Project no	:	SSP8-CT-2004-513670
Project acronym	:	**PROTECT**
Project title		"Marine Protected Areas as a Tool for Ecosystem Conservation and Fisheries Management"
Instrument	:	PRIORITY 8, Scientific Support to Policy (SSP)
Thematic Priority	:	Area 1.3 Modernisation and sustainability of fisheries, incl. aquaculture-based production systems

Deliverable No. 21

Final Report: Project Synthesis

Due date of deliverable: Dec 08
Actual submission date: April 09
Start date of project: 1 January 2005
Duration: 3.5 years
Responsible partner: Technical University of Denmark (Partner 1)
Revision: Final

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
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)	X
CO	Confidential, only for members of the consortium (including the Commission Services)	

PROTECT

Marine Protected Areas as a Tool for Ecosystem Conservation and Fisheries Management

Project Synthesis

April 2009

Compiled by Thomas Kirk Sørensen, Per Nilsson and Anita Tullrot

in collaboration with Ulf Bergström, Peter Karås, Ole Vestergaard and PROTECT partners

Table of Contents

An overview of the PROTECT project - Marine protected areas as a tool for Ecosystem Conservation and Fisheries Management 4
INTRODUCTION 4
What is PROTECT? 4
What is an MPA? 7
Why does PROTECT study MPAs? 7
The Habitats Directive/Natura 2000 8
Common Fisheries Policy 8
Integration? 9
MPA Goals, Objectives, Indicators & Success Criteria 10
Development of tables with Goals, Objectives, Indicators and Success criteria (GOIS tables) 10
Origin of GOIS tables 10
GOIS tables in PROTECT 12
Multi-sector engagement 14
Monitoring of MPAs 16
Generic monitoring approaches 16
Before vs. after 16
Inside vs. outside 16
Worst-case scenario 16
Monitoring in PROTECT 17
Challenges and obstacles in PROTECT MPA monitoring 19
The importance of high-resolution fisheries data, e.g. from logbooks and VMS for the evaluation of MPAs and other management measures 20
Logbooks 21
VMS 21
Shortcomings of VMS in relation to MPAs 21
VMS to monitor fisheries in relation to offshore nature protection MPAs 22
Use of VMS for non-surveillance purposes 23
MPA design in relation to enforcement 24
PROTECT Modelling to evaluate MPA effects 26
Objectives of the modelling activities within PROTECT 26
Modelling contributions within PROTECT 27
Empirical evaluation assessments of MPA effects 27
Dynamic models for assessing MPA effects 27
Dynamic models of larval dispersal 29
Empirical approaches for collecting biological parameters 29
Empirical approaches for fleet analysis 30
Empirical assessment of public preferences 30
Theoretical economic modelling 30
Model requirements for MPA assessment 31
Grounding the models in real data 31
Computer development and performance issues: think generic 32
Facilitating the use and reuse of modelling tools, and incorporating uncertainty in model output 32
Modelling and adaptive MPA management 32
Data needs and priorities for more efficient MPA evaluations 33
Challenges for the future in MPA modelling 33
Improvement in statistical experimental design 33
Taking habitat variability into account in experimental design 33

Adapting an ecosystem approach to evaluate MPA effects 34
Dynamic modelling 34
Data for model calibration 34
Economic and social models 34
PROTECT case study studies and their results 35
The Baltic Case Study 35
Brief description of the ecological and geographical setting 35
Recent cod fisheries closures in the Baltic Sea 38
Baltic case study: GOIS & Monitoring strategies 39
GOIS 39
Monitoring compliance 41
Baltic case study: Modelling approaches and results 41
A simple model of the Baltic cod population forced by environmental scenarios 41
Spatial fishery simulation model ISIS-Fish in the Baltic Sea 42
Baltic Sea fleet movement models 43
Main conclusions from the Baltic case study 44
The North Sea case study 46
Brief description of the ecological and geographical setting 46
Previous closures of the sandeel fishery 46
North Sea Plaice 47
Objectives of the North Sea case study 48
North Sea case study: GOIS and monitoring strategies 48
GOIS 49
Monitoring strategies for the North Sea case study 49
Sandeel monitoring needs 50
Monitoring fleet responses and compliance 51
North Sea case study: Modelling approaches and results 52
Empirical modelling using BACI design testing 53
Connectivity among sandeel areas 53
Adaptive management in North Sea case study 55
North Sea plaice modelling 56
Main conclusions from the North Sea case study 56
The Deep Sea Coral case study 58
Brief description of the ecological and geographical setting 58
Previous closures of fisheries affecting corals 59
Purpose of the work done in the coral case study 60
Deep sea coral case study: GOIS & Monitoring strategies 60
GOIS 60
Monitoring of compliance 61
VMS to monitor coral MPAs in Norway 62
Deep sea coral case study: Modelling approaches and results 63
Coral/Fish Production Function Approach 63
Empirical assessment of public preferences: choice modelling 64
Main conclusions from the Deep Sea Coral Case study 65
PROTECT general framework for establishing and managing MPAs 68
Initial MPA planning 68
Identifying conservation and resource management focus 68
Formulating goals and objectives, success criteria and indicators 69
Reviewing the legal basis for the MPA 70
Gathering information on human activities 70

Identifying knowledge required for site selection 71
Site selection & MPA design 72
Mapping of species and habitat distributions in potential areas 72
Modelling the expected performance of planned and implemented MPAs 72
Selecting sites using criteria lists or site selection software 72
Setting boundaries and level of protection 72
Establishment of MPAs 73
Formulating the management plan 73
Implementation process 73
Regulations allowing for adaptive management 73
Modelling to evaluate MPA effects 74
Evaluation and adaptive management of MPAs 74
Evaluating ecological effects 74
Evaluating bio- and socio-economic effects 75
Adapting management measures 75
Stakeholder involvement & information to the public 76
Lessons learned 79
References 83
References 84
Annex I Case-specific GOIS tables and lessons learned 90
GOIS: Lessons learned 104
Annex II: Further reading: PROTECT Scientific reports and publications 106

An overview of the PROTECT project - Marine protected areas as a tool for Ecosystem Conservation and Fisheries Management

INTRODUCTION

This report aims to give an overview and synthesis of the work done in the PROTECT[1] project, including the project's main findings, and to place these findings in a generic context that might be applied elsewhere. This report complements the full technical and scientific reports from PROTECT work packages and case studies (see Annex II). Such reports should be consulted for the full information regarding e.g. methods used and results.

What is PROTECT?

PROTECT is an interdisciplinary, policy-oriented research project involving 17 European institutions aiming to enhance the decision basis for the development and management of marine protected areas (MPAs) in Europe as part of an ecosystem-based approach to fisheries management. The project is a Specific Targeted Research Project running from 2005 to 2008 with support from the EU 6th Framework Programme.

The objectives of the PROTECT project were:

- to evaluate the potential of MPAs as a tool in fisheries management and protection of sensitive species, habitats and ecosystems from the effects of fishing,
- to outline a suite of scientifically based monitoring, assessment and evaluation tools for assessing the impact of MPAs on fisheries and marine ecosystems, and
- to assess the effect of different levels of protection, including the impact and socio-economic effects of MPAs on fishing communities.

These objectives have, through a number of work packages, been applied to three different regional MPA case studies (see Figure 1), each representing a different ecosystem type and underlying reason for MPA establishment (see also Table 1):

- ***The Baltic Sea case study*** is an illustration of the use of closures to regulate a fishery on a fish population that is extremely dependent on environmental conditions (i.e. Baltic cod *Gadus morhua*). It is also an example of the use of closed areas to protect a migratory, TAC-regulated fish stock that is under intense fishing pressure, and where the analysis of displacement of fishing effort (in time and/or space) from the closed area is a crucial factor when predicting whether or not the MPA will meet its goals.

- ***The North Sea sandeel case study*** is an example where a fishery may be regulated through spatial closures, both for the conservation of the fish stock and for the benefit of other parts of the ecosystem (in these cases birds and other predators on sandeels and other fish species). The sandeel work also includes an illustration of how to design a network of dynamic MPAs of limited sizes, the configuration of which is altered from year to year on the basis of environmental monitoring. It also shows how connectivity among MPAs can be operationally analysed.

[1] http://www.mpa-eu.net/

- ***The deep-water coral case study*** is an example of MPA creation where biodiversity conservation is the main goal but where the MPA will simultaneously have an influence on some fish populations and fisheries. This study is also an example of the legal, practical and economic challenges of establishing MPAs in offshore areas.

