profitability of different fleet segments. The economic data used comes from the Annual Economic Reports (AERs) from EC Member States (MS) aggregated into fleet segments. Since the fishing sector is not a homogenous group of stakeholders disaggregated data from fisheries/mŽtiers is a prerequisite to explore economic impacts and ensure equal chances for fishers. Access to this data is problematic and national authorities are reluctant to provide anonymous data due to small fleet sizes and the need to safeguard the identities of fishers. However, management plans have to be adaptive to existing fisheries/mŽtiers providing equal chances in terms of effort reductions and quota allocations. In order to make progression, policy makers need to be aware that their decisions impact the economic structure of the fishing sector and may create imbalance between fleet sectors, thus decision making needs to be well informed making use of the best available evidence from research. Knowledge gained by the UNCOVER project for understanding the impacts of the multiannual cod management plan on small-scale fishing communities in the Baltic Sea revealed that effort reductions, as stipulated by the plan, have much stronger adverse effects on small-scale fishers. The annual reduction in days at sea is increasingly preventing small gillnetters to fish their annual cod quota, since they pursue more labor-intensive fishing practices and are highly susceptible to adverse weather.

Qualitative research and data quality relies on the establishment of partnerships between the various stakeholders. Managing fish in a socio-ecological context by taking into account the social dimension can help to mitigate possible detrimental consequences on fishing communities and result in fair and equitable fisheries management plans. In this regard, **it is vital to collect socio-economic data at regular intervals and make SIAs and EIAs an inherent part of management plan evaluations.**

In order to mitigate possible negative impacts of recovery plans on fishing communities’ structural funds such as the European Fisheries Fund (EEF) or benign subsidies could be used. There is, however, a need to ensure that fisheries subsidies neither undermine stock recovery objectives nor lead to significant environmental externalities. While subsidies fostering the diversification of livelihood strategies may be viewed as ‘good’ other forms of subsidies, such as capacity reduction subsidies, have a tendency to ‘leak’ resulting in an overspill of excess capacity into other, often overfished fisheries (Milazzo, 2003).

Sanctions must be equally enforced across MS to ensure that fishers adhering to the rules are not disadvantaged by free-riders. The unequal distribution of authority among MS may result in unequal opportunities for fishers. By establishing the Community Fisheries Control Agency (CFCA), which became operational in 2007, the European Commission increased efforts to encourage compliance of national enforcement authorities within the Common Fisheries Policy (CFP). This can be seen as a first step to standardize national control procedures.

In the light of shifting towards an ecosystem-based approach for fisheries management within the CFP, fishers involvement in policy making processes may ensure both, the integration of local knowledge into a framework of governance consisting of public and local-level management leading to a more sustainable management of fisheries resources, as well as developing a form of environmental stewardship providing fishers can reap the benefits of restraint.[11] On a larger regional scale, the Regional Advisory Councils (RACs) provide the main conduit for stakeholders to participate in fisheries policy making. Transferring rights and responsibilities to more localized institutions gives room for co-management and may allow for more efficient, equitable and sustainable resource use. The adoption of informal, non-codified rules may be a possible solution for fishing communities to mitigate the impact of national or European formal fisheries management measures on small-scale fishers. This could include the more flexible use of fishing quotas, the adoption of certain size limits and/or area respectively time restrictions. Fisheries cooperatives could play a key role in the adoption of these voluntary management measures, since they already organize the majority of fishers, provide forums for discussion, while at the same time acting as a link between the state authority and the fishing sector. In the context of regulation compliance, peer groups issuing pressure could carry out enforcement of cooperative fisheries management (*c.f.*, Eggert and EllegŒd, 2003).

8.5 General conclusions

The general conclusions arising from the UNCOVER final suite of recovery scenarios are:

- Any management plan should be robust to all levels of stock size. It takes time to move to agree and implement a recovery strategy. **Thus, a management plan that cannot automatically respond to rapidly reducing stock sizes cannot be considered precautionary**.
- **There are possible multispecies and environmental drivers that can affect the target stock, so the management rule can only be considered to be precautionary under the range of scenarios evaluated**. Climate change is one, but by no means the only, possible cause that could result in a HCR ceasing to be precautionary. It is therefore important to evaluate the 'precautionary' nature of the HCRs in a wider sense than has traditionally been done, and specify what range of scenarios (*e.g.*, climate, environmental, mixed-fishery, enforcement) the rule has been shown to be precautionary against.

[11] Principals to guide the organization of institutions and the establishment of good governance can be found in the European Union's White Paper. They apply to all system levels from global, European, national, regional to local level. These principles are openness, participation, accountability, effectiveness and coherence and should be applied according to the principles of proportionality and subsidiarity. (EC, 2001)

- **It is critical to remember that management plans are about more than just target F**. It is obviously important to set target F values correctly, however these should be considered only one part of a successful management plan. Enforced management on area closure, minimum landing size, bycatch in other fisheries, ban on discards, and capacity and gear controls should be considered at least as much a part of a precautionary management plan as the target Fs.
- **The total induced fishery mortality (including, for example, discards and IUU fishing) is the driving factor, not merely that part of it that is the landed targeted catch**.
- **Social and economic factors will also play an important part in determining the success or failure of a management plan**.
- **An otherwise viable plan may fail if it is not fully implemented and enforced.**
- **Any evaluation of a management plan must consider this whole range of factors, and not just the target Fs**.

Regarding the final suite of recovery plans contributed to and evaluated within UNCOVER, it is important to note that these recovery plans and LTMPs have a history of having been developed in an *ad hoc* manner when the European approach to these matters was in an essentially evolutionary phase. Thus, they do not always follow the ideal design that is described above. There is a tendency to ask for advice on the design of a management plan/HCR and UNCOVER believes that this proposal is the way to go.

9 EXECUTIVE SUMMARY OF MAJOR SCIENTIFIC AND POLICY OUTCOMES FROM UNCOVER

This section provides a synopsis of the main results and conclusions from the UNCOVER project including drawing attention, finally, to the scientific support for policy provided by the project. Further information concerning the principle components and constraints of recovery plans are provided in UNCOVER Deliverable 32 (UNCOVER 2010).

9.1 Preamble

The UNCOVER project has produced a rational scientific basis for developing Long-Term Management Plans (LTMPs) and recovery strategies for 11 of the ecologically and socio-economically most important fish stocks/fisheries in some of the major European regional seas.

Case Study area	*Target stocks/fisheries*
1) Barents and Norwegian Seas	Northeast Arctic (NEA) cod; Norwegian spring-spawning (NSS) herring; and Barents Sea capelin.
2) North Sea	North Sea (NS) cod; Autumn-spawning (AS) herring; and North Sea plaice
3) Baltic Sea	Eastern Baltic (EB) cod; and Baltic sprat
4) Bay of Biscay and Iberian Peninsula	Northern hake; Southern hake; and Bay of Biscay anchovy

The objectives of UNCOVER were to identify changes experienced during stock depletion, and even collapses in some cases, to understand the prospects for recovery, to enhance the scientific understanding of the mechanisms of fish stock/fishery recovery, and to formulate recommendations how best to implement LTMPs/recovery plans.

9.2 Criteria for successful fish stock/fishery recovery

An analysis by UNCOVER of the development and success of fish stock/fishery recovery plans in Australia, Europe, New Zealand and the USA, based on information collected at the project's start, showed that the four best combined factors able to predict successful stock/fishery recovery were: a) the 'Rapid reduction in fishing mortality'; b) the 'Environmental conditions during the recovery period', c) 'Life history characteristics' of fish stock; and d) the 'Management performance'. Recovery is more likely when fishing effort reductions occur through regulating days at sea and decommissioning, and inclusion of harvest control rule (HCR) schemes, and there are positive recruitment events during the recovery period either stimulated by or coincident with effort reductions. Socio-economic factors such as governance and wider stakeholder participation are playing an increasingly important role. Accordingly, UNCOVER focused on addressing the following:

9.2.1 Management strategy evaluations (MSE)

MSE's have been conducted in all four UNCOVER Case Study areas. These benefit from rigorous, scientific testing with a view to evaluating their performance. The UNCOVER results clearly demonstrated the importance of considering: i) Changes in productivity of the stocks (most importantly recruitment); ii) Biological interactions (predation and competition) within and between stocks; and iii) interactions between fish stocks and fisheries (including mixed-fisheries aspects and discarding), each with important associated uncertainties, when designing and testing HCRs and management plans. Most critical, however, was a sound implementation. Most HCRs and management plans were highly sensitive to implementation failure, *i.e.*, overshooting scientific advice in agreed catch and effort limits or overshooting the agreed limits by the fisheries. Other technical fisheries management measures, such as seasonal/area closures or gear regulations, have been successfully integrated in MSE frameworks, being powerful tools for testing the performance of the entire fisheries management system.

9.2.2 Timely response and management plans to counteract negative events

A substantial and rapid reduction in fishing mortality is a key factor contributing to the overall success of a recovery plan, whereas 'too little, too late' catch reductions delay the onset of recovery or prevent recovery at all. The key is the speedy initial reduction in fishing mortality. This is because the effect of small reductions may easily be subservient to the uncertainty of the assessments. As a result of small reductions there will probably be a sequence of years in which recovery responses are not evident, whereas the public debate on further reduction of TAC and quota will be continued year after year, as a process undermining the credibility of the scientific advice if the effect of previous reductions cannot be shown.

A central part of most LTMPs are HCRs, which define thresholds of stock size (limits) and related measures (*e.g.*, adaptation of TACs or fishing effort) for not exceeding those limits. There is now essentially no difference between LTMPs and recovery plans. In practice, recovery plans are a vital component of LTMPs, especially if LTMPs are to be applied for fish stocks that are already dangerously depleted. Thus many, but not all, LTMPs also contain specific measures (emergency measures) if a stock is at risk of—or even experiencing—declining below limits, that would risk the stock's recruitment success. In case a stock has already has fallen below those limits, these measures might be formulated so as to become a 'recovery plan'. An example is the EC's 2007 'Multiannual Plan for the Cod Stocks in the Baltic Sea', where the SSB of the Eastern Baltic cod stock at the time of its implementation was at a historically low level. So, this plan contains effective measures regarding how to manage the fishery on this stock under these conditions.

9.2.3 Accounting for environmental and ecosystem conditions

Preserving the stock's reproductive potential

Process studies revealed that sexual maturation schedules are linked to growth rates and in turn are related to population densities or sizes, thus maturation at an earlier age tends to be linked with lower population sizes rather than larger populations. Individual egg production varies with size of mature female and there is the influence of the condition of the fish, and so large good-condition fish will produce a greater number of eggs. Therefore, the stock's egg production will not only depend on the stock's size structure but also on the 'well being' of individuals within the stock. There is a link between fecundity and environmental conditions in relation to available resources (prey availability, and physiological constraints like thermal conditions).

There is no clear consensus on what constitutes egg or larval 'quality'. Thus, the influence of maternal/paternal effects on stock recovery, through survival of spawning products, cannot be quantified yet. Stock reproductive potential is generally considered in the context of egg production, while the influence of paternal effects—whether through total sperm production, quality of sperm or numbers of available males for spawning—is not quantified. In stocks with sexual dimorphism in growth or behaviour, selective culling (whether it is for size, locations or time of year) changes the overall sex ratio within the stock, but the influence on stock reproductive potential is still unknown.