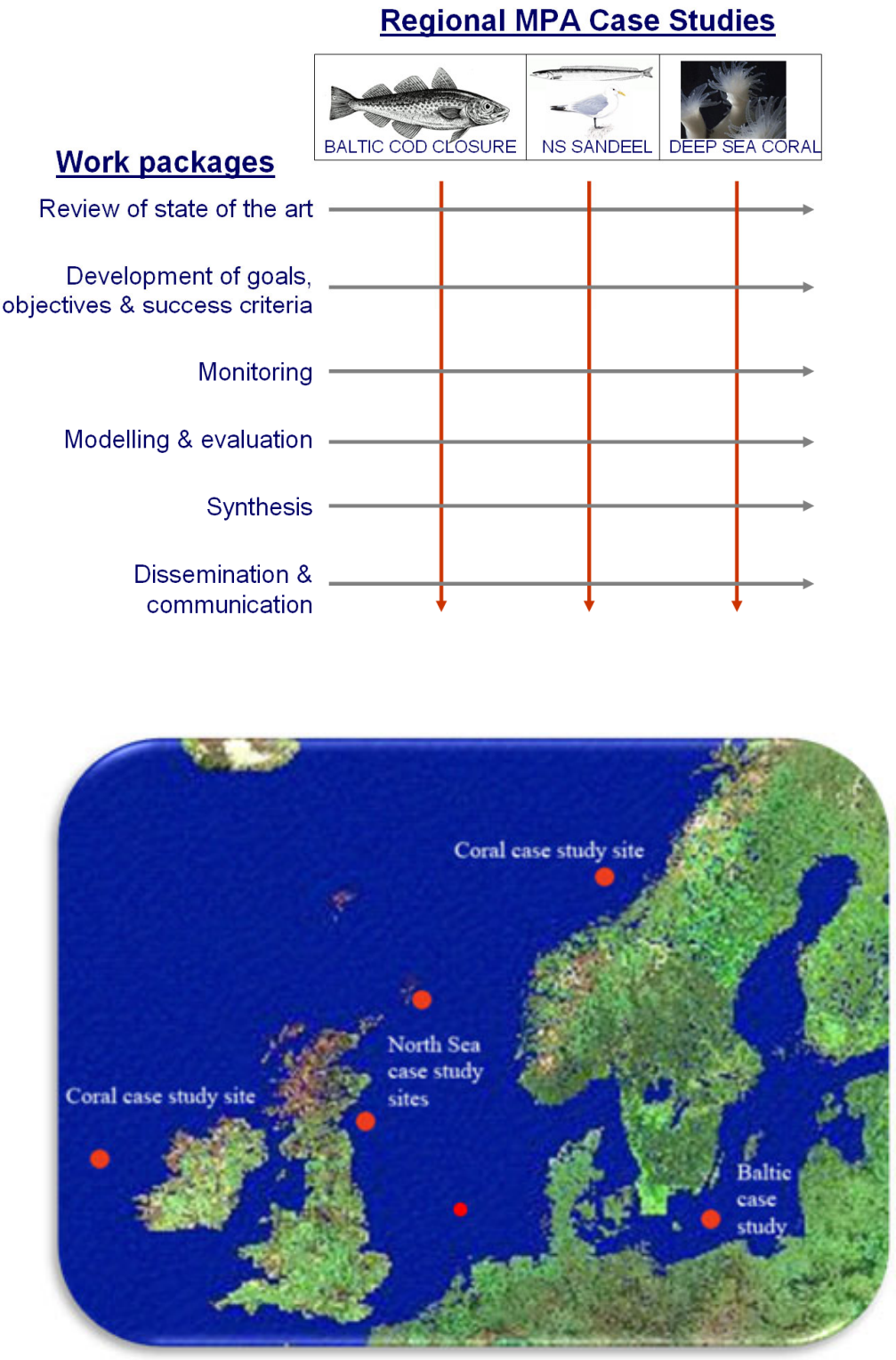

Figure 1 Work packages and case studies of the PROTECT project.

Table 1. Characteristics of the three PROTECT-Case studies

Case Study	Focal species type	Regional type of ecosystem	Mobility of focal species	Importance for fishery
Baltic	Top-predator fish species	Semi-enclosed brackish water area	++	++
North Sea	Planktivorous forage fish	Ocean shelf basin	+	++
Deep Sea Corals	Sessile organism	Deep sea habitat forming species	-	Important as fish habitat

PROTECT further aims to address the link between science and management in MPA design and implementation, including the timing and level of stakeholder involvement in relation to MPA planning and management. Moreover, PROTECT serves to promote adaptive management in relation to the use of MPAs.

What is an MPA?

MPAs have in recent years moved from the world of science and advocacy to the global political arena. However, MPAs have come to mean different things to different people, based primarily on the level of protection provided by the MPA. Some see MPAs as sheltered or reserved areas where little, if any, uses or human disturbance are permitted. Others see them as specially managed areas designed to enhance ocean use and exploitation. Correspondingly, a broad variety of definitions exist for MPAs, causing some confusion among e.g. policy makers regarding the relevance of MPAs for their respective sectors.

For the purpose of PROTECT, and this report, the following definition has been adopted: *An MPA represents any marine area set aside under legislation or other effective means to protect marine values* (marine values referring to e.g. conservation, commercial, scientific, recreational, cultural and aesthetic). The definition is rather broad and potentially covers almost any area-based marine management measure. A broad definition nonetheless has several advantages. For instance, the definition is not sector-dependent, i.e. the specific rationale behind the designation of the MPA is not relevant in relation to the terms used. By stating that MPAs must be set aside under legislation *or any other effective means*, voluntary agreements such as e.g. a code of conduct among fishermen are not excluded. The definition requires management measures to be area/site specific, thereby excluding the use of the MPA term in relation to other management measures and regulations.

Why does PROTECT study MPAs?

The use of MPAs as tools for ecosystem conservation and fisheries management is a multifaceted task that requires integration and synergies between different scientific disciplines as well as integration between sectors. However, management of the European marine environment and its living resources is sectorally divided and largely determined by central directives and policies stemming from the European Union, such as the Habitats Directive and the Common Fisheries Policy.

The Habitats Directive/Natura 2000

The introduction of the EU Habitats Directive[2] in 1992 put EU member states under the obligation to designate and protect marine sites purely for the sake of the conservation of marine biodiversity. As a consequence it has by any account become the main driver for MPA designation in European seas. The legally binding Habitats Directive is the means through which the EU aims to meet its obligations as a signatory of the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention). It requires member states to take measures to, by 2015, maintain or restore a predefined set of natural habitats and wild species at a so-called "favourable conservation status", i.e. introducing robust protection for those habitats and species of European importance. Sites for protection under the Habitats Directive are termed Special Areas of Conservation (SACs**)**, and are identified and designated by member states for subsequent approval by the EU Commission[3] (see Fig. 2). Among the habitats listed in Annex I of the directive are reefs (including deep-water coral reefs) and submerged sandbanks, while Annex II lists a large number of marine species. However, only a small number of (threatened) fish species are included among these, i.e. commercially important fish species are not included. The Habitats Directive and a corresponding Birds Directive[4] from 1979 together serve as the building blocks of the European Natura 2000 network of protected areas.

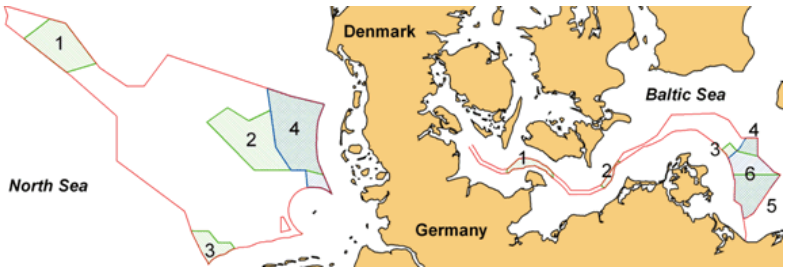

Figure 2. Nominated Natura 2000 sites in the German EEZ (Source: www.habitatmare.de)

Common Fisheries Policy

Fishing activity taking place in the majority of European waters is regulated through the EU's Common Fisheries Policy (CFP). In addition to e.g. the setting of catch limits for respective commercial species, the CFP is responsible for development and implementation of technical measures such as MPAs (which in fisheries terms are usually referred to as fisheries closures, boxes, etc.)(See Fig. 3). Such closures have been implemented for a number of reasons, most commonly as a means to protect spawning or nursery areas and, more recently, to protect sensitive habitats such as deep water coral reefs from damage caused by fishing. However, most of these area closures have had limited success, if success has at all been measurable given lacking baseline studies, focused monitoring etc.

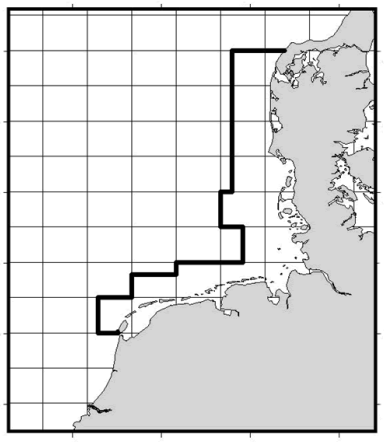
Figure 3. The North Sea Plaice box.

Integration?

In the context of the EU, in March 2008 the Directorate-General for Fisheries and Maritime Affairs (DG FISH) was re-named the Directorate-General for Maritime Affairs and Fisheries (DG MARE), clearly signifying an intent to integrate policies and related management of all maritime activities (including the Common Fisheries Policy) in EU waters under the European Maritime Policy. The European Marine Strategy Directive[5], the "environmental pillar" of this Policy, aims to protect marine species and habitats through a

[2] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora

[3] Pedersen et al. 2009

[4] Council Directive of 2 April 1979 on the conservation of wild birds (79/409/EEC)

[5] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)

number of measures, MPAs being one mentioned example. As a consequence of these developments, it is not prudent to consider MPAs without placing them in a wider marine spatial planning context, i.e. also taking into consideration both the accumulated impacts on the marine environment (including fish populations) of other activities than fisheries and the socio-economic interests of other stakeholders than fishermen.

Developments are currently taking place in the context of the EU[6], the Northwest Atlantic Fisheries Organisation (NAFO)[7] as well as the UN Food and Agriculture Organisation (FAO) to protect sensitive habitats and species in the high seas. These developments have much relevance especially for the PROTECT coral reef case study described in this report. Furthermore, a communication released in 2008 by DG MARE[8] underlines the commitment of the Common Fisheries Policy to the progressive implementation of a precautionary, ecosystem approach to fisheries management through a reduction in fishing pressure and by ensuring that fisheries policy is fully coherent with and supportive of the actions taken under the European environmental directives.

As a result of these increasingly common high-level calls and initiatives to protect marine habitats and species as well as fish populations, MPAs are moving more and more from the world of marine science towards the centre stage in international marine policy. Projects such as PROTECT are therefore important to ensure a solid science-base for development of these MPAs and to bridge the gaps between science and policy.

[6] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0604:FIN:EN:PDF
[7] http://www.nafo.int/about/frames/media.html
[8] COM (2008) 187 final. The role of the CFP in implementing an ecosystem approach to marine management.

MPA Goals, Objectives, Indicators & Success Criteria

Development of tables with Goals, Objectives, Indicators and Success criteria (GOIS tables)

One aim of PROTECT was to develop practical tools for MPA planning and evaluation. MPAs are established for a wide range of purposes, and there are different considerations involved in determining to what extent a given MPA is reaching its predetermined goals. To evaluate performance against a predefined MPA *goal*, specific and measurable *objectives* must be defined in terms of what outputs and outcomes are expected. This in turn requires well-defined management plans, pre-defined criteria for MPA *success*, and monitoring of the impact of management actions. The results of these activities should be fed back into the MPA planning process for possible revision of objectives, plans and outcomes, i.e. so-called adaptive management.

Origin of GOIS tables

Development of goals and objectives for MPAs has of course been a part of MPA work for a long time. The work on developing the kind of GOIS tables for MPA evaluations that we have used in PROTECT started in 2000, when the World Conservation Union (IUCN) together with the World Wide Fund for Nature (WWF), formed the MPA Management Effectiveness Initiative (MPA-MEI). This programme had four main objectives:

- To develop a set of natural and socio-economic indicators to evaluate MPA management effectiveness;
- To develop a process for conducting an MPA evaluation – in the form of an easy-to-use guidebook;
- To ground-truth and field-test the guidebook and indicator methods; and
- To encourage uptake.

The MPA-MEI programme conducted a survey of MPA goals and objectives from around the world, and categorized these into three broad types: biophysical, socio-economic and governance. 130 'indicators' were investigated and mapped to relevant MPA goals and objectives. Operational descriptions and definitions were subsequently provided for 44 indicators as well as a detailed narrative of methods of measurement and guidance on analysis/interpretation of results[9]

Formulating goals and objectives

Closures may be introduced for many reasons, including biological, social and economic. In modern fisheries management, closures are usually part of a package of measures taken to achieve sustainable fisheries, expressed in terms such as ensuring that a stock is kept "within safe biological limits" or ensuring that some aspect of the ecosystem is protected. These terms are usually rather vague, and when coupled with other measures, it becomes very difficult to work out what precisely was intended by an individual MPA. The first, and potentially most critical challenge to be faced when designing an MPA is therefore to define the goals that the MPA is expected to achieve[10]. While this might seem obvious enough, conceptualising required outcomes into clear objectives at a level that can be expressed in outcome-orientated terms is difficult when the goals are expressed at a high level, are complex or are only short-term in nature[11]. Nonetheless, the setting of clear objectives is the most critical step to get right and is

[9] Pomeroy et al. 2004; see www.effectivempa.noaa.gov/guidebook/guidebook.html
[10] Ward 2004
[11] Ward 2004

recognized as a fundamental initial step in the process of establishing MPAs within the context of an ecosystem-based management system.

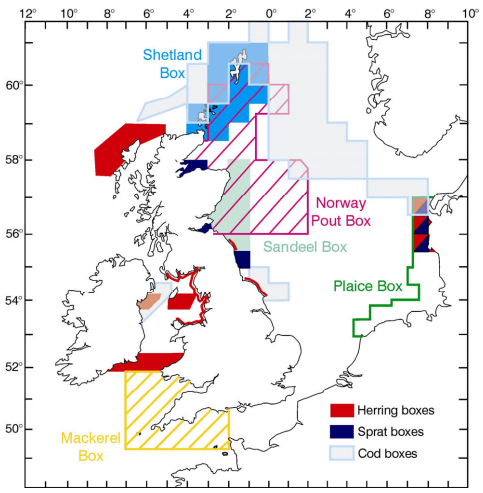

Figure 4. Some examples of closed areas under the Common Fisheries Policy (2004)

The EU Commission recently requested that a Scientific, Technical and Economic Committee for Fisheries (STECF) evaluate the utility and effectiveness of existing spatial management measures in the North Sea (e.g. Fig. 4). A subgroup of STECF was convened (SGMOS-07-03) and reported in November 2007. Overall SGMOS-07-03 found that most closures had been established without clearly stated objectives. This made it exceedingly difficult for the subgroup to evaluate the effectiveness, regardless of the amount of evidence that might be available. To facilitate future evaluation of closed areas SGMOS-07-03 recommended that when a closed area is established, explicit consideration be given to its objectives and ways of measuring whether or not those objectives have been met.

The process of goal setting is closely linked to stakeholder expectations[12]. If goals are not well articulated, it is difficult to define criteria to measure 'success' or to identify and quantify indicators of progress[13]. A 'goal' is a broad statement of what the MPA is ultimately trying to achieve, i.e. why was the MPA created and what are the main aspirations. By contrast, an 'objective' is a more specific measurable statement of what must be accomplished to attain the related goal. Attaining a goal is typically associated with the achievement of two or more corresponding objectives. A useful objective[14] is one that is:

- *Specific and easily understood,*
- *Written in terms of what will be accomplished (not how to go about it),*
- *Realistically achievable,*
- *Defined within a limited time period, and*
- *Achieved by being measured and validated*

When MPA objectives are simple, as may be the case for a fishery where a specific habitat is recognized as a critical nursery area for the target species (e.g. herring and sprat 'boxes' in the North Sea) then implementation of an effective MPA is intuitively easier. When objectives are more complex, only expressed at a strategic level (such as "protection of biodiversity" or "mitigate against the impacts of fishing"), or expressed at a mixture of levels, the design problem is much more complex [15]. When MPA objectives are specified in different ways and at different levels of ecological organization, the risk is that the "easy" objectives will be addressed first and "difficult" objectives deferred for later implementation. Successful MPAs result from careful planning and design, yet the history of MPA establishment is that most MPAs have been established with only limited systematic analysis or with data that relates, typically, to only a few species, and it has been difficult to extract meaningful general principles because of weak design[16].

[12] Agardy, 2000
[13] Kay & Alder, 1999
[14] Margolius & Salafsky, 1998
[15] Ward 2004
[16] Botsford et al. 2003

In Europe, very few, if any, of the spatial management measures introduced under the auspices of the Common Fisheries Policy (CFP) have been subject to pre-planned monitoring and assessment (although such plans are being put in place for some proposed Special Areas of Conservation (SACs) under the EU Habitats Directive. This is partly because of poorly articulated goals and objectives. A consequence of this has been that scientists have had to struggle to deduce the intentions of the Commission. In some cases this has been relatively easy, in others it has proven a mystery why some closures were established at all.[17]

Where the objectives of closed areas under the CFP can be deduced, they generally focus on: (a) protection of spawning stocks or grounds; or (b) protection of juveniles and nursery grounds.

However, a growing number of area closures introduced under the CFP in recent years, as part of an ecosystem based approach to fisheries management, are designed to achieve benefits for habitats/ecosystems or species of conservation concern (e.g. seabirds), and are not entirely related to the resource-management of commercial fish stocks specifically, *e.g.* the Firth of Forth sandeel closure (to protect prey resources for vulnerable predators), Darwin Mounds, Hatton Bank, Logachev Mound, NW Rockall, Reykjanes Ridge, Faraday, Hecate, Antialtair and Altair seamounts (vulnerable habitats). In such cases, the MPA may have many high-level objectives and goals that are particularly difficult to conceptualise and articulate (multipurpose MPAs), with different expectations among different stakeholder groups.