Consequences of changing habitats

Stock production and recovery dynamics depend on the availability of preferred habitat conditions at various stages of ontogeny which influence optimal growth, spawning, recruitment and survival. These habitats are defined by abiotic and biotic conditions such as temperature, salinity, oxygen, food type and availability, ocean currents, and limitations on pollution or other forms of human encroachment that degrade habitats. The ‘ocean climate’ and its variability affects many of the above-mentioned variables and so plays a major role in determining habitat quality and hence productivity of the stock, be it directly or indirectly. Accordingly, favourable environmental conditions are associated with successful stock recovery but are not alone in influencing recovery. For example, there is concern that the spawning stocks, of demersal fish in particular, in losing the buffering demographic presence of older age-groups of fish as a result of intensive fishing mortality, have increased their susceptibility to the combined effects of high fishing mortality and climate change/variability.

The quantitative estimate of fish production in a system affected by global change is a key ingredient for effective fisheries and ecosystem management. However, despite the large number of studies examining the effects of environmental processes upon fish stocks and performance, our current ability to predict the influence of environmental forcing upon fish production is limited. Three issues contribute to this situation: a) Fish are exposed to a multidimensional environment, the complexity of interactions and dynamics of populations are very difficult if not impossible to replicate experimentally or mathematically; b) Predicting animal movements in a heterogeneous environment requires addressing a number of questions about potential fitness gain, individual movement ability and decision-making process and ramifications for stock dynamics; and c) The difficulty of transferring understanding of adaptation relative to environmental forcing from the organism to population level.

A pragmatic approach to developing a framework for addressing the effects of climate change and variability on fish stocks is required owing to the emergent nature of the challenge. To create such an approach, the following issues need to be incorporated into management plans: a) Climatic/environmental drivers are important in influencing the carrying capacity for fish stocks in influencing, for example, vital rates, production at the base of the food-web and transport processes. Our ability to predict the dynamics of stocks in relation to changes in climatic forcing is limited due to the complex relationship between abiotic processes and food-web interactions. To assess the trajectory of a stock, indicators of key stock and ecosystem status need to be identified based on historic relationships linked to stock dynamics and potential physiological constraints on stock viability. The dynamics of these indicators have the potential to provide an early warning system helping to ensure achieving MSY for the exploited stocks.; b) Given that over ontogeny exploited species utilize specific habitats defined by abiotic and biotic characteristics for spawning, larval and juvenile nursery areas, multispecies spatially-specific management strategies are necessary so as to avoid bycatch (*e.g.*, juvenile stages of commercially important fish) or to preserve key components of the stock (*e.g.*, spawning biomass) as a buffer to detrimental environmental conditions; and c) In recognition of point a) above, population models should be developed and applied that include biological variation and environmental drivers, based on existing statistical relationships and status indicators, in recognition that these relationships provide a short-term indicator of potential stock dynamics.

Effects of multispecies interactions

Multispecies interactions and trophic controls have a strong influence on stock recovery potential, and the magnitude of impacts depends on the prevailing environmental conditions. Predation on small fish has a high impact on recruitment success and hence recovery potential of commercially important fish species. Density dependent (*i.e.*, intra-specific) but often more important inter-specific trophic interactions lead to different and mostly slower recovery rates of depleted fish stocks, compared to single species predictions. When trophic conditions are beneficial for the targeted stock, the speed and magnitude of stock recovery will be more effective compared with unfavourable conditions. These trophic aspects are influenced by climate variability/change, for example, regulating the strength of recruitment and consequent abundance of key species at various tropic levels in the ecosystem, and by modifying environmental gradients and ocean currents which affect the productivity and distribution of predator and prey organisms. Additionally, the level of fishing mortality exerted on fish stocks has both direct and indirect effects on multispecies interactions and trophic controls in the ecosystem.

It is not possible to simultaneously achieve yields corresponding to MSYs predicted from single-species assessments for interacting species. Therefore, an interpretation of the MSY concept within the ecosystem context is needed, mainly for the time after a recovery. There is a need to set target levels for fishing mortality and stock size for predator and prey fish stocks in a dependent manner. Reference limits for the harvested prey species (*e.g.,* herring and sprat in the Baltic Sea, capelin in the Barents Sea, and anchovy in the Bay of Biscay) cannot be defined realistically without considering changes in the biomass of their predators. Likewise reference limits for the predator species (*e.g.,* cod and hake) cannot be defined without considering changes in the biomass of its prey. This includes predatory interactions on all life stages, *i.e.*, a prey species may act as predator on early life stages of its predator (*e.g.*, sprat preys on cod eggs in the Baltic).

Credible fisheries-related multispecies models have several needs, including being supplied with data and knowledge concerning: i) Stock/species distributions, from periodic survey data with good temporal and spatial coverage, collected by various means; and ii) Diet composition data based on stomach sampling programs. The latter has been largely ignored within the EU data collection framework, resulting in a situation whereby the necessary multispecies data either hardly exist (*e.g.*, Bay of Biscay) or are out-dated (*e.g.*, Baltic Sea, North Sea). Additionally, there is a requirement for continual advances in the development and application of current and new multispecies models, including bridging the gap between fisheries and ecosystem models with linkages to lower (*e.g.,* plankton and benthos) and higher (*e.g.,* marine mammals and seabirds) trophic levels. However, without new field-derived data covering these different trophic levels, it will hardly be possible to further reduce the uncertainties in multispecies model predictions.

9.2.4 Significance of life history traits

Taking life history traits into account in management plans entails comprehensively understanding the species' biology throughout all its life stages, its specific environmental requirements and its role in the ecosystem. This includes parameters such as size/age-at-maturity, maximum size and longevity, growth rate, spawning requirements and larval survival. In addition, UNCOVER concludes that evolutionary effects of fishing on fish stocks occur and also need to be considered. These effects are expected to result in changes in growth, size/age-at-maturity, and reproductive investment. Rapid evolutionary effects may occur and have been demonstrated for collapsing stocks. Generally, however, evolutionary responses are likely to be small compared to the direct effects of overfishing and the direction of change in affected traits are dependent on the extent of the imposed fishing mortality. Thus, evolutionary changes are not expected to be generally responsible for a lack of recovery, even though they may contribute to a slower recovery rate. So, dealing with evolutionary effects of fishing is less urgent than reducing the direct, detrimental effects of overfishing on exploited stocks and on their associated marine ecosystems. Nevertheless, there is a need to develop and set clear management goals for genetic diversity and explicitly implement them within the framework of fisheries management legislation. Only if the major factors are understood, both functionally and quantitatively, will it be possible to design management plans which allow stocks to not only recover but also hopefully to fully rebuild. A prerequisite is basic biological research on the species' biology and quantification of the energy flow through the ecosystem.

9.3 Tackling major uncertainties and bias

9.3.1 Assessments

Assessment uncertainties can be critical in determining the success or failure of a management or recovery plan. One important area concerns observation error. Techniques, such as bootstrapping, provide an understanding of the random error in the observations, and the resulting effect on the assessment. However, biases also can be of critical importance, perhaps more so than random error, and these are not picked up by bootstrapping. Issues such as partial stock coverage from a survey, unrecognized trends in fishing, or changes in stock distributions or behaviour may all produce bias. These must be identified using the best available scientific knowledge, and either corrected a) at the data collection level (*e.g.*, improving survey design) or b) within the models (*e.g.*, with an efficiency correction factor on CPUE data).

Model formulation errors also may be important. In some cases, this is due to the wrong functional form or parameter values have been chosen within the model. An UNCOVER example is the Southern hake, where incorrect age data and growth rates were distorting the assessment models. This has been rectified within UNCOVER by moving to models where such growth rates do not need to be pre-specified. A second area of concern is where processes which are modeled as constant actually show trends through time. This has traditionally been of concern with trends in fishing catchability and efficiency, but changing environmental conditions are likely to result in changes in carrying capacity, growth, maturation and other critical biological processes. In general, any of the issues discussed above in the sections on 'Accounting for environmental and ecosystems conditions' and 'Significance of life history traits' may result in a previously adequate model ceasing to perform well as underlying assumptions of stationarity in the biology cease to hold. Thus, importantly stocks need monitoring to identify where modeling assumptions become outdated, and models suitably adjusted. It is also useful to compare different stock-models (*c.f.*, Barents Sea Case Study) so as to identify which dynamics are common across models and which may be artifacts of particular models.

Another uncertainty is the lag between data collection and implementation of the assessment. This is especially critical as it imposes delays on the ability to respond to reduced stock sizes and prevent a full collapse. This problem is exacerbated by the above-mentioned uncertainties, since it may take several years of assessments for a downward trend to be confirmed. In some cases, such as Barents Sea capelin, reducing this gap has improved the stock management. In other cases, delay is inevitable, but management rules should then be able to respond quickly once a decline has been observed.

9.3.2 Implementation and compliance

Experience from UNCOVER indicates that the single most important factor in determining the success or failure of a recovery plan or LTMP is the degree to which it is successfully implemented. A plan that is not precautionary to likely implementation errors is not precautionary.

The total induced fishery mortality (including, for example, discards and IUU fishing) is the driving factor, not merely that part of it that is the landed targeted catch. It was demonstrated by UNCOVER that large unreported catches and related biased assessment data pose a threat to effective stock/fishery management.

Negative examples concerning implementation errors are North Sea cod (quota set above scientific advice; high levels of discarding), North Sea herring (failure to comply with the management plan that required speedy and substantial reductions in TAC due to poor recruitment), Baltic Sea cod (IUU fishing) and Anchovy and Southern hake in the Bay of Biscay and Iberian Peninsula (TAC overshooting). Positive examples identified during the project resulting in successful recovery are Barents Sea cod (reduction of bycatch in the pink shrimp fishery; reduction of IUU fishing), Baltic Sea cod (reduction in IUU fishing) and North Sea plaice (capacity reduction leading to reduction in unreported mortality).

Successful implementation depends on compliance, both in terms of the likelihood of the managers following the plan, and in terms of excess fishing mortality above that specified in the plan (discards, IUU fishing, *etc.*). Thus, UNCOVER emphasizes that: a) Managers and politicians should use transparent decision-making that takes proper account of scientific advice and which avoids setting TACs higher than recommended (*i.e.*, avoid TAC-overshooting by politically agreed 'decision overfishing'); b) For the recovery plan to be successful, the agreed measures must be effectively implemented and fully complied with; c) For assessing implementation and compliance, appropriate inspection and monitoring schemes must be operationalized, the data quality-assured and the conclusions made quickly and openly available; and d) Importantly, the political will to support the LTMP/recovery plan must not waver.

9.4 Importance of a suite of management tools

9.4.1 Other measures than F

It is critical to recognize that management plans are about more than just target fishing mortality (F). It is obviously important to set target F values correctly, but these should be viewed as only one part of a successful management plan. Enforced management on measures like area closure, minimum landing size, bycatch in other fisheries, minimizing discards, and capacity and gear controls should at least be viewed as much a part of a precautionary management plan as the target Fs. Examples of additional measures include partial F allocation (allocation of TAC proportions) to specific fleet segments, or incentives to phase out the fishery by certain fleets that produce substantial discards. However, not all such measures are necessarily useful unless they act cohesively. For example, the expected effect of introducing technical measures intended to improve the selectivity of trawl fisheries by reducing the bycatch and discarding of young Baltic cod was counteracted by compensatory measures in the industry such as tampering with trawl panels. ICES emphasizes that such technical measures should not be substituted for reducing fishing effort.

Positive examples include Norwegian spring-spawning herring concerning introduction and enforcement of high minimum landing size. Also fishery closures provide an option, if location and timing are based on sound information, knowing that the spatial distribution of fish in spawning areas is a determinant for recruitment and management success. Results from UNCOVER in the Baltic demonstrated that closed seasons covering the entire fishing area had a much greater impact on recovery rates, final stock sizes, and yield compared with regionally restricted spawning area closures. Although with the latter scenario, in which all effort from dense pre-spawning and spawning concentrations could be effectively removed, the capacity of the cod fleets was obviously high enough to compensate the closure effect to a large degree by reallocating the effort into open areas and maintaining high catch levels. In summary, spatio-temporal fishing closures were only effective for stock recovery when they reduced overall fishing effort. For Bay of Biscay anchovy, it could be shown that in forecast scenarios the highest biomass levels are generally obtained with the combination of an appropriate HCR option, a closure of coastal areas during the spawning season (from April to September) and a reduction of total effort by 33%.

UNCOVER underlines that: a) When designing and evaluating a viable recovery strategy or management plan, other fishing regulations, and the biology of the stock must be considered in combination; and b) The performance of spatio-temporal fishing closures needs to be evaluated relative to environmental regimes, especially for stocks facing strong environmental variability.

9.4.2 Social and economic impact studies

Social impact assessments (SIA) are a critical tool in assessing both the impact and viability of recovery plans and long-term management plans. The UNCOVER study on SIA and community profiling has highlighted the importance of this work and further developed the methodology. Properly evaluating the social and economic consequences of fisheries recovery plans is, in general, not an easy task as the appropriate data are rarely available at all or not present at an appropriate scale. One successful method includes using community or fleet profiles as a tool for investigating the social and economic conditions of the fisheries/community in a ‘community profile’. From these profiles, social impact assessments are more easily conducted. Methods for fishing community profiles developed by UNCOVER have been adopted by the European Commission’s DG MARE. They are currently being used by this DG in new initiatives, such as a Baltic cod small scale fishery study and a comparative study of community dependency on fisheries.

The analysis of the economic implications of recovery plans and LTMPs has long been recognized by the Commission. Such analysis helps determine harvesting levels that are economically optimal. UNCOVER’s innovation was to use economic analysis as an assessment tool to understand the implications of the structure of fishing fleets for support and compliance with recovery plans and eventually LTMPs. Both the economic and social analysis pointed to the ability of fishing operations to diversify as being the critical variable determining industry response to required recovery plans.

9.5 Governance

UNCOVER's research on governance found that recovery plans have been focal points for collective action around reforming fisheries management with various kinds of objective setting processes carrying these reforms forward. At the highest level, objective setting is framed by international and EU agreements such as the 2015 MSY objective that stemmed from the 2002 World Summit on Sustainable Development (WSSD) and the European Community's Marine Strategy Framework Directive's (MSFD) requirements for 'good environmental status'. At the level of particular recovery plans, Regional Advisory Committees (RACs) have played the critical role of bringing about stakeholder consensus concerning ways to make these high level objectives operational. Recovery plans as such have not been rigidly defined. This has greatly facilitated stakeholder agreement on moving toward the international requirements. At the lowest level, the particular measures and HCRs that implement the recovery plans must have specific and measureable objectives to allow the scientific assessment of both their prospective suitability and retrospective effectiveness. These specific objectives have been set through a scientific, governmental and stakeholder processes with broad, if not universal, support. EU policy needs to recognize these three objective setting levels and facilitate their unique contributions.

An important result of the stakeholder consensus has been the generation of *active* support by the fishing industry. Joint work by RACs, fishing organizations, scientists, and environmental NGOs on recovery has, in several cases, gone beyond generating passive support in the form of legitimacy and increased compliance. Such work has included improved stock assessment and data collection, systems for increased compliance with measures, the avoidance of catching recovery species, and the reduction of discards. Such activities can generate greater socio-ecological resilience as an asset for responding to future demands of sustainable fisheries. The socio-economic analysis revealed that communities with a combination of the ability to diversify fishing activities and a strong, fisheries-oriented civil society showed the highest potential for active support. The direct policy implications of this phenomenon is reflected in the fact that all of these activities have required support from both science and government and this kind of support needs to be continued and expanded.

The greatest challenges to the legitimacy of recovery plans have stemmed from their focus on single species. The environmental NGOs in particular raise questions about how the recovery plans should fit into an ecosystem approach to management. For the fishing industry and managers, the worst problems arise in mixed-fisheries. The advantages of effort management in mixed-fisheries, combined with the continuing need for quota management to share stocks, have resulted in recovery plans with hybrid effort and quota management schemes that have greatly increased bureaucracy. To meet the challenge of mixed-fisheries, the active support generated by the recovery plans needs to be harnessed through collaborative research at EU Member State and regional levels. The efforts of the RACs to create effective LTMPs for mixed-fisheries, such as the North Sea RAC's LTMP for demersal mixed-fisheries, need to be supported by direct input of scientific advice and governmental support.

9.6 UNCOVER's primary conclusions

9.6.1 Main recommendations

UNCOVER emphasizes that it is essential to set 'realistic' long-term objectives and strategies for achieving successful LTMPs/recovery plans. The project recommends that such plans ideally should include:

1) Consideration of stock-regulating environmental processes;
2) Incorporation of fisheries effects on stock structure and reproductive potential;
3) Consideration of changes in habitat dynamics due to global change;
4) Incorporation of biological multispecies interactions;
5) Incorporation of technical multispecies interactions and mixed-fisheries issues;
6) Integration of economically optimized harvesting;
7) Exploration of the socio-economic implications and political constraints from the implementation of existing and alternative recovery plans;
8) Investigations on the acceptance of the plans by stakeholders and specifically incentives for compliance by the fishery;
9) Agreements with and among stakeholders.

9.6.2 Scientific support for policy

UNCOVER has provided imperative policy support underpinning the following fundamental areas: a) Evolution of the CFP with respect to several aims of the 'Green Paper'; b) Contributing to the Marine Strategy Framework Directive with respect to fish stocks/communities; c) furthering the aims of the 2002 Johannesburg Declaration of the World Summit on Sustainable Development regarding achieving MSY for depleted fish stocks. This has been done by contributing to LTMPs/recovery plans for fish stocks/fisheries, demonstrating how to shift from scientific advice based on limit reference points towards setting and attaining targets such as MSY, and furthering ecosystem-based management through incorporating multispecies, environmental and habitat, climate variability/change, and human dimensions into these plans.

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12 ANNEXES

12.1 Annex 1. Explanation of acronyms used in this report.

Acronym	Explanation
ABC	Acceptable biological catch
ACFM	Advisory Committee on Fishery Management (of ICES)
ACL	Annual catch limit
AFMA	Australian Fisheries Management Authority
ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas
CAS	Complex adaptive systems
CAY	Current annual yield
CBD	Convention on Biological Diversity
CFP	Common Fisheries Policy (of the European Union)
DG	Directorate General of the European Commission
NSRAC	North Sea Regional Advisory Council (for fisheries in EU regional seas)
DG MARE	Directorate General for Maritime Affairs and Fisheries
EAM	Ecosystem Approach to Management of Human Activities
EAFM	Ecosystem Approach to Fisheries Management
EC	European Commission/European Community
EEA	European Environment Agency
EEZ	Exclusive Economic Zone
ENSO	El Ni–o - Southern Oscillation
ERA	European Research Area
ESA	Endangered Species Act (of USA)
EU	European Union
F	Fishing mortality
FAO	Food and Agriculture Organization (of the United Nations)
FLR	Fisheries Library in R
FMP	Fishery management plan
FP6	Sixth Framework Programme (for Research and Technological Development) of the European Community
GCM	Global climate models
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environment Protection
GIWA	Global International Waters Assessment (of UNEP)
HELCOM	Helsinki Commission — Baltic Marine Environmental Commission
HCR	Harvest control rule
IAS	Invasive alien species
IBSFC	International Baltic Sea Fishery Commission (now disbanded)
ICES	International Council for the Exploration of the Sea
IPCC	Intergovernmental Panel on Climate Change
ITQ	Individual transferable quota
IUU	Illegal, unregulated and unreported (fishing)
LTMP	Long-term management plan
M	Natural mortality
MBAL	Minimum biologically acceptable level
MCY	Maximum constant yield
MFMT	Maximum fishery mortality threshold (of SFA)
MMPA	Marine Mammals Protection Act (of USA)
MSFCMA	Magnuson-Stevens Fishery Conservation and Management Act
MSFD	Marine Strategy Framework Directive
MSST	Minimum stock size threshold (of SFA)
MSVPA	Multispecies virtual population analysis
MSY	Maximum sustainable yield
MP	Management plan (for fish stocks/fisheries)
MPA	Marine protected area
NAO	North Atlantic oscillation

NEAFC	Northeast Atlantic Fisheries Commission
NOAA	National Oceanic and Atmospheric Administration (of USA)
NGO	Non-governmental organization
NMFS	National Marine Fisheries Service (of NOAA)
NSRAC	North Sea RAC
OCS	Offshore Constitutional Settlement (of Australia)
OECD	Organisation for Economic Co-operation and Development
OM	Operating model
OSPAR	OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic
QMS	Quota management system (of New Zealand)
SBL	Safe biological limits
SSB	Spawning stock biomass
RAC	Regional Advisory Council (for fisheries in EU regional seas)
RP	Recovery plan (for fish stocks/fisheries)
RTD	Research and Technological Development
SFA	Sustainable Fisheries Act (of USA)
SIA	Strategic impact assessment
STECF	Scientific, Technical and Economic Committee on Fisheries (of EU)
TAC/TACC	Total allowable catch/Total allowable commercial catch
UNCOVER	Understanding the mechanisms of stock recovery. EU FP6 project.
UNCLOS	United Nations Convention on the Law Of the Sea
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change
US/USA	United States/United States of America
VPA	Virtual population analysis
WSSD	World Summit for Sustainable Development

12.2 Annex 2. The UNCOVER project's partners and sub-contractors.

Partners			
No.	***Acronym***	***Institution***	***Country***
1	vTI-OSF	Johann Heinrich von ThŸnen-Institut - Institut fŸr Ostseefischerei	Germany
2	AZTI	FUNDACIî N AZTI - AZTI FUNDAZIOA - Marine Research Unit	Spain
3	CEFAS	Centre for Environment, Fisheries and Aquaculture Science, Lowestoft Laboratory	United Kingdom
4	CEMARE	University of Portsmouth Higher Education Corporation - Centre for the Economics and Management of Aquatic Resources	United Kingdom
5	DTU Aqua	DTU Aqua - National Institute of Aquatic Research	Denmark
6	FRS	Fisheries Research Services, Marine Laboratory	United Kingdom
7	IEO	Instituto Espa–ol de Oceanograf’a	Spain
8	IFM	Innovative Fisheries Management	Denmark
9	IFM-GEOMAR	Leibniz Institut fŸr Meereswissenschaften an der UniversitŠt Kiel	Germany
10	IFREMER	Institut fran•ais de recherche pour l'exploitation de la mer - Ecologie et Mod•le pour l'Halieutique	France
11	IMR	Institute of Marine Research	Norway
12	SFI	Morski Instytut Rybacki w Gdyni (Sea Fisheries Institute, Gdynia)	Poland
13	PINRO	Knipovich Polar Research Institute of Marine Fisheries and Oceanography	Russia
14	IMARES	Wageningen IMARES, Institute for Marine Resources & Ecosystem Studies	The Netherlands
15	Uni-Abd	University of Aberdeen - School of Biological Sciences	United Kingdom
16	UiB	Universitetet i Bergen - Dept. of Biology	Norway
17	UNI-HH	University of Hamburg - Institute for Hydrobiology and Fisheries Science	Germany
Subcontractors			
No.	***Acronym***	***Institution***	***Country***
1	AMA	AquaMarine Advisers	Sweden
2	AtlantNIRO	Atlantic Research Institute of Marine Fisheries & Oceanography	Russia
3	EMI	Estonian Marine Institute	Estonia
4	IIASA	International Institute for Applied Systems Analysis	Austria
5	IOW	Baltic Sea Research Institute WarnemŸnde	Germany
6	LATFRA	Latvian Fish Resources Agency	Latvia
7	MRAG	Marine Resources Assessment Group	United Kingdom
8	SWEM	Schrum & Wehde: Ecosystem Modelling GbR.	Germany
9	Uni-Bangor	School of Biological Sciences - University of Wales Bangor	United Kingdom
10	Uni-Mons	Mons-Hainaut University	Belgium

12.3 Annex 3. Leadership of UNCOVER Workpackages (WP) and Case Studies (CS).

The situation at the end of the UNCOVER project and formerly is shown.