GOIS tables in PROTECT

As part of the PROTECT project, GOIS tables were devised for each of the three case studies. The GOIS tables for the case study on deep-water corals proved particularly useful, because most deepwater MPAs under the CFP were established only relatively recently and many more are currently planned under the EU Habitats Directive. The GOIS-table provides guidance on the type of data required to establish baselines prior to monitoring exercises.

Table 2 (and two others focussing on socio-economic and governance goals) was derived from the MPA-MEI guidebook[18](see Fig. 5) and this was used to help match indicators to the aims and objectives of the three case-study MPAs. This could in turn facilitate the mapping of hypothetical monitoring needs and for matching indicators to the aims and objectives of the MPAs concerned. Biophysical (natural) goals of MPAs are considered to fall into 5 distinct categories (table 2).
The three case-studies being considered under PROTECT fall within this overall framework

- one focuses on an MPA to protect/maintain seabirds [MPA-MEI Goal 3B],
- one focuses on an MPA to protect vulnerable deep sea habitats [MPA-MEI Goal 4C],
- and one focuses on an MPA to potentially increase/restore fishery yields in the Baltic [MPA-MEI Goal 1A].

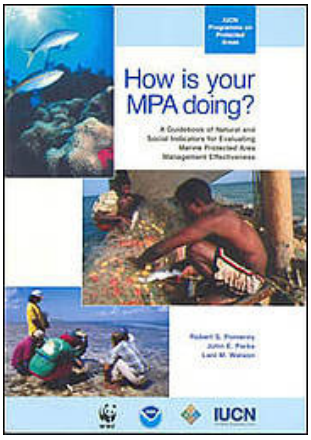

Figure 5. Source IUCN.org

[17] see review by SGMOS-07-03
[18] Pomeroy et al. 2004; see www.effectivempa.noaa.gov/guidebook/guidebook.html

Table 2. Biophysical goals and objectives of MPAs (redrawn from Pomeroy et al. 2004).

Goal	Objective	
Goal 1 Marine resources sustained or protected	1A	Populations of target species for extractive or non-extractive use restored to or maintained at desired reference points
	1B	Losses to biodiversity and ecosystem functioning and structure prevented
	1C	Populations of target species for extractive or non-extractive use protected from harvest sites and/or life history stages protected where they are vulnerable
	1D	Over-exploitation of living and/or non-living marine resources minimized, prevented or prohibited entirely
Goal 2 Biological diversity protected	2A	Resident ecosystems, communities, habitats, species & gene pools adequately represented and protected
	2B	Ecosystem functions maintained
	2C	Rare, localized or endemic species protected
	2D	Areas protected that are essential for life history phases of species
	2E	Unnatural threats and human impacts eliminated or minimized inside and/or outside the MPA
	2F	Risk from unmanageable disturbance adequately spread across the MPA
Goal 3 Individual species protected	3A	Focal species abundance increased or maintained
	3B	Habitat and ecosystem functions required for focal species' survival restored or maintained
	3C	Unnatural threats and human impacts eliminated/minimized inside and/or outside the MPA
	3D	Alien and invasive species and genotypes removed from area or prevented from becoming established
Goal 4 Habitat protected	4A	Habitat quality and/or quantity restored or maintained
	4B	Ecological processes essential to habitat existence protected
	4C	Unnatural threats and human impacts eliminated/minimized inside and/or outside the MPA
	4D	Alien and invasive species and genotypes removed or prevented from becoming established
Goal 5 Degraded areas restored	5A	Populations of native species restored
	5B	Ecosystem functions restored
	5C	Habitat quality and/or quantity restored or rehabilitated
	5D	Unnatural threats and human impacts eliminated or minimized inside and/or outside the MPA
	5E	Alien and invasive species and genotypes removed from area or prevented from becoming established

Throughout the PROTECT project attempts have been made to devise goals, objectives, indices and success criteria for each of the three case-study systems, resulting in a set of criteria against which modelled MPAs and real MPAs could be judged. It became apparent along the way that the developed indices and corresponding targets were too vague and needed further clarification. Indices for fish stock recovery, for example, were simply listed as 'surveys' or 'assessments', and not the specific numerical time-series (such as 'spawning-stock-biomass') or the target (B_{pa}) which must be achieved. Hence further effort was expended in order to acheive the precision that makes goals, objectives, indices and success criteria useful.

In each case existing MPAs were already in place on which to base the tables (the Firth of Forth sandeel closure, seamount closures in the NE Atlantic, cod closures in the Baltic), however in no 'real' case were objectives and goals clearly defined in policies and/or legislation, and thus most of the detail had to be devised by the scientists involved.

To read examples of goals, objectives, indicators and success criteria developed for each case study, please see the specific case study section below and/or the attached Annex I.

Multi-sector engagement

The consideration of MPAs for fisheries management and for biodiversity conservation is generally a great challenge. According to Jennings (2009)[19] the selected management objectives determine whether marine environmental management will be dubbed "fisheries management" or "conservation". Historically, the boundaries between fisheries management and conservation were clearer than today, since fisheries management objectives focused almost exclusively on the role of fisheries in providing food, income and employment. With the advent of the ecosystem approach to fisheries (EAF), a wider range of fisheries management objectives were introduced, many of which were comparable with those adopted by conservation organisations; often because they were based on common policy drivers such as international commitments[20].

Diverse legislation governs MPA designation. Jennings (2009)[21] argues that designation would be simplified by pre-arranged and pre-negotiated agreements among all relevant authorities, elaborating that agreements could specify how to make trade-offs among objectives, interpret scientific advice, ensure effective engagement among authorities and stakeholders, deal with appeals and support progressive improvement. The jurisdiction and competence of fisheries management authorities means they are well placed to contribute to the design, designation and enforcement of MPAs[22].

In an attempt to set the scene for an EU process regarding pre-arranged/negotiated MPAs, a guidance document *Introducing fisheries measures for marine Natura 2000 sites: A consistent approach to requests for fisheries management measures under the Common Fisheries Policy* was in June 2008 drawn up by the EU Commission services (DG Mare and DG Environment). The document aims at facilitating the tasks of the Member State authorities and stakeholders when preparing and requesting fisheries management measures under the Common Fisheries Policy in relation to Natura 2000 sites. The document is intended to be regularly updated but is not legally binding.

Overlapping objectives establish favourable platforms for integrated management of the marine environment. However, it is also a scientific challenge, because the scientific communities involved in fisheries and in biodiversity conservation are quite distinct, working with different tools and methods to support different sectors. More joint, integrated work between these two fields of marine science may prove quite helpful and mutually beneficial and make the process of implementing MPAs more efficient.

[19] Jennings 2009
[20] Jennings 2009
[21] Jennings 2009
[22] Jennings 2009

Monitoring of MPAs

Monitoring is an integral component of marine area management; it provides the data required to evaluate changes in marine ecosystems as a result of the implementation process. The management criteria and monitoring systems put in place for an MPA are case specific, however, analysis of the effects of any MPA is likely to require certain fundamental knowledge of fisheries and ecosystems, independent of the specific case.

Generic monitoring approaches

Before vs. after

There are two approaches to analysing the impacts of MPAs on living resources[23]. In the first approach, changes within the MPA are evaluated temporally such that conditions are documented before the implementation and then compared to conditions following implementation (before vs. after). A limitation of this approach is that environmental variation in the years before and after the establishment of the MPA may obscure trends resulting from protection. For instance, variable recruitment in a fishery due to a change in oceanic conditions may affect, either positively or negatively, the apparent recovery of a stock after closure of an area. Attempts to detect explained and predicted effects of MPAs should be based on statistical tests that distinguish between natural variability and the influence of management[24].

Inside vs. outside

In the second approach, changes in the MPA are evaluated spatially such that conditions inside the MPA are compared to conditions in a similar 'reference' area outside (inside vs. outside). The limitation of this approach is that MPAs often encompass unique habitats and are set up because the area is distinctive or 'special' in the first place; hence, there are few situations in which comparison areas accurately represent the features found within the MPA. A further alternative would be to use a 'spectrum' of sites with different (quantified) levels of fishing pressure, to look for trends and correlations rather than a simple 'pairwise' comparison (inside vs. outside).

Worst-case scenario

The worst-case scenario occurs when only one MPA has been established long before an evaluation program was initiated and only post-establishment monitoring takes place (**Table 1**). Such circumstances are not altogether rare in European seas and in most cases the MPA is compared to some 'non-MPA' reference site or sites, although in such cases, it is never clear whether observed differences (MPA vs. non-MPA) are caused by the MPA or if these differences already existed before the MPA was established[25].