WP 1: Fisheries and environmental impacts on stock structure and reproductive potential		
Name	***Partner***	***Country***
Richard Nash (WP leader)	11	IMR, Norway
WP 2: Impact of exogenous processes on recruitment dynamics		
Name	***Partner***	***Country***
Brian MacKenzie (WP leader)	5	DTU Aqua, Denmark
WP 3: Trophic controls on stock recovery		
Name	***Partner***	***Country***
Jens Floeter (WP leader)	17	Uni-HH, Germany
WP 4: Evaluation of strategies for rebuilding		
Name	***Partner***	***Country***
Finlay Scott (WP leader)	3	CEFAS, UK
Former WP leaders:		
Carl O'Brien, Laurence Kell	3	CEFAS, UK
WP 5: Social, economic and governance influences on recovery plan effectiveness		
Name	***Partner***	***Country***
Douglas Wilson (WP leader)	8	IFM, Denmark
WP 6: Project Synthesis		
Name	***Partner***	***Country***
Fritz Kšster (WP co-leader)	5	DTU Aqua, Denmark
Michael St. John (WP co-leader)	17	Uni-HH, Germany
WP7: Management and communication		
Name	***Partner***	***Institution/Country***
Cornelius Hammer (Project coordinator)	1	vTI-OSF, Germany
Harry V. Strehlow (Project Manager)	1	vTI-OSF, Germany
Former Project Manager:		
Christian von Dorrien	1	vTI-OSF, Germany
CS 1: Barents and Norwegian Seas		
Name	***Partner***	***Country***
Bjarte Bogstad (CS co-leader)	11	IMR, Norway
Sergey Belikov (CS co-leader)	13	PINRO
CS 2: North Sea		
Name	***Partner***	***Country***
Finlay Scott (CS leader)	3	CEFAS, UK
Former CS leaders:		
Laurence Kell, John Pinnegar	3	CEFAS, UK
CS 3: Baltic Sea		
Name	***Partner***	***Country***
Stefan Neuenfeldt (CS leader)	5	DTU Aqua, Denmark
Former CS leaders:		
Gerd Kraus	9	IFM-GEOMAR, Germany
Christian Mšllmann	5	DTU Aqua, Denmark
CS 4: Bay of Biscay		
Name	***Partner***	***Country***
Inaki Quincoces	2	AZTI, Spain
Former CS leaders:		
Hilario Murua	2	AZTI, Spain

12.4 Annex 4. Deliverables from UNCOVER

Del. No. [12]	Deliverable name	WP	Lead party	Esti-mated person-months	Nature[13]	Dissemination level[14]	Delive-ry date[15] (project month)
WP 1: Fisheries and Environmental Impacts on Stock structure and reproductive potential							
1	A review, time-series and synthesis of available data on growth, maturation, condition, fecundity, potential and realised egg production, egg quality and viability of offspring in the selected stocks under differing stock structures and environmental conditions in the selected fish species	1	5	35.1	R	RE	8
2	Process models that predict immature fish growth and maturation, and the seasonal growth and reproductive investment of mature fish considering abiotic and biotic factors that affect energy allocation, atresia and spawning omission	1	5	37.2	O (M)	RE	20
3	A review of available information on genetic changes in marine fish populations imposed by human activities with an evaluation of the effects of different management strategies on the genetic variability of marine fish populations	1	5	3.7	R	RE	20
4	Recommendations for management strategies to avoid/minimize negative effects	1	5	4.5	R	RE	32

[12] Deliverable numbers in order of delivery dates: D1 – Dn

[13] Please indicate the nature of the deliverable using one of the following codes:

R = Report

P = Prototype

D = Demonstrator

O = Other

[14] Please indicate the dissemination level using one of the following codes:

PU = Public

PP = Restricted to other programme participants (including the Commission Services).

RE = Restricted to a group specified by the consortium (including the Commission Services).

CO = Confidential, only for members of the consortium (including the Commission Services).

[15] Month in which the deliverables will be available. Month 1 marking the start of the project, and all delivery dates being relative to this start date.

Del. No. [12]	Deliverable name	WP	Lead party	Esti-mated person-months	Nature[13]	Dissemination level[14]	Delivery date[15] (project month)
	on the genetic variability of marine fish populations						
5	A synthesis of, and models that capture, the dynamics of fisheries-induced evolution in the selected species	1	15	6.6	R; O (M)	RE	32
6	Models for spatial distribution changes and habitat preferences under varying stock status (size, demography, history) and climatic condition	1	11	39.9	O (M)	RE	32
7	Models that encapsulate the variability in migration patterns under varying stock sizes (collapsing and recovering) and climatic conditions	1	11	23.8	O(M)	RE	32
8	Operational models capturing variability in stock reproductive potential, genetics, distributions and migration patterns under varying stock sizes and environmental conditions	1	11	16.8	O (M)	RE	47
WP 2: Impact of exogenous processes on recruitment dynamics							
9	Testable hypotheses of recruitment variability, and initial time series of preliminary proxy variables	2	10	18	R; O	PP	18
10	Initial results of analyses of existing field and experimental data available	2	14	17.8	R; O	PP	24
11	Preliminary versions of new process-based biological-physical IBMs based on input from wp 2.1 and 2.2	2	9	13.5	R; O	PP	24
12	Final versions of proxy variables, and statistical analyses of recruitment variability for some target species in CS regions	2	10	17	R; O	PU	36
13	Final analyses and interpretations of field and experimental data	2	14	16	R	PU	42
14	Advanced versions of new process-based biological-physical IBMs for some species in CS regions.	2	9	12	R	PU	42
15	Biological-physical-IBM-based analyses of historical recruitment varation for some species in CS regions	2	17	34.5	R; O	PP	48

Del. No. [12]	Deliverable name	WP	Lead party	Esti-mated person-months	Nature[13]	Dissemination level[14]	Delive-ry date[15] (project month)
WP 3: Trophic controls on stock recovery							
16	Review of the key physical and biological processes associated with slow or sudden historic changes in food webs and how these processes affect the potential for future stock recoveries	3	9	16.9	R	RE	8
17	Methods to implement predation on early life stages and small-scale, high-intensity predation process within large-scale, multi-species models	3	17	26	R; O (M)	RE	36
18	Time series of historical changes in food web fluxes and trends in stock sizes via application of improved deterministic and stochastic ecosystem and multi-species models	3	3	58	O	PP	40
19	Prediction of the impact of trophic control, exerted by direct and indirect species interactions under contrasting environmental and mixed-fishing regimes, on stock recovery paths.	3	5	14,7	R; O (M)	RE	44
WP 4: Evaluation of strategies for rebuilding							
20	Specification of technical requirements for input into FEMS, and the priority for evaluation set.	4	15	7.75	R	PP	8
21	Initial modules for each generic stock-recovery evaluation ready for transfer to WP4.2.	4	15	22.6	R	PP	20
22	Base case scenarios defined.	4	3	9	O	PP	30
23	First results for strategic recovery questions evaluation of the performance of alternative biological models or candidate management options relative to the base-case scenario.	4	3	27.85	R	PP	32
24	Final modules for each case-study specific or generic stock-recovery evaluation that will be implemented in FEMS.	4	3	20.85	O (M)	PP	44
25	Results from the final model runs (both generic - Level 1 and Case Study specific - Level 2 questions).	4	3	24.05	R, O (M,Da)	PP	48

Del. No. [12]	Deliverable name	WP	Lead party	Esti-mated person-months	Nature[13]	Dissemi nation level[14]	Delive-ry date[15] (project month)
WP 5: Social, economic and governance influences on recovery plan effectiveness							
26	Updated review of existing recovery plans	5	8	4	R	PU	12
27	Report on the application of bio-economic and compliance theory to three case studies.	5	4	17.9	R	PU	30
28	Social impact assessments for six communities affected by three existing recovery plans.	5	8	9	R	PU	30
29	Report evaluating strategy options in terms of expectations of compliance and cooperation.	5	8	5.5	R	PU	36
30	Report evaluating strategy options in terms of expectations of compliance and cooperation.	5	8	2.5	R	PU	47
WP 6: Project Synthesis							
31	Report on evaluation of preliminary suite of recovery scenarios based on results from WP1-3 and WP5.	6	5&17	16.2	R	PP	33
32	Report on the evaluation of final suite of recovery scenarios and production of an executive summary of the principle components and constraints of recover plans, for communication to decision makers	6	5&17	16	R	PU	44
33	Summary document from the International Conference on development and implementation of recovery plans at the end of the project	6	5&17	3	R	PU	47
WP 7: Project Management							
34	Organisation of Kick off meeting.	7	1	1	O	PP	1
35	Project website.	7	1	1	O	PU	2
36	First Newsletter	7	1	1	O	PU	3
37	Organisation of Steering Committee and Informal Cluster Meetings with other FP6 EU projects.	7	1	4	O	RE	9; freq.
38	"Interim activity report" giving project status and progress overview.	7	1	1	R	CO	12

Del. No. [12]	**Deliverable name**	**WP**	**Lead party**	**Esti-mated person-months**	**Nature**[13]	**Dissemination level**[14]	**Delivery date**[15] (project month)
39	Mid Term Activity & Management Report as specified in Article II.7.2 of Annex II of the contract.	7	1	2	R	CO	24
40	Second Newsletter	7	1	1	O	PU	24
41	"Interim activity report" giving project status and progress overview.	7	1	1	R	CO	36
42	International Conference on Stock Recovery organised to review and discuss results.	7	1	1	O	PU	47
43	Final Activity & Management reports as specified in Article II.7.2 of Annex II of the contract.	7	1	2	R	CO	48
44	Workshop proceedings, synthesis reports and final project report published.	7	1	2	O	PU	48
45	Audit Certificates of all partners.	7	1	1	R	CO	48
46	Policy Implementation Plan (PIP).	7	1	1	R	CO	48
TOTAL				618.2			

12.5 Annex 5. Multivariate statistical analyses for examining fish stock/fishery recovery factors

The **methodology** applied by Hammer *et al.* (submitted), to the Wakefield *et al.* (2009) data, to identify and model key performance criteria for successful recovery of global fish stocks/fisheries is examined in detail here. **Additional results**, which are superfluous to section 2.1 (in order to keep that section concise), are provided here as corroboration of the conclusions arrived at in section 3.3.

12.5.1 Methodology

Of the 13 performance criteria (i – xiii), all were normally distributed with the exceptions of criteria (vii) and (ix) which showed standardized skewness values (2.2 and 3.0, respectively) outside the expected range (-2 to +2). The potential implications for such deviations from normality are considered under the applied Canonical Correspondence Analysis (CCA) and Discriminant Analysis (DA) below.

CCA

A CCA was applied to examine the relationship of the 13 performance criteria with respect to each other and to two newly constructed variables '*Recovered*' and '*Non-recovered*'. These new variables were built on the original classification in table 7 of Wakeford *et al.* (2009) in which they identified stocks/fisheries as being 'Rebuilt' Yes (Recovered, in our terminology) or No (Non-recovered, in our terminology): for our CCA the new 'Recovered' variable has positive response values of 1 and negative response values of 0, and the new 'Non-recovered' variable has the reverse response values compared with 'Recovered'. In other words, we constructed two new, nominal variables with values of 1 and 0. CCA has most frequently been used to examine species – environmental relationships in ecology, being applied to multivariate ecological data typically consisting of frequencies of observed species across a set of sampling locations, as well as a set of observed environmental variables at the same locations (Ter Braak, 1986). In this context, the principal dimensions of the biological variables (*e.g.*, species) are sought in a space that is constrained to be related to the environmental variables (*e.g.*, humidity, soil-type) (Greenacre, 2007). Thus, in our study using CCA , we can consider the 13 performance criteria as being analogous to species, and 'Recovered' and 'Non-recovered' as analogous to specific environmental variables in the traditional ecological-type CCA. It is notable that CCA does not require particular assumptions concerning the normality of the data or whether the data are numerical or categorical (Ter Braak, 1988; Lepš and Šmilauer, 2003).

DA

Following the CCA, a DA (McLachlan, 2004) was applied to distinguish between the two groups (*i.e.*, 'Recovered' and 'Non-recovered') of stocks/fisheries using various performance criteria. In the DA, the intention was to examine which of the performance criteria, in a stepwise selection procedure, can provide a model which provides statistically significant discriminators among the two groups of stocks/fisheries having an *a priori* classification by Wakeford *et al.* (2009) as either 'Recovered' or 'Non-recovered' (*c.f.* Table 12.1). For DA, it is assumed that the data represent a sample from a multivariate normal distribution. As mentioned above, criteria (vii) and (ix) deviate from this assumption due to their standardized skewness values. However, violations of the normality assumption are not 'fatal' and the resultant significance tests are still reliable as long as non-normality is caused by skewness and not outliers (Tabachnick and Fidell, 2007). In the case of criterion (vii), the most extreme value was that in row 23 (North Sea herring), which is 2.11 standard deviations from the mean. In the case of criterion (ix), the most extreme value was that in row 4 (Atlantic sea scallop) which is 2.38 standard deviations from the mean. Both these extreme points do not exceed the critical value of 3 sigma (*i.e.*, standard deviations from the mean) commonly taken to denote the presence of outliers (Iglewicz and Hoaglin, 1993). Thus, the violations of the normality assumptions are viewed as not fatal. In the DA, we have carried out a forward stepwise analysis, in which a model of discrimination is built step-by-step. Specifically, at each step all variables are reviewed and evaluated to determine which one will contribute most to the discrimination between groups. That variable will then be included in the model, and the process starts again. The stepwise procedure is 'guided' by the respective *F* to enter value. The *F* value for a variable indicates its statistical significance in the discrimination between groups, that is, it is a measure of the extent to which a variable makes a unique contribution to the prediction of group membership. The DA was conducted using the Statgraphics XVI Professional statistics package.

Cross-checking using alternative approaches

For cross-checking the classifications arrived at by DA and the original classifications of Wakeford *et al.* (2009), we have also applied K-Means Clustering (KMC. Hartigan and Wong, 1979) and a Probabilistic Neural Network Bayesian Classifier (PNN. Bishop, 1995) using the Statgraphics Centurion XVI Professional statistics package.

- The KMC algorithm classifies/groups data based on attributes/features into K number of groups. KMC requires specification of the number of clusters (K) in advance, thereafter the algorithm calculates how to assign cases to the K clusters. The best number of clusters *k* leading to the greatest separation (distance) is not known as *a priori* and must be computed from the data. The grouping is done by minimizing the sum of squares of distances between data and the corresponding cluster centroid.
- The PNN implements a non-parametric method for classifying observations into one of *g* groups based on *p* observed quantitative variables. Rather than making any assumption about the nature of the distribution of the variables within each group, it constructs a non-parametric estimate of each group's density function at a desired location based on neighboring observations from that group.

Thus, both techniques provide classification of the stocks/fisheries into groups (*i.e.*, 'Recovered' and 'Non-recovered') which can be compared with the DA model classification and the original Wakeford *et al.* (2009) classification.

12.5.2 Results

CCA

The CCA biplot is shown in figure 3.1 in section 3.3. The importance of the 13 performance criteria (i-xiii) relative to the 'Recovered' and 'Non-recovered' vectors (arrows) is evident from their ordination from left to right in the case of 'Recovered', and right to left in the case of 'Non-recovered'. Thus, (vii) and (ix) are most closely associated with 'Recovered' fish stock/fisheries and (xii) and (iii) are most closely associated with 'Non-recovered' fish stocks/fisheries. Further consideration of these performance factors is provided in section 3.3.

DA

The DA produced a highly significant model as shown by the following outputs:

Functions Derived	*Wilks Lambda*	*Chi-Squared*	*DF*	*P-Value*
1	0.203688	44.5526	4	0.0000

All four variables (predictors) add very significantly to the model fit as they are entered:

*Stepwise regression***:**

F-to-enter: 4.0; F-to-remove: 4.0.

Step 0: No variables in the model.

Step1: Adding variable (vii) (F-to-enter = 30.0219).
- 1 variable in the model. Wilk's lamda = 0.499817. F=30.0219, P = 0.0000.

Step 2: Adding variable (viii) (F-to-enter = 14.014).
- 2 variables in the model. Wilk's lamda = 0.336976. F = 28.5297, P = 0.0000.

Step 3: Adding variable (ix) (F-to-enter = 8.63396).
- 3 variables in the model. Wilk's lambda = 0.257557. F = 26.9046, P=0.0000.

Step 4: Adding variable (ii) (F-to-enter = 7.14059).
- 4 variables in the model. Wilk's lambda = 0.203688. F = 26.3889, P = 0.0000

Final model selected.

Classification Function Coefficients for 'Recovery status'

	1	*2*
ii	4.98312	3.12632
vii	3.74984	1.6015
viii	11.4523	6.90292
ix	6.00273	3.31678
CONSTANT	-48.8422	-16.6711

There is a function for each of the 2 levels of 'Recovery status' (1 = Yes, 'Recovered'; 2 = No, 'Non-recovered'), as noted above, so that the classification of the 'Recovery status' of the stock/fishery may be predicted. As there are two groups (level 1 and level 2) prior probability was set at 0.5 for each group. In accord with the above table, the model function for example, used for the first level (*i.e.*, 'Recovered') is

*-48.8422 + 4.98312*ii + 3.74984*vii + 11.4523*viii + 6.00273*ix*

These functions can also be used to predict which of the two levels of 'Recovery status' (*i.e.*, 'Recovered' and 'Non-recovered' new observations belong to.

Compared with the original Wakeford *et al.* (2009) classification of the 'Recovery status' (*i.e.,* 'Recovered' and 'Non-recovered') of the stocks/fisheries, the DA classified all but one of the stocks/fisheries correctly (*i.e.*, 96.9%).

KMC and PNN

Compared with the original Wakeford *et al.* (2009) classification of the 'Recovery status' (*i.e.* 'Recovered' and 'Non-recovered') of the stocks/fisheries, the KMC—in creating two clusters (*i.e.*, 'Recovered' and 'Non-recovered)—classified all but two of the stocks/fisheries (Hoki classified as 'Recovered', and Summer flounder classified as 'Non-recovered' by KMC) correctly (93.8%) in accord with the Wakeford *et al.* (2009) classification. The DA classification and the KMC classification were in accord (including the hoki) with each other but for the Summer flounder stock/fishery, which was classified as 'Recovered' by DA). The PNN achieved the same 'success' level (96.9%) in classifying the 'Recovery status' of the fish stocks/fisheries as the DA, but differed with both the DA and Wakeford *et al.* (2009) over the classification of Summer flounder (*i.e.*, classified as 'Recovered' by both DA and Wakeford *et al.* (2009)). Interestingly, KMC, PNN and DA all predicted the status of the Gummy shark (which was not classified by Wakeford *et al.* (2009)) as 'Non-recovered'. Thus, both KMC and PNN provide good independent corroboration of the overall dependability of the DA classification of 'Recovery status' of the investigated stocks, and thereby also the basic robustness of the Wakeford *et al.* (2009) classification.

Conclusion

The conclusions from the CCA and DA are in close accord. The DA model provided a very high level of accuracy (ca. 97%) in predicting the 'Recovery status' (*i.e.*, 'Recovered' and 'Non-recovered') of the investigated stocks/fisheries, as classified by Wakeford *et al.* (2009), using four performance criteria (vii: Rapid reduction in fishing mortality; viii: Environmental conditions during the recovery period; ix: Life history characteristics of the target stock; and ii: Management performance). The accuracy of the model's classification predictions for the various stocks/fisheries has been independently corroborated using the KMC and PNN techniques. The results of the DA classification according to the final, four predictor (*i.e.*, performance criteria) model is shown in table 12.1.

Table 12.1. Results of the derived discriminant functions to classify the 33 fish stocks/fisheries. AG = actual group classification by Wakeford *et al.* (2009, their table 7). PG = discriminant model predicted group. Code: 1 = 'Recovered', 2 = Non-recovered'. * = 'incorrectly' classified, *i.e.*, discrepancy between model prediction and Wakeford *et al.* (2009). Performance criteria scores, i-xiii, from Wakeford *et al.* (2009) used as input to the discriminant function model. Area: US =United States; AUS = Australia; NZ = New Zealand; EUR = Europe.