BACI: Before-After –Control-Impact

If instead, sampling can be initiated at the proposed MPA site(s) and non-MPA "control" site(s) prior to MPA establishment, then inferences about MPA effects become much stronger (Table 3 next page). Two general philosophies are commonly used when 'Before' and 'After' data are available. The Impact vs Reference Site (IVRS) approach treats MPAs and controls as formal randomized experimental replicates, and hence makes inferences about 'MPA' effects in general. IVRS requires that sites are truly independent and that they are assigned randomly to either MPAs or control treatments[26]. In practice, often these conditions do not hold and so the alternative Before-After-Control-Impact (BACI) sampling design is used.

[23] Houde et al. 2001
[24] Allison et al., 1998
[25] Syms & Carr 2002
[26] Stewart-Oaten and Bence 2001

BACI requires that reference sites be as similar to MPAs as possible, and is based on the model that temporal differences in sites are attributable to MPA effects. Consequently, BACI approaches make site-specific statements of MPA effectiveness. BACI designs have been used frequently in the literature, in particular to test for single coastal environmental impacts.

Table 3. Sampling designs that have been used to measure MPA effectiveness[27].

Design	**Frequency of application**	**Comments**
Impact Only: Samples taken only within MPA, after MPA establishment	Uncommon	Very poor inferential ability.
Control-Impact: Samples taken both within MPA and 'control' areas, after MPA establishment	Very common	Poor inferential ability confounds spatial patterns with MPA effects.
Before-After: Samples taken before and after MPA establishment, only within MPA	Uncommon	Poor inferential ability confounds natural temporal patterns/variability with MPA effects.
Before-After-Control-Impact (BACI): Samples taken before and after MPA establishment, within MPA and 'control' site(s).	Uncommon	If temporally replicated, strong design to make statements of effects of particular MPA's. Weaker ability to make global statements of effectiveness. Conditional on MPA and non-MPA sites having correlated dynamics.
Impact vs Reference sites: Samples taken before and after MPA establishment, within multiple MPA and 'control' site(s).	Uncommon	If replicated, strong design to make global statements of effectiveness. Weak design to evaluate particular MPAs. Conditional on MPA and non-MPA sites having uncorrelated dynamics, and MPA 'treatment' being allocated randomly to sites.

Monitoring in PROTECT

The PROTECT project has focussed heavily on systematic evaluations of MPAs, which in turn has required modelled or real observations of outcomes of a given MPA management measure, i.e. some form of monitoring. Monitoring is expensive and time-consuming, and therefore monitoring must be site specific and directed toward the meaurement of formulated goals, objectives and corresponding indicators and success criteria of a given MPA. Monitoring is also linked functionally with indicators, as many of the indicators of the efficiency of an MPA in attaining management objectives rely on statistical assessments (statistical models) and/or dynamic models. Ultimately, modelling results (in terms of indicators built from monitoring data) can therefore in turn help to improve monitoring protocols.

Three case studies of different MPA designs in temperate waters have been investigated within PROTECT. The focal species, objectives and other characteristics of each case study require different monitoring strategies to evaluate MPA effectiveness (Table 1). Specifically, there are differences in the required distribution of monitoring efforts within the MPA and adjacent areas (see Fig. 6). In the Central Baltic Sea, where spawning aggregations and/or nursery areas of cod will be protected, effectiveness will be measurable by the stock structure of cod and the development of the ecosystem in the entire area and less within the protected zone. The monitoring program thus needs to cover the core distribution area of the population. In contrast to this, the success of a marine reserve for deep-water corals will be mainly measurable within the reserve and hardly in surrounding areas, where fishing activities will be allowed.

[27] From Syms & Carr 2002

Each species has a different diffusion potential with respect to a closure. A spill-over from protected deep-water coral habitats can only happen by larval stages which means that fishing effort in respect to the focal species need not to be monitored in adjacent areas of the MPA. For mobile fish species other monitoring strategies need to be developed. Adult sandeels are resident to certain banks and a spillover is thus expected in the immediate vicinity to the MPA, which makes a high spatial resolution of fishery-dependent measures necessary. Cod is a highly mobile fish species and, in the scenario of protecting spawning aggregations, the fishing activities along the boundaries of the seasonal closure can be expected to increase considerably, which means that the surveillance of fishing effort would be one very important aspect in the development of monitoring strategies.

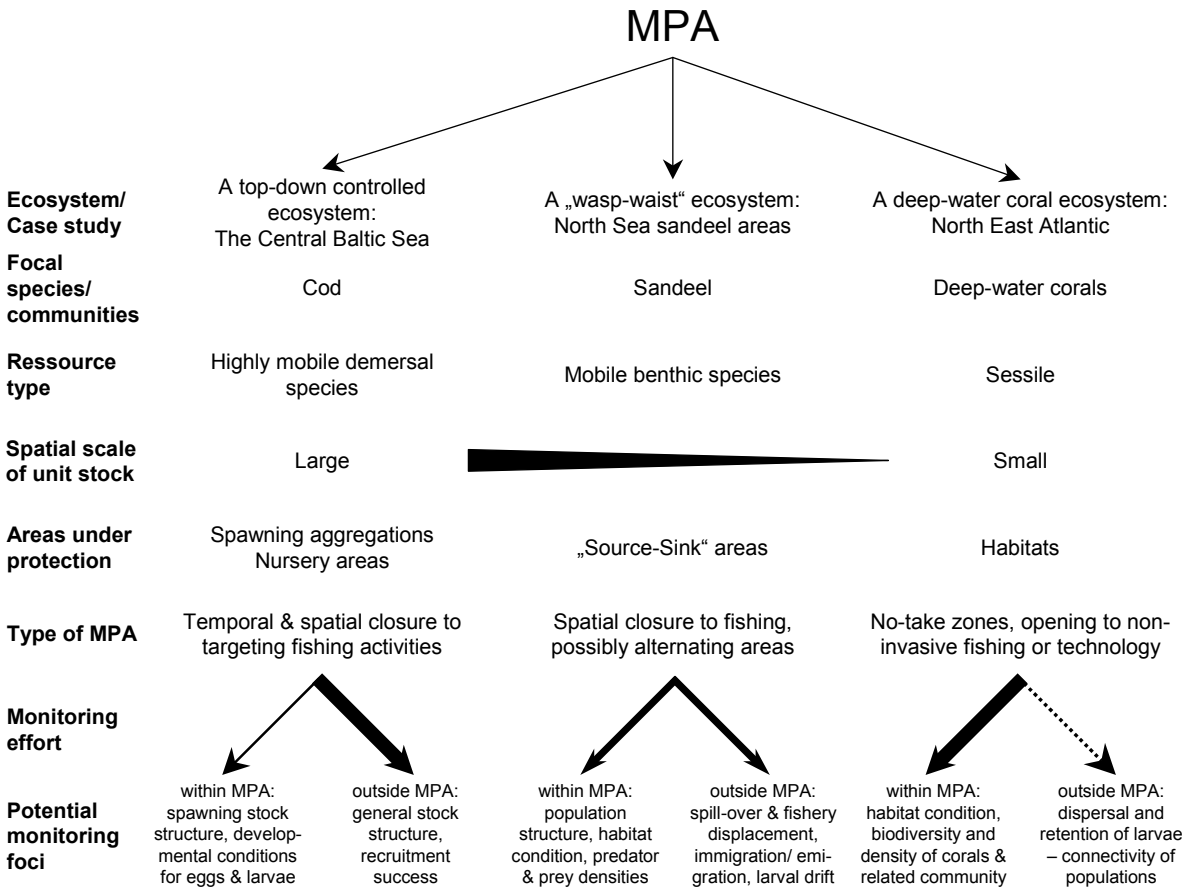

Figure 6: Monitoring effort necessary within the MPA and in adjacent waters, considering three different case studies of the EU-project PROTECT as an example.

The Baltic case study targeted a highly mobile piscivorous top-predator in a large area. In terms of realised habitat the North Sea and coral case studies dealt with less mobile organisms. Additionally these case studies differ in important habitat characteristics, typical to shelf and deep sea areas such as depth, productivity and human exploitation. Finally fish species such as cod and sandeel are directly affected by exploitation, while the destructive fisheries effect on corals is an indirect effect of the fisheries.

Due to the fundamentally different nature of the 3 case studies, the monitoring schemes must be differ correspondingly.

Challenges and obstacles in PROTECT MPA monitoring

The Baltic case study found it difficult to apply a spatially-resolved monitoring for potentially detecting positive effects of fishing closures inside the MPA compared to outside. The mobile nature of Baltic cod makes the detection of such an effect unlikely. As a conclusion, it was decided to develop and ecosystem-based monitoring scheme as well monitoring lower trophic levels which are connected to the cod stock via trophic interactions and feedback-loops[28].

In contrast to the Baltic case, the North Sea case study focused on a benthic-pelagic forage fish resident as juvenile and adult on well-defined sandbank habitats within the North Sea basin. The effects of the availability on the ecosystem of this forage fish were monitored by breeding success of local seabird populations[29]. The Firth of Forth 'sandeel box', introduced under the EU Common Fisheries Policy (Regulation 850/98), can be considered to have employed a relatively unique sampling design whereby sandeel populations and breeding success of dependent seabirds were closely monitored 'before' an industrial fishery was instigated, 'during' the 8 year operation of the fishery, and 'after' the implementation of a fishing ban (establishment of an MPA) in the year 2000[30].