Area	*Row/ Stock No.*	*Stock/Fishery*	*AG*	*PG*	*P-level*	*i*	*ii*	*iii*	*iv*	*v*	*vi*	*vii*	*viii*	*ix*	*x*	*xi*	*xii*	*xiii*
US	1	Pacific lingcod	1	1	0.9992	4	5	3	5	4	1	3	4	2	3	3	4	3
	2	Summer flounder	1	1	0.7246	2	5	1	5	2	1	1	3	3	1	3	3	2
	3	King mackerel	1	1	1.0000	3	5	3	5	1	2	2	4	4	3	4	4	2
	4	Atlantic Sea scallop	1	1	1.0000	4	3	3	5	3	3	4	4	5	2	4	3	3
	5	Bering Sea tanner crab	2	2	0.9998	4	4	4	5	5	3	3	1	2	2	3	4	4
	6	Georges Bank cod	2	2	1.0000	4	4	2	4	2	1	1	1	2	1	2	2	3
AUS	7	Brown tiger prawn	1	1	1.0000	5	4	5	4	5	3	4	3	5	3	4	3	5
	8	Grooved tiger prawn	1	1	1.0000	5	4	5	4	5	3	4	3	5	3	4	3	5
	9	School shark	2	2	0.9997	3	3	4	4	3	1	1	3	1	1	1	2	4
	10	Gummy shark		2	0.9991	2	1	4	4	3	3	2	3	2	4	1	2	4
	11	Blue warehou	2	2	1.0000	2	2	4	2	3	1	1	3	1	1	2	2	2
	12	Eastern gemfish	2	2	1.0000	2	1	4	2	3	1	1	3	1	1	2	2	2
	13	Orange roughy	2	2	0.9997	3	3	4	2	1	2	1	3	1	1	2	2	2
	14	Redfish	2	2	1.0000	2	1	4	2	3	1	1	3	1	2	2	2	2
	15	Silver trevally	2	2	1.0000	2	1	4	2	3	1	1	3	1	2	2	2	2
	16	South bluefin tuna	2	2	1.0000	2	1	2	3	2	3	1	2	2	1	1	1	3
NZ	17	Hoki	2	*1	0.8250	3	3	5	3	3	3	3	3	3	3	3	4	3
	18	Snapper	2	2	0.9993	3	2	5	3	2	2	1	3	2	2	3	4	3
	19	Southern blue whiting	2	2	0.9209	3	2	5	3	3	4	2	3	3	3	3	4	4
EUR	20	Northern hake	2	2	0.8064	3	4	1	3	3	2	2	3	2	1	1	4	3
	21	Southern hake	2	2	0.9999	3	1	1	3	1	2	1	3	2	1	1	4	2
	22	European eel	2	2	1.0000	1	1	1	3	2	1	2	1	2	1	1	2	2
	23	North Sea herring	1	1	1.0000	2	3	1	4	3	4	5	4	4	2	2	1	3
	24	Iceland cod	2	2	0.9787	2	4	5	4	4	2	3	2	2	1	2	2	4
	25	NE Arctic cod	1	1	0.9934	4	4	1	4	1	3	5	3	2	1	1	1	3
	26	Norwegian coastal cod	2	2	1.0000	1	1	1	2	1	3	1	2	2	1	1	1	1
	27	Faroe Plateau cod	1	1	0.9999	3	4	4	3	3	3	5	4	2	3	1	1	4
	28	West of Scotland cod	2	2	1.0000	2	5	1	3	1	2	1	1	2	1	1	2	2
	29	Kattegat cod	2	2	0.9998	2	4	1	3	1	2	3	1	2	1	1	2	2
	30	Irish Sea cod	2	2	0.9981	2	5	1	3	1	2	1	2	2	1	1	2	2
	31	Baltic 22-24 cod	2	2	1.0000	3	1	1	3	1	4	1	2	2	3	1	3	2
	32	Baltic 25-32 cod	2	2	1.0000	3	3	1	3	1	4	1	2	2	1	1	3	2
	33	North Sea, Eastern Channel, Skagerrak cod	2	2	1.0000	2	4	1	3	2	1	2	1	2	1	1	2	2

12.6 Annex 6. ICES/PICES/UNCOVER Symposium

The following section is reproduced, with some modifications, from the Introduction of the Proceedings of the UNCOVER Symposium, held from 3-6 November 2009 in WarnemŸnde, Germany (Hammer *et al.*, in press).

Introduction

The ICES/PICES/UNCOVER Symposium on *Rebuilding Depleted Fish Stocks – Biology, Ecology, Social Science and Management Strategies*, held in WarnemŸnde, Germany, from 3-6 November 2009, was positioned near the end of the EU UNCOVER project *Understanding the Mechanisms of Stock Recovery (C*ontract No. 022717), which, more than five years ago, was developed and applied for funding from the European Union's 6th Research Framework Programme (FP6). The symposium was hosted by Institute for Baltic Sea Fisheries, Johann Heinrich von ThŸnen-Institute (vTI), Federal Research Institute for Rural Areas, Forestry and Fisheries, Institute for Baltic Sea Fisheries, Rostock, Germany, *i.e.*, the UNCOVER Coordinator. In addition to the EU, ICES and PICES, the symposium was co-sponsored by several research institutions or programmes including vTI, the Canadian Department of Fisheries and Oceans (DFO), the Norwegian Institute of Marine Research (IMR), the Northwest Atlantic Fisheries Organization (NAFO) and the European Research Council's (ERC) Committee on Science and Technology (COST) Action Fish Reproduction and Fisheries (Fresh). More than 150 research scientists, fisheries managers and national and international contact points from a large number of countries from the Atlantic and Pacific areas attended the symposium.

For these areas and stocks the European Commission expected a thorough analysis of the state of stocks within the ecosystem and clear-cut recommendations of how to rebuild depleted stocks. Thus, the primary objectives were: firstly to identify changes experienced during stock decline and to understand the prospects of their recovery; secondly, to generally enhance the scientific understanding of the mechanisms of fish stock recovery; and, and thirdly, to formulate recommendations for fisheries managers as to how best to implement successful recovery plans. The general UNCOVER-approach was supposed less to do *de novo* research by generating new data but more to draw conclusions from existing knowledge from published science and existing or ongoing projects.

Therefore, the UNCOVER perspective has not been limited to the case study areas but also to make use of universal knowledge and understanding. The recovery scenarios for the areas and stocks in question were put into context with the success and failure of recoveries, or non-recoveries, around the world. Approaching the end of the UNCOVER project in early 2010, the symposium was conducted to conclude on the state of recovering of depleted or collapsed fish stocks. Therefore, not only important UNCOVER project results were presented to the Commission and participating scientists, but also relevant contributions from other colleagues were welcomed to discuss state-of-the art results. For this reason, the symposium was designed as an attempt to integrate general experiences and to set the symposium up as a combined initiative of several research and advisory bodies.

Addressed scientific topics

The **Opening Address** was given by Dr. Steven Murawski (USA) who concluded that 25% of the world's fish stocks are overfished and that the most successful recovery programmes are characterized by immediate reductions in fishing mortality (F) instead of long-term, gradual reductions in F. Conceptually, there should be made a distinction between 'recovery' and 'rebuilding', the first refers to increase in stock biomass while the latter contains a suite of criteria including restoring of age structure, evolutionary mechanisms and behavioural traits. Here as in other presentations, it was made clear that 'rebuilding' has a much longer time horizon than 'recovery'.

The Symposium was structured in topical theme sessions:

Session 1 dealt with the '***Impact of Fisheries and Environmental Impacts on Stock Structure, Reproductive Potential and Recruitment Dynamics***' (Chair C. Tara Marshall (Scotland) and Toyomitsu Horii (Japan)). The session's subtitle was "Yes we can" rebuild the stock. The motto was meant to be a little provocative since it was apparent from the contributions that even though there is evidence of a lot of recovered stocks, others may remain collapsed despite long periods of low fishing mortality. It is evident that some stocks have collapsed and have not recovered despite implementation of recovery plans. Stocks may decline even in the absence of fishery or at low fishing intensities when recruitment fails in a sequence of years, as currently seen in the western Baltic Spring Spawning Herring. Then higher fishing intensity can only make this decline worse. The contributions showed that the fishery itself may have evolutionary effects on stock characteristics (such as at age at maturity) and models indicate that rebuilding to the full original state (and stock structure) may be extremely slow. To understand the recovery and rebuilding processes a variety of approaches are required. For example, information on individual spawning components and their biology and spawning habitat requirements (cf. the well-documented existence of meta-populations) along with drift of eggs and larvae and their likely natural mortality is needed to understand the recovery as a whole. Equally important is the process-based understanding for estimating and predicting rates of recovery and its reduction of the uncertainty by comparing long-term datasets for many species and regions.

More specifically, several presentations addressed how fishing impacts 1) demographic structure, reproduction and stock recovery rates (*e.g.,* North Sea plaice), and 2) genetic structure and life history traits, and stock recovery rates (*e.g.,* Barents Sea cod). These should as far as possible be disentangled from how environment impacts 3) growth of individuals and reproduction, and stock recovery rates (*e.g.,* Gulf of St. Lawrence cod) and 4) recruitment/mortality and stock recovery rates (*e.g.,* meta-analyses on cod, herring and haddock). It was acknowledged that modeling provides useful insight but predictive ability should be examined more rigorously. Likewise, new biological data (*e.g.,* data storage tags, genetic markers, fecundity) have the potential to challenge conventional assumptions as *e.g.,* spatial structure remains poorly understood and reproduction is more variable than assessment often assumes (skipped spawning, maternal and paternal effects, r and K life styles etc.). Within the present scenario of climate change more research is needed into the effects of temperature (and CO_2) on growth, distribution and reproduction (*e.g.,* fecundity and egg quality and effect of larval development and recruitment).

Session 2 was on '***Trophic Controls on Stock Recovery***' (Chairs: Axel Temming (Germany) and Bjarte Bogstadt (Norway)). This session concentrated on the multispecies interactions in the case study areas. Recovery scenarios for the Baltic Sea were presented, showing that the long-term perspectives for cod, sprat and herring largely depend on the environmental conditions, primarily the inflow situation of oxygen-rich saltwater into the Baltic Sea. This has a direct effect on the zooplankton composition and the available 'reproductive volume' (water masses where eggs and larvae can survive) for the cod. The simulations showed that if the inflow situation remains low and unfavourable, as it presently is, herring will remain in a nutritionally poor state. A recovering cod stock will likely reduce the herring and sprat stock to a state where the fishery on these will have to be strongly reduced or even stopped. The cod recovery will be potentially slowed by cannibalism, an effect which, however, is less pronounced in the early phases of recovery due to spatial separation of juveniles and adult, and due to the relatively small number of adults as compared to a fully recovered stock, in which more adults occur, and thus the likelihood of encounter is greater. This was shown both for Baltic Sea cod and for Bay of Biscay hake.

For the North Sea, multispecies models showed how the system is controlled by predators which have taken over the role of cod, which was the large top-predator. The middle-size predators have recently been grey gurnard and horse mackerel preying increasingly on 0-group of cod and herring, respectively. The multispecies models also show that the system as a whole recovers slower than expected based on single species modeling due to cannibalism. Moreover, recovery in the North Sea depends much on the recovery of the top-predator cod and mackerel, which itself depends (for cod) to a great extent on the predation of juveniles by new predators on small fish such as grey gurnard, which, in the absence of cod, have increased in stock size. However, if the cod recovers, cascading effects will occur and a number of other stocks will decline, first of all middle predators such as whiting and haddock, and prey species such as Norway pout and herring, and possible also *Nephrops* and *Crangon*.

The case of the Pacific herring, which has so far not recovered, showed how much the process depends on the ecological conditions. For Pacific herring, a decrease of food availability for immature fish over two decades has prevented stock recovery. At the same time, the recovering Pacific sardine may be competing for feed with herring, while marine mammals prey on herring, keeping the natural mortality on the stock high.

In the Barents Sea the capelin stock, as prime prey species of the Northeast Arctic cod stock, has collapsed three times within 25 years. These collapses were, however, primarily caused by predation of juvenile herring on the capelin larvae, although high abundances of this size class of herring do not necessarily lead to failure of capelin recruitment (*e.g.,* when little coincidence occurs in their spatio-temporal distributions). In the case of the capelin collapses, the resulting cascading effects are far-reaching. During the mid-1980s the collapse resulted in strong detrimental influences on the stocks of cod, harp seals and seabirds. Cod switched to increased cannibalism, reduced growth and delayed maturation occurred, possibly even skipped spawning partially.

Session 3 was on '***Methods for Analyzing and Modelling Stock Recovery***' (Chairs Ana M. Parma (Argentina) and Laurence T. Kell (Spain)), the question was raised "whether we have the right tools and methods?" The overarching theme of the session was the level of uncertainty. This was broken down into the question of which uncertainties really matter and how to address these uncertainties in the formulation and evaluation of rebuilding plans. Moreover, how shall a recovery process be tracked in a data-poor situation? This seems important and often new indicators or methodological approaches need to be developed or strengthened, such as egg surveys which render an index for spawning stock biomass. Indicators can be biased due to inherent systematic errors. Meta-analyses may be helpful in such situations. For the Baltic Sea, a biological 'Ensemble Model Approach' was tested to compare predictions from several existing models to look for the most 'robust' advice or divergent predictions. By using the same framework the sensitivity of different model assumptions could be tested.

For the use in the evaluation of the management strategies the knowledge gathered within operating models through different kinds of process-oriented research should be integrated, allowing better management support and evaluation of the effects of all kinds of uncertainties on performance of harvest control rules. Indeed, for most of the processes their uncertainties did matter and had an impact on the conclusions about management performance. This may in particular be the interaction between management of a single stock and the multispecies dynamics, the interactions amongst different sources of uncertainties, and the influence of fisher's reactions or environmental variables.

The question remains "How much uncertainty should be presented?" Too much uncertainty will make the advice impractical and will erode the support of the stakeholder for the recovery plans. Too little uncertainty would erode the credibility of science, as for instance overly optimistic predictions may turn out to be wrong. However, the available tools allow for integrating existing knowledge and turning scientific production into the delivery of management support advice, although the question still remains whether we have done this level of integration yet.

Session 4 tackled '***Social an Economic Aspects of Fisheries Management and Governance***' (Chairs: Denis Bailly (France) and Douglas C. Wilson (Denmark)). Recovery plans serve the purpose of restoring the business opportunities for fishers. The bio-economic models demonstrate huge potential for restoring economic rent, assuming that lessons learnt from stock collapse will improve post-recovery management efficiency. Providing multi-annual guidance on recovery plans, recognizing the importance of limiting inter-annual variation and being progressive in implementation rather than being too hard is beneficial in terms of business management, even at the price of delayed stock recovery.

From an economic and social aspect recoveries of fisheries are of big business by nature, with the prospect of high revenues and a great number of employment opportunities involved, both in the fleet and catch sector as well as in the processing industry. It is noteworthy that recovery of stocks goes along with great changes in predator-prey abundances and therefore these shift catch opportunities between fleets and thus redistribute opportunities and eventually wealth. Fishers want to have their claims for the entitlement to fish on recovered stocks to be taken into account and are able to turn down the best science and management system by moving politically. This holds even though the fishing sector is not homogenous. There are well organized groups, either grouped by mŽtiers, *i.e.*, catching sector, or nationally or both.

Viewed from the other side, the managers do not all hold the same views or values about the key objectives and other claims are also to be considered (conservation, social aspects, fairness etc.). In addition the management framework also concerns the maintenance of a particular culture, norms and social networks (social capital) that are key to social organizations and social reproduction. The fisheries communities are not equal in terms of resilience, some are vulnerable to fisheries collapse and mismanaged recovery plans (high dependence, few economic alternatives, aging population and low education), whereas others are very well able to adapt to change.

From this it is concluded that community profiles, baseline assessment on social aspects and social impact assessments are useful tools to help design dedicated policies. The question remains, however, how to make it part of the overall assessments, how to implement the process and how to develop this in a participatory way.

If the collapse of fish stocks is, as in most cases, a failure of governance due to fishing pressure, then recovery plans are not likely to work without rethinking the governance structure. As a consequence effective governance will need to be more inclusive of all parties, which are fishers, managers, scientists and NGOs. The participatory approach needs to include all diverse views. Likewise, a great amount of flexibility is required to allow different groups take part in the decision-making. The objectives as such should be defined at a high service level, but the operation implementation should be left to lower service levels.

Session 5, the last session, addressed '***Management and Recovery Strategies***' (Chairs: Joseph E. Powers (USA) and Fritz W. Köster (Denmark)). Management evaluation frameworks have been and are still developing and comprise aspects ranging from stock productivity, fleet structure, catch composition and related economics, and technical measures, such as gear regulations or spatial/temporal closures. The frameworks are environmentally sensitive, spatially explicit, economically driven and capable of handling uncertainty. However, they currently miss, in most instances, species interactions. Furthermore, they currently still do not consider in some instances the consequences of implementation of recovery plans and associated probabilities of failure.

The question is raised whether all this is needed in order to implement successful recovery plans, or is rapid reduction in fishing mortality sufficient? And if this is the case, how then should the fishing mortality be reduced? Should it be done by effort reduction, by a Total Allowable Catch (TAC) reduction, or both together, or even accompanied by spatial/temporal closures of fishing areas, by gear restrictions or prohibitions and or other technical fixes? Are the answers to these questions stock and/or ecosystem-specific? Although many of these questions are not yet sufficiently answered it is apparent that clearly defined objectives and management objective criteria are needed. From the variety of possible management performance criteria it became clear that the following four performance criteria are, in combination, of most importance: 1) rapid reduction of the fishing mortality; 2) taking environmental characteristics into account; 3) tuning the measures towards the specific life history characteristics of the stocks in question; and 4) the development and acceptance of the right management criteria.

The symposium's final day included a ***Panel Discussion***, which was moderated by a professional moderator (Ralf Rüchert). Eight international experts represented science, the international organizations PICES and FAO, the fishing industry, conservation NGOs, and the European Commission and DFO, Canada, as management authorities. The Panel Session was divided into five blocks (representing the five theme sessions), each opened with a brief summary by the corresponding Session Chairs of the principal findings of his/her theme session, followed by discussions and comments by the Panel members and by the audience. The outcome from the panel discussion, together with the final summing up by the main keynote speaker, identified a number of important aspects to stock recovery and rebuilding.

The panel expressed the view that there is overwhelming evidence that collapsed and severely depleted fish stocks can recover and be rebuilt, although the process may be slower than previously thought. Rebuilding the life history, age composition, stock structure, spatial distribution and ecosystem functioning may take longer than the recovery of the stock biomass. Stock rebuilding plans represent the most widespread wildlife management experiments ever undertaken and it is imperative that these plans be well documented, archived, and the results clearly communicated. Given that the fish and system they occupy may have changed from states prior to depletion, rebuilding plans need to be adaptive. On the other hand they should not assume lower rebuilding targets based on recent productivity rather than those based on historic data until monitoring of the rebuilding process provides justification for revising targets. The productivity of depleted stocks my increase to historic levels, albeit slowly, as they rebuild and the evolutionary impacts of size-selective fishing are reversed and ecosystem functioning restored.

There are considerable socioeconomic impacts in the short term associated with rebuilding fish stocks although these will be offset by increasing benefits in the longer term. These downside losses and upside benefits of recovery programs need to be communicated to those associated with the fishing industry and to the civil public. If fishery participants have secure rights to the fishery of the future they will be more open to rebuilding. Stock rebuilding invariably implies fewer fishermen in the future and significant transition costs will exist. This should be understood and anticipated far in advance.

If fisheries-induced evolutionary changes have occurred, or if ecosystem and climate changes have significantly altered the productivity, demography, or dynamics of depleted fish stocks, restored stocks (in terms of biomass) may differ markedly (*i.e.*, genetically, physiologically, and ecologically) from their status prior to depletion. In some cases, recovery to former biomass levels and stock structure may not even be possible, due to dominance shifts in the ecosystem and/or to evolutionary effects to the stock in times of decline.

A precautionary and adaptive approach may be required to avoid delays in taking effective action, not only for stocks already in dire straits, but to keep those that are beginning to show signs of reduction from becoming depleted.

The current evidence is overwhelming that management can be effective in recovery of fisheries and restoring the economic and social benefits derived from sustainable fisheries. However, significant investments into fishery science are required for the near future, largely because fishery science will need to be more integrative by incorporating environmental changes, ecosystem factors and habitat changes. In addition, there is the request to combine fishery assessments and the advice for governmental decisions with socio-economic implications. To achieve this, fishery science needs to change from single-species assessments which still are the dominant paradigm in textbooks of fishery science and current advice to a more holistic ecosystem assessments in which stock abundance is part of a dynamic ecological matrix. This request is definitely not new and the ICES Working Group on Integrated Assessment in the Baltic has taken up the challenge as well as ICES multispecies working groups, for instance as has been done in the North Sea. It goes without saying that such a paradigm shift, in expectation of the deliverables of fishery science to governments, implies a significant increase in scientific resources and primarily on the required field data.

In contrast to these expectations and clear-cut requests from the managerial side, it has been the trend since the 1980s to reduce monitoring programmes and surveys to cut expenses. The reality of data collection (*e.g.*, survey data on adult abundance, food consumption data, economic data) contradicts the political request for holistic assessments.

Concluding remarks

We are now at the half-way point between the World Summit on Sustainable Development held in Johannesburg in 2002 and 2015, the year when governments committed themselves to restore fish stocks to levels that can provide Maximum Sustainable Yield. Scientific understanding of the biological, ecological, social and economic processes influencing the recovery of fisheries has improved substantially in the recent period as a consequence of concerted research effort by programmes like UNCOVER. There is now sufficient knowledge to develop effective recovery strategies for most fish stocks. We urge governments and regional fisheries (management) organizations to increase their effort to implement these plans and not to delay in taking effective action, not only for those stocks that are already in dire straits, but also for those stocks that are beginning to show signs of becoming overfished. The evidence is overwhelming, in many cases, that effective action can recover fish stocks/fisheries within a limited number of generation times and thereby restore economic and social benefits derived from sustainable harvesting.

12.7 Annex 7. Summary of the main conclusions from ICES WKEFA 2007

The ICES Workshop on the Integration of Environmental Information into Fisheries Management Strategies and Advice (WKEFA) focused on five main topics of relevance to the influence of environmental change on fishery management.

12.7.1 Entries and exits from populations

Three main subjects were considered: a) Migration; 2) Mortality (in single species models and projections); and c) Recruitment. Recruitment and natural mortality are the main source of population growth and loss (apart from fishing mortality), and are affected by environmental variability and change in the short and medium term. In addition, environmental variability and change may affect migration rates in and out of the assessment/management area, and thus perturb advice. These aspects may influence assessments, projections and/ or management considerations.

a) Migration

Variability in population migrations is an important issue that requires adequate understanding, parameterization and estimation.

b) Mortality (in single species models and projections)

Natural mortality is a process that is subject to large variability connected to environmental variability and change. Estimating natural mortality (M) is one of the most difficult problems faced and so it is often set as a constant value between years and across ages. There are case studies where estimates of M are used in evaluations but variable values are not applied or recommended to be used in assessment. Retrospective analyses can be used to determine inconsistencies in cohort patterns that may help in the identification of variable M rates. Natural mortality variation is one plausible explanation that should be evaluated relative to alternative hypotheses (*e.g.*, movement into or out of an area). The necessity to include predation in medium-term projections (*e.g., Bax et al.*, 1998) and the determination of biological reference points (*e.g.,* Gislason, 1999) are widely accepted. For several pelagic species and some young age-groups of demersal species (*e.g.,* different eastern Atlantic cod stocks) predation mortality estimated by multispecies models are used in assessments and predictions. But, short-term inter-annual variability is assumed to be limited and thus fluctuations are ignored in short-term predictions. This assumption probably does not hold for pelagic prey species (Stephenson, 1997), especially in ecosystems with few dominating and fluctuating predator species, *e.g.,* capelin in the North Atlantic (*e.g.*, Carscadden *et al.*, 2001) and sprat in the Baltic (*e.g.*, Kšster *et al.*, 2003b).

c) Recruitment

Estimation of recruitment in the face of environmental variability and change is a crucial aspect of successful assessment and management. Change can be detected directly, through recruitment surveys (preferred) or indirectly through commercial CPUE, VPA or environmentally-based recruitment estimates. Regarding the latter, however, there are currently few examples where environmental estimators have stood the test of time, although an environmental signal is included in the S/R relationship and HCR of the California sardine. Detecting recruitment changes is particularly important in short-lived species (anchovy, sprat, capelin, *etc.*), where the catch consists mostly of recruits, and in heavily exploited stocks where successful recruitment is crucial to maintain populations at exploitable levels. In longer-lived species, one should be able to pick up trends before the fish recruit to the fishery. Whatever method is used to derive recruitment from simple means to information based methods there is a need to develop decision-making rules regarding the use of R estimates in management plans. As more complex methods are developed it is important to ensure that the error structure of the method is fully accounted for. In particular some environmental indicator methods may be non-linear and have asymmetric error strictures. It is important that the rules used are evaluated with these possibilities in mind.