A further important difficulty for monitoring the success of an MPA is to disentangle the effect of the closure and the environment. This is especially true for the highly variable habitats of the Baltic and North Sea. Baltic cod and North Sea sandeel are strongly dependent on the physical/chemical and biotic environment. This is accounted for in these case studies by the extensive use of coupled biophysical models and habitat maps. In terms of monitoring, the importance of the variable environment was incorporated in the Baltic case by a special monitoring programme for the environment.

A further difference experienced within the different PROTECT case studies is the level of data availability and monitoring programmes already in place. While data availability from biophysical monitoring is generally high in the Baltic and North Sea, monitoring and research activities have to be further developed in the coral areas. A weak point in all case studies is the relative lack of monitoring activities for socio-economic data. As the socio-economic side of the efficacy of an MPA is of crucial importance for the acceptance of a closure and hence the compliance of the fishery, these kind of monitoring activities need to be further developed. Monitoring compliance is not incorporated in the present monitoring strategies. It is in the future best conducted using VMS-data, depending on its legal availability.

The importance of high-resolution fisheries data, e.g. from logbooks and VMS for the evaluation of MPAs and other management measures

Evaluating the effects of MPAs is of course very difficult without data on the activity of the fishery. All case studies in PROTECT have experienced the value of good fisheries data, and the difficulty in analysing the consequences of different MPA options having only fisheries data of poor quality or no relevant fisheries data at all. Therefore, the issue of access to high-resolution fishery data of good quality is discussed in some detail in the present section.

[28] Möllmann et al. 2008b
[29] Daunt et al. 2008; Frederiksen et al. 2008
[30] Frederiksen et al. 2008

Logbooks

EU fishing vessels larger than 10-metres in length are currently required to maintain an up-to-date EU fishing logbook. The data entered are the dates of fishing trips, the size of the catch by species, the gear and number of gears used in fishing, the trawling time in hours and the ICES statistical rectangle. Although the information entered into logbooks may appear substantial, it is difficult to utilise this fisheries information in relation to MPAs and other area-based measures due to the low spatial resolution of the data. The ICES statistical rectangles that fishermen must enter into logbooks are approximately 30 x 30 nautical miles in size, i.e. very low spatial resolution.

Reports such as the recent special report from the European Body and Institutions Court of Auditors raise serious questions regarding the quality of logbook data[31]. Fisheries scientists have long requested that logbook data be entered at higher spatial resolutions, albeit with little success. Scientists, and in particular MPA scientists, have therefore looked to Vessel Monitoring Systems (VMS) to provide a high resolution overview of the distribution of fishing effort, i.e. information that is considered critical in area-based planning and management in the marine environment.

VMS

A Vessel Monitoring System (VMS) uses electronic satellite transmitters placed on fishing vessels to track vessel movements, providing information on a vessel's speed and course (see Fig.7). Monitoring authorities can use VMS to check a range of factors including whether the vessel operates in an area where some or all fishing activities are not allowed, such as in some MPAs. From 2005 all EU vessels above 15 m length are required to have VMS installed. Its primary function is to monitor and control fishing activities. Current EU regulations require that the fishing vessels transmit a signal every two hours. However, because the frequency is a legislative decision in the EU, the frequency can be altered. A number of factors bear on the effectiveness of the VMS.

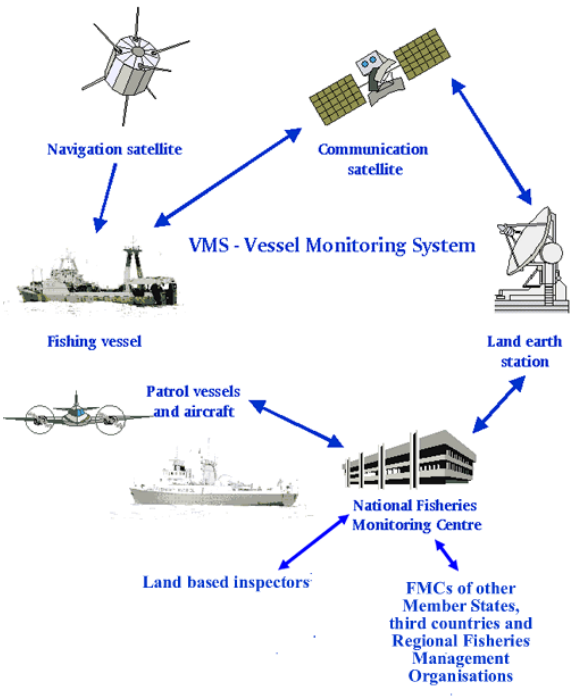

Figure 7. The principles for the VMS system.
Source: http://ec.europa.eu/

Shortcomings of VMS in relation to MPAs

The regulatory requirement to transmit VMS data every two hours may result in the failure by the FMC to detect an unauthorised vessel entering an MPA. A fishing vessel may, having first made a VMS transmission outside the MPA prior to entering then enter the MPA and fish for two hours exiting the MPA before his next transmission is made. Besides undertaking trawling activities within an MPA an unauthorised vessel may just enter to shoot or haul gillnets or long-lines. In some fisheries such as that for orange roughy the duration between shooting and hauling can be significantly less that two hours.

[31] EUCOA (2007) Notices From European Institutions and Bodies Court of Auditors SPECIAL REPORT No 7/2007 on the control, inspection and sanction systems relating to the rules on conservation of Community fisheries resources together with the Commission's replies *(pursuant to Article 248(4) second paragraph, EC)* (2007/C 317/01) [online] URL http://eca.europa.eu/portal/pls/portal/docs/1/673627.PDF Last accessed 17 Mar 2008

The fact that not all transponder units fitted to FV's operating in EU waters are tamper proof means that a skipper of an FV may switch his unit off claiming unit failure. Alternatively some FV's have been known to input an "offset" which transmits a false position suggesting that the FV may be in a different position to that where it actually is operating. Measures are now been taken to overcome this.

Some fishers, either not belonging to EU member states, or who have no agreement regarding the need to have such a unit fitted to their FV may enter the EFL of a member state and fish within EU waters including MPAs.

Measures to overcome the VMS shortcomings outlined above might include increasing the frequency of transmissions when operating near an MPA. This may require the creation of a buffer zone around the most protected portion of the MPA. This will require a regulatory amendment. In some countries VMS design is such that once a fishing vessel enters an MPA an e-mail is automatically transmitted to the fishing vessel and the coastguard informing each that the fishing vessel has just entered an area into which it is not authorised to enter. The introduction of vessel detection technology such as that envisaged with the Vessel Detection System (VDS) will go some way to overcoming some of the shortcomings identified with the interference with or failure to transmit VMS data.

VMS to monitor fisheries in relation to offshore nature protection MPAs

A growing number of MPAs are designated in offshore waters to achieve benefits for fish stocks or sensitive habitats and species. However, monitoring and enforcement of these offshore MPAs is often both infrequent and difficult, due to great distances from shore and a lack of ocean-going monitoring vessels. In such circumstances, VMS is the only feasible tool available to monitor compliance.

According to the PROTECT Baltic Sea case study, control of the Baltic Sea cod, herring and sprat fishery has suffered from considerable time delay (2–3 years) between acts of violation and their detection[32]. Harvests could thus ideally be monitored by VMS. VMS monitoring could also be used for verification of landings and fishing ground prior to an entry into a landing port. This type of online monitoring would exclude the time delay and hence, increase enforcement and rule compliance with an aim to reduce overexploitation of the stocks.

[32] Nielsen and Mathiesen, 2003

Use of VMS for non-surveillance purposes

Although VMS was not designed for scientific purposes it can nonetheless provide a wealth of geo-referenced information on fishing effort that can prove invaluable in MPA planning and management (even if the link with resulting catch is often difficult to establish). Among other things, VMS can be used to analyse the distribution of fishing activities in MPA planning or to monitor and analyse the spatial responses of fishing fleets to MPA establishment. However, to access these data for purposes other than the ones originally intended (monitoring, control, and surveillance), some countries require written permission from each individual fisher before the data are released for analysis. This problem was encountered in PROTECT, e.g. in connection with the analysis of the orange roughy fishery in the Coral Case Study.