Concerning management consequences of recruitment variability, ICES WKEFA (2007) further recognized that environment changes affect BRPs that are tied to estimates of stock productivity (*e.g.,* the S/R relationship). In practice, however, HCRs are developed with relatively static BRPs and the sensitivity of these to natural fluctuations are rarely evaluated. Operating models should be developed to reflect plausible hypotheses about these changes so that the relatively static HCRs can be evaluated. Approaches have been presented (*e.g.,* Kell *et al.*, 2006) where the environment affects the stock recruitment relationship both regarding stock productivity (initial slope at the origin) and carrying capacity parameters. The former is apparently most critical for severely depleted stocks whereas carrying capacity has the largest impact for stocks that are declining from relatively high abundance levels. The Baltic cod is an example for the latter, where environmental change affected first of all the carrying capacity, while the slope at the origin appears to be rather stable during periods of favourable and unfavourable conditions for reproduction.

Recruitment estimation is also used in medium- to long-term projections. Stock assessments may be used to provide advice for upcoming annual harvest levels based on a combination of future recruitment scenarios (*e.g.*, low, average, high) and performance measures in relation to a biomass reference points. Current estimates of recruitment strength in recent years may be used to forecast biomass trends under optimum yield assumptions and provide an indication of where the stock will be in relation to management reference points in, for example, 10 years.

An area worthy of future development involves the use of IPCC methodology and Global Climate Model outputs to produce stock projections under climate change scenarios. The biggest difficulty at present is the lack of adequate tools to downscale Global Climate Model outputs to the scales of biological relevance, as well as the inability of GCMs to capture all the variability in shelf seas.

12.7.2 Individual biological parameters

Two main subjects were considered: a) the detection of change; and b) how important are the biological parameters? WKEFA noted that there is considerable potential for incorporating environmental information connected with management aspects related to individual biological parameters such as growth and maturation. This is because relatively large amounts of data are collected annually on weight-at-age and maturity-at-age. Short-term responses, even without a cause being determined, may be expected to continue allowing short-term (deterministic) projection, whereas medium-term projection may require an understanding of the relationship between an environmental driver and the parameter of interest. For the longer term, as all of the biological parameters respond to environmental forcing at a variety of scales, environmental factors could be used directly in calculations of biomass, yield and reference points. In this case, the decision to include or not should be based on the information content, if incorporating change in a parameter adds information to the management that exceeds the uncertainty in the parameter.

There are a number of areas for immediate action: a) Growth, and b) Maturation. *Stage 1*: Evaluate changes by cohort and over time, separating influence of variability or noise in the data and predictable change. The modeled results should be used for short-term projections. This should avoid the kind of errors in catch and SSB that have been seen in the past (*e.g.*, effect of weight differences in NEA cod). ICES should arrange the provision of projection software that can handle these types of issues. There should be appropriate rationales for assumptions used in projections. Where long-term means are supported by the data they should be used, but where trends or short-term correlated variability is observed this should be modeled and taken into account. The aim is to provide cohort and year effect based short-term prediction software to replace the current approach. Methods should involve detection of 'signal' (real change) in 'noise' (annual variability in either growth or measurements) using statistical methods and apply appropriate prediction methods to give growth and maturation one or two years forward. Retrospective analysis should be used to monitor the performance of the methods chosen. Other fixed demographic parameters used in projections should be evaluated against known ranges of measurement variability. The impact of sex ratio changes and age structure differences should be evaluated. *Stage 2*: Understanding processes so that medium to long-term projections reflect process oriented studies that document how changes in food availability and hydrography affect growth and reproduction. As a starting point, one can investigate the impact of year-class effects, temperature, and density dependence on maturity and growth. If there are apparent trends in the effective reproductive output due to environmental changes, then proxies for reproductive output (e. g., SSB, B_{pa}) could be affected, and hence accounting for this would be important. For short-term predictions, variability in effective fecundity is taken into account as part of the expected inter-annual recruitment variability and cannot practically be provided for as a separate effect in management adjustments. However, this information could provide added information on subsequent medium-term recruitment (see above). The assessment working groups should provide medium-term projections that account for trends and uncertainties in effective reproductive output if these have been identified (see above). Where trends in parameters are found that change the reproductive potential, the impact on biomass reference points should be considered. Regarding age structure, indicators on population age structure as part of management goals should be evaluated, recognizing that some fishing actions (*e.g.*, population truncations) have medium and long-term impacts on life history traits and recruitment.

12.7.3 Habitat issues

Three main topics were considered: a) Changes in horizontal movements, including contraction/expansion; b) Changes in vertical distribution; and c) Suitable reproductive habitat mapping. As habitats change due to environmental drivers, this can have many different consequences. Some consideration of habitat change leads to additional consideration of recruitment and migrations in addition to those highlighted earlier in this annex. The primary consideration is how habitat change influences stock carrying capacity or productivity (*e.g.*, Baltic Sea cod). If stock carrying capacity changes, then biomass targets based on a different carrying capacity may no longer be appropriate/achievable. If productivity changes the risks to the stock and the potential for recovery will be changed. WKEFA concluded that when the habitat has changed such that mean recruitment is altered or growth rates are changed for the medium term, it is necessary to consider whether previous biomass or fishing reference points are still applicable. There is a need to re-evaluate reference points under such circumstance. However, re-evaluation should include consideration not only of the current carrying capacity but also the potential for further stock depletion and the ability of the stock to recover should the habitat return to previously observed conditions. This leads to biomass limit points that infer maintenance of recruitment in the current stock status and inclusion of the possibility to recover if the habitat changed again. For fishing mortality limits, if productivity has changed fishing mortality limits should allow stock expansion under both regimes.

It is expected that quality of spawning habitat affects recruitment also in other stocks, specifically if such habitat is located at the border of the species distribution range. If available, measures of reproductive habitat should be integrated into the evaluation of reference points and construction of environmental sensitive stock recruitment relationships to be used in medium- to long-term projections. The value of using such information in short-term predictions depends on the availability and performance of pre-recruit surveys, and if these are not available or reliable on the understanding and predictability of other processes affecting reproductive success.

12.7.4 Multispecies interactions and modeling

Three main subjects were considered: a) The detection of change in multispecies interactions; b) How important are multispecies interactions; and c) How and where to incorporate multispecies interactions in advice.

The Primary method for detection of change comes from stomach contents analysis combined with estimated abundance of the predator and prey stocks. This may involve more than commercial fish/shellfish species and should include changes in plankton which may be important as indicators of food, such as the changes in the North Sea in the late 1980s (Pitois and Fox, 2006). Additional factors such as the arrival of new species in an area can also be an indicator of change.

Potentially multispecies interactions are very important for medium to long-term expectations. The effects may be less important for short term advice. So far results tend to provide clear larger signals in ecosystems with smaller numbers of dominant species, such as the Barents Sea and the Baltic Sea. The effects in more diverse areas, such as the North Sea, may be less pronounced and the need to consider multispecies aspects of predator -prey interactions may be less important for the understanding of single species evaluation. In situations where most of the forage fish are depleted, it may though be necessary to examine the situation in a multispecies context, also in these higher diversity areas.

To date the most extensive use of multispecies modeling directly applied in advice is the use of natural mortalities in single species models derived from more complex multispecies models. While this approach is not so sensitive to changes, it does a least improve the scaling of total biomass from the catch. WKEFA concluded that this practice should continue and be expanded to other stocks. Currently a move to multispecies modeling for a full range of single species advice would require extensive development and testing. WKEFA suggested, from the inputs reviewed at the workshop, that the stability of suitability functions for selection of prey may not be stable enough to provide good annual single species advice. So progression would require considerable resources. Exceptions may be simple systems in which single predator and very few prey species may be tightly coupled. The other main use of multispecies models is to allow hypothesis testing. This can take the form of full Management Plan evaluation, or examination of issues such as the compatibility of multispecies objectives. In Europe efforts are well underway to interface both MSVPA and GADGET with the FLR (Fisheries Library for R) framework (Kell *et al.,* 2007) as part of the EU FP6 'UNCOVER' project. Multispecies modeling should continue to develop such frameworks.

12.7.5 Composite (ecosystem) issues in advice

Two main subjects were considered: a) biophysical models; and b) adapting management to shifting regimes.

Presently, biophysical modeling (BPM) is being developed to investigate the sensitivity of fish to environmental variability. These are aimed at different life stages of fish. WKEFA was unaware of any BPMs that are currently used and incorporated into advice and management. The usefulness of BPMs is highly dependent on their specific characteristics. For example, if the BPM does not incorporate any processes that are directly or indirectly affected by water temperature, comparing the model results with a water temperature time-series is meaningless. Therefore, the BPM must incorporate all potentially relevant processes (although not necessarily explicitly). Simplicity and transparency are also important components of advice, and whilst BPMs may provide useful tools for investigating the sensitivity of organisms to change, their results may be difficult to interpret and incorporate into advice.

Special consideration needs to be given to both naturally occurring and fishery induced regime shifts due to climate/ocean forcing. Such situations can generate productivity changes of sufficient magnitude to necessitate changes to management, as it is unlikely that a single management strategy will be optimal under different regimes. Simulations suggest that fishing mortality management strategies are more robust to regime shifts than biomass related management strategies. The necessary time frame to detect change in regimes depends on the life history and age of recruitment to the fishery and the exploitation rate. Short lived species with low age of recruitment and high exploitation rates would require very rapid detection, but their management, which normally involves rapid response to fluctuating recruitment, may already be more adapted to conditions of regime shifts. However, if their management is not robust, changes in regimes will make the situation even worse. In contrast long lived species exploited at a low rate and with older age of entry to the fishery allow for slower management response. If stock carrying capacity changes then biomass targets may no longer be appropriate. If productivity changes the risks to the stock and the potential for recovery will be changed. Under such circumstances it is necessary to re-evaluate previously defined biomass or fishing reference points However, re-evaluation should include consideration not only of the current carrying capacity but also the potential for further stock depletion and the ability of the stock to recover should the habitat return to previously observed conditions. This leads to biomass limit points that infer maintenance of recruitment in the current stock status and inclusion of the possibility to recover if the habitat changed again. For fishing mortality limits, if productivity has changed they should allow stock expansion under both regimes. Assessment working groups are encouraged to take this into consideration medium to long term projections and in the determination of biological reference points that are relevant to specific productivity regimes. Management targets and precautionary limits should be revised accordingly.

13 APPENDICES

Four Case Study (CS) Area reports are provided as '***stand alone***' appendices supplementing this report.

13.1 Appendix 1. Case Study Report for the Norwegian and Barents Seas

13.2 Appendix 2. Case Study Report for the North Sea

13.3 Appendix 3. Case Study Report for the Baltic Sea

13.4 Appendix 4. Case Study Report for the Bay of Biscay and Iberian Peninsula

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