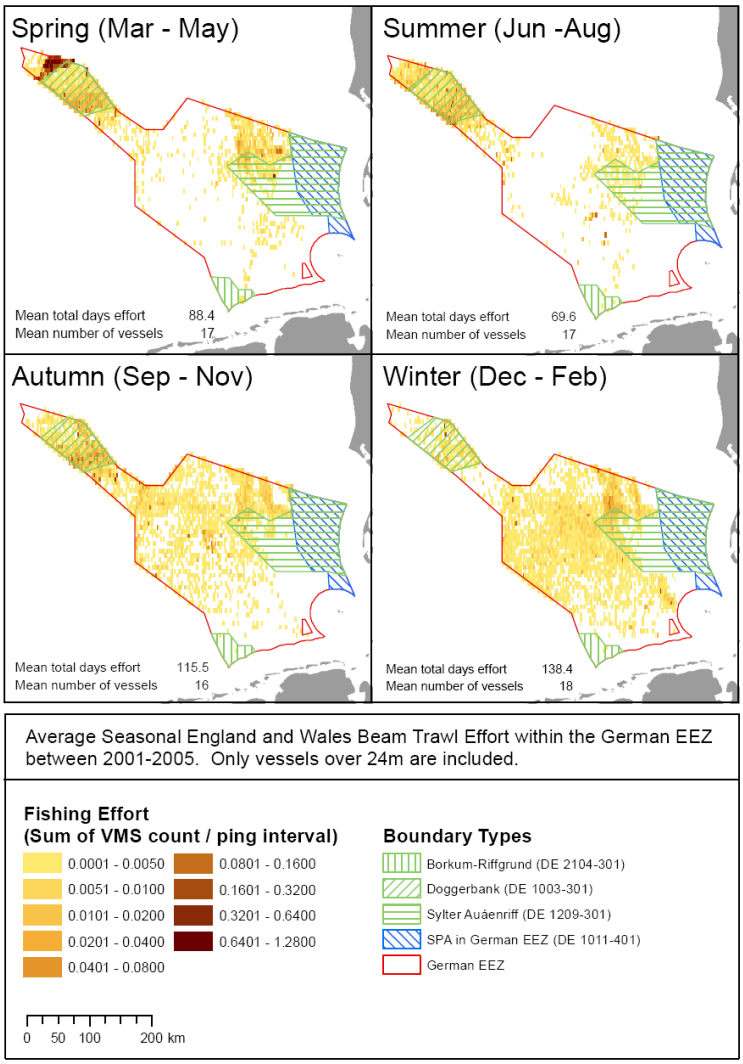

Figure 8. Average Seasonal England and Wales Beam Trawl Effort within the German EEZ between 2001-2005. Only vessels over 24m are included (data supplied by Cefas).

VMS data analyses are crucial for identifying potential conflict areas between fisheries and nature conservation objectives. For instance, VMS data have proven very useful in recent years as each country begins to designate offshore Natura 2000 areas (SACs). Several countries have proposed complimentary SACs to protect: sandbanks, reefs and hydrocarbon deep communities. Some of the largest are those surrounding the Dogger Bank in the central North Sea. Figure 8 shows fishing effort among English and Welsh vessels within the German EEZ. These analyses illustrate the level of potential conflict between British fishing interests and German efforts to protect marine ecosystems (proposed SACs). Similar analyses of VMS data have been conducted for proposed SACs in the UK and Netherlands sector of the North Sea.

VMS data has also proven useful to monitor the displacement of fishing effort away from areas that are closed to fishing. Dinmore et al.[33] showed that in the absence of corresponding effort reductions/controls, fishing vessels temporarily displaced from a closed area will impact fish populations and the marine environment elsewhere.

[33] Dinmore et al. 2003

A recent example of a temporary area closure that resulted in displaced fishing effort and negative effects on neighbouring marine areas are the North Sea "cod box" of 2001 (also reviewed in PROTECT WP2 Report). Figure 9 shows patterns of trawling effort by 75-day periods in the 2 years relative to the closure in 2001. Effort was clearly displaced to the west of the cod box during closure and moved in again afterwards. The authors[34] argue that macrofauna would require several years to recover from the impacts of effort displaced to previously unfished areas. In rarely fished sites, the benthic fauna is more likely to be dominated by organisms suited to a regime of low anthropogenic disturbance, such as fragile free-living large-bodied species or biogenic habitat forming species which are slow growing and vulnerable to heavy gear. If new fishing grounds were explored, these fragile species would suffer high mortality rates from the first trawling event.

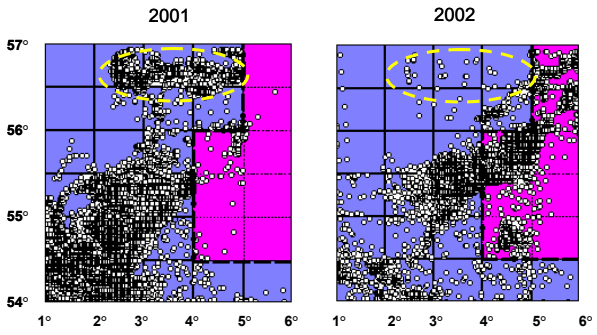

Figure 9. Frequency distribution of VMS records from beam trawlers during closure of the "North Sea cod box" (February 14th – April 28th) in 2001 and equivalent period in 2002 (from Dinmore et al. 2003, see also PROTECT WP2 Review).

In the PROTECT North Sea sandeel case study, general compliance of an area closed to sandeel fishing was monitored by VMS. An increased VMS signal transmission frequency was required for those vessels contracted in the Firth of Forth monitoring fleet, but this was in order to, for research purposes, document the exact localisation of fishing effort on the relatively small sandeel fishing grounds (on one of the sandbank habitats only a proportion was closed).

VMS data might thus in general be used more effectively if the frequency of signals was increased to several signals per hour. Fishing tracks of individual vessels could be reconstructed, allowing area swept by trawls to be calculated at any scale from the total distance of trawl track crossing a specified area in a specified time period. To better understand the effects of MPAs and other area-based management measures, more detailed spatial information on fishing and the impacts of fisheries needs to be collected in cooperation with the national research institutions, fisheries organizations, and the fishers.

MPA design in relation to enforcement

From the standpoint of compliance monitoring, the lack of a standard definition of the key characteristics of the MPA and the area to be protected poses a challenge. Harmonising these characteristics between disparate MPAs, would allow for a more standardised control methodology. Considerations should include the size, the area and the shape of the MPA. In the case where a number of small MPAs are located closely together these could be merged into a larger buffer area within which increased frequency of transmission of VMS could potentially be introduced, i.e. in order to increase resolution of costly satellite transmission and corresponding data without affecting more sea area than necessary. Although modern satellite technology has made it less relevant, the use of straight lines can be helpful to both the fisher and the enforcer. Consideration should also be given to addressing the minimum allowed distance between two MPAs.

From an enforcement perspective No Take Zones (NTZ) may be easier and cheaper to enforce than zones that limit the types of activities. In the case of the NTZ the enforcer can more easily see unauthorised activity because any fishing vessel entering an NTZ may be restricted to certain criteria such as a minimum

[34] Bergman and van Santbrink 2000

speed and also may be required to stow fishing gear in a particular manner, making it impossible to carry out any unauthorised activity within the zone. In cases where certain fishing practices are permitted, unauthorised fishers may also attempt to enter the restricted area in hope that their activity will not be easily distinguishable from that of the authorised fishers. Other related considerations touch upon equity and discrimination, i.e. in cases where large pelagic vessels of several thousand tonnes are permitted to fish within an MPA while smaller bottom trawlers of just a few hundred tonnes are not.

PROTECT Modelling to evaluate MPA effects

Models in science are physical, mathematical, or logical representations of a system of entities, phenomena, or processes, i.e. they provide a simplified, abstract view of complex realities. Models are typically used when it is either impossible or impractical to create experimental conditions in which scientists can directly measure outcomes. Nowhere is this more applicable than in marine science, which deals with an environment that is characterised by a myriad processes which in turn are influenced by other processes. In addition, activities that are based on the extraction of marine resources (e.g. fisheries) are dependent on both environmental, political, social and economic factors that are equally difficult to measure.

As a result, modelling has formed an important part of the work conducted in PROTECT, partly in terms of development of generic models, but in particular using them to generate analyses and predictions in the different case studies. The case-specific results are described below in the respective case study sections. Here we decscribe the more generic conclusions from the modelling work in PROTECT. For a more in-depth description, see Pelletier et al (2009)[35]

Objectives of the modelling activities within PROTECT

The objectives of PROTECT WP5 were to develop a suite of modelling tools for assessing the performance of planned and implemented MPAs, in the context of EU fisheries and environmental priorities. MPA modelling in this context refers to quantitative modelling tools that enable one to assess, directly or indirectly, the performance of planned or existing MPAs. Tools used ranged from ecosystem indicators and community metrics to stock-specific spatial models, multi-species and multi-fleet models and bio- and socio-economic models.

Modelling tools for MPA assessment are either classified as *empirical approaches* or *dynamic modelling*. *Empirical approaches* are fully based on field data, in general not describing the underlying processes in the studied socio-ecosystem, while *dynamic modelling* depicts the evolution of populations, communities and fisheries and aims at quantifying the consequences of MPAs on these. *Empirical approaches* should provide a quantitative assessment of the impact of existing MPAs on the ecosystem and resources. They are also needed for devising and assessing sampling designs for monitoring programmes. *Dynamic models* enable exploring the consequences of MPA designs and other management policies by evaluation of "what if"- scenarios.

Some acronyms used in the modelling section:
BEMCOM: BioEconomic Model to evaluate the Consequences of Marine protected areas
ISIS-Fish*:* a spatial and seasonal simulation model describing the dynamics of resources, exploitation and management to model the impact of a range of management measures upon fisheries dynamics.
TEMAS: (technical management measures) is a fleet-based bio-economic software for evaluating management strategies accounting for technical measures and fleet behaviour.
HABFISH: a habitat-fishery model
IBM: Individual Based Model
SPAM: Sandeel Population Analysis Model
SLAM: Sandeel Larval Advection Model

Modelling contributions within PROTECT

The majority of PROTECT contributions correspond to the aforementioned *dynamic modelling*. First, a number of mathematical models relying on conventional fisheries equations (ISIS-Fish, BEMCOM, TEMAS, Production Function Approach) or resource modelling equations (HABFISH) were developed or adapted. Second, individual-based models relying on decision rules were developed (North Sea sandeel

[35] Pelletier et al (PROTECT WP 5 report)

model) or used (North Sea plaice model). Some models may be considered as intermediates between *empirical approaches* and *dynamic modelling* in that they use both methods in conjunction to investigate MPA effects. With respect to purely empirical approaches, there are two main contributions: a) the analysis of bird breeding success to evaluate the effect of the sandeel closed areas in the North Sea upon sea birds via trophic interactions; b) the choice modelling applied to deep-sea coral reefs to determine the economic non-use benefits derived from the implementation of protection to this fragile ecosystem (as determined by public preferences). A number of other models were produced that do not directly assess the consequences of MPAs, but that provide parameter estimates or other input information for assessment models. These models focused on processes that are poorly known and quantified.

Empirical evaluation assessments of MPA effects

In the project, there were relatively few examples of empirical approaches to the assessment of MPA effects. One example is an empirical assessment of ecosystem effects of the sandeel closures on seabird breeding success. The analysis relied on a large data set that fits in a so-called BACI (Before After Control Impact) design, thereby allowing for sound assessment of the closure effects controlling for environmental variability. This work illustrates the possibility of straightforward empirical assessments when data sets are obtained from an appropriate sampling design. The main reason as to why few empirical assessments were carried out during the project lies in the fact that most case studies are either fisheries management closures with many different regulations beside the closure being implemented simultaneously (Baltic Sea cod and North Sea plaice) or no-take zones that are not yet implemented (North Sea deep-water corals). In the latter case, it is indispensable to carry out a baseline assessment of deep-water corals and surrounding fisheries before implementation of the no-take zone, and preferably with more than one year of survey. This would provide the “Before” data of a sound BACI assessment protocol. For the Baltic cod and North Sea sandeel case studies, as the closures are aimed at restoring resources, empirical assessment may provide a local diagnostic but cannot encompass changes at the fisheries scale. At least not from the kind of monitoring designs generally used for MPA, unless there is long time-series of data. Even in the latter case, if the protocol is not tailored for MPA assessment, it is difficult to interpret spatial-temporal variations of abundances in relation to fisheries closures. In such situations, dynamic modelling is recommended.

Dynamic models for assessing MPA effects

A number of tools were developed or adapted and used during the project: single-species dynamic models for assessing the effects of MPAs on a resource, multi-fleet, multi-species bioeconomic dynamic models for assessing the effects of MPAs on fisheries, and individual-based models for assessing the effects of MPAs on resources and related populations.

The modelling has some weaknesses, however, as the biological model is simplified and the model appears sensitive to the spatial and temporal scales chosen. The value of the model lies in the joint consideration of environmental variables, larval dispersal and linkage between spawning areas and recruitment areas, and fishing pressure (under the form of a single fishing mortality coefficient).

With respect to *multi-fleet, multi-species models*, three models (TEMAS, ISIS-Fish and BEMCOM) were used for the Baltic Sea cod case study and one was used in addition for the North Sea sandeel case study (BEMCOM). An ISIS-Fish application is under development for the deep-water coral case study. The three models were developed with a generic perspective. TEMAS focuses on the fleet dynamics and on technical measures in general. ISIS-Fish was designed for incorporating all kinds of fisheries management measures, with a particular emphasis on MPAs, integrating biological knowledge with a detailed exploitation model. Bioeconomic considerations were introduced in ISIS-Fish from version 3.0, but were not implemented in the Baltic cod application. BEMCOM (BioEconomic Model to evaluate the Consequences of Marine

protected areas) is a bioeconomic model, where the biological component is less developed and more emphasis is put on the economic component.

As for ISIS-Fish, the large amount of knowledge available for Eastern Baltic cod enabled construction of a detailed population dynamic model accounting for larval dispersal, growth and reproduction, where parameters could be estimated from real data. Population areas also could be delineated from existing data. For several key processes that depend on environmental conditions, specific parameters or population areas could be estimated from different environmental regimes. This was made possible through the available biological time series data and outputs from a coupled biophysical model for Eastern Baltic cod. The exploitation model is at a coarser scale than the biological model due to the coarser resolution of the fisheries data. The model was calibrated using time-series data.

As for BEMCOM, the model was parameterized based on the existing fisheries and economic data. BEMCOM relies on the assumption that the net present value of profits is optimised in the fishery (here over a time frame of 7 or 8 years). In the present version of the model, there is no entry-exit of vessels in the fishery. The outcomes of the models provide assessment at the fisheries scale and throughout a period of time. They provide a quantitative assessment of system dynamics for all scenarios and under all hypotheses to be explored. They may apply to existing MPAs or be used to test a range of MPA designs under study.

The third category of dynamic models is IBM or *Individual-Based Models*. They aim to model key aspects of individual fish in order to examine the emerging dynamics at the population or ecosystem level. One model deals with North Sea plaice, but could be adapted to other species, while the second one focuses on sandeel. The NS plaice model mimics the real distribution of fishing effort and fleet behaviour. The essential processes at the individual fish level lies in the representation of habitat-fish relationships (North Sea plaice) and predator-prey interactions (North Sea sandeel). Results were only provided for the NS plaice model, which was used to investigate MPA designs around the Plaice box. IBM models are interesting tools for spatially explicit issues such as MPAs, as they allow for explicit and intuitive representation of small-scale processes, which may nevertheless be important for ecosystem-scale outcomes.

Dynamic models of larval dispersal

Dynamic models describing (fish) larval dispersal as a function of environmental dynamics provide quantification of the correspondence and connectivity between spawning areas and nursery areas, information that has been largely lacking up to now in fisheries science. As an example, the sandeel model used a hydrodynamic model to trace the origin of recruits found in ichthyoplankton (fish eggs and larvae) surveys. However, the model does not capture enough processes to estimate whether this immigration could be sufficient to recolonise in case of stock collapse. In the Baltic Sea case, larval particles are released in a hydrodynamic model at known spawning areas during known spawning periods for years 1979 to 1904, thus encompassing a wide range of environmental conditions. The model thus serves to identify the correspondence/connectivity and quantify transfer rates between spawning areas and nursery areas. It is also used to analyse and identify the sites and habitats in which larvae and juvenile cod potentially dwell and where larvae and juveniles are able to settle, i.e. change from pelagic to demersal habitat. Furthermore, it gives an indication of the effect of climate variability on the final destination of juveniles in their nursery areas in terms of decadal variability. These models thus generated data that are needed for MPA evaluation.

Empirical approaches for collecting biological parameters

There are also statistical approaches that provide inputs for MPA assessment models. The analysis of spawning habitat quality described by long-term local averages of environmental variables was used to identify the most favourable spawning habitats for Baltic cod. Several biological parameters of the ISIS-Fish cod model were estimated through the analysis of field data. Finally, a disaggregated Multi-Species Virtual Population Analysis (MSVPA) with cod preying on all groups of sprat and herring, plus cannibalism within cod populations, produced estimates of predation mortality rates, which were subsequently used in the ISIS-Fish model of Baltic Sea cod.

The parameterisation of the sandeel SPAM model was based on scientific cruise collection of data regarding sandeel maturity and fecundity at size and age for estimation of local egg production. Larval and juvenile growth and initially also hatch period was estimated from ichthyoplankton and other surveys[36],[37]. A new method for back-calculating hatch period at different locations directly from fisheries samples was developed within the PROTECT project[38]. The essential estimation of sandeel habitat carrying capacity was estimated iteratively within the SPAM model by calibration of density dependent juvenile/adult growth and survival, egg production and larval drift at equilibrium local biomasses all under known fisheries exploitation.

Empirical approaches for fleet analysis

Statistical models for describing fleet and effort dynamics make it possible to characterise and quantify fleet response to economic conditions and management constraints. Although detailed catch-effort data are available for many fisheries in Europe, this information has rarely been used in modelling. Vessel Monitoring Systems (VMS) also provide an incredible wealth of georeferenced information on fishing effort, even if the link with resulting catch is often difficult to establish. One major problem with VMS data is that in many countries it is not available for research purposes. This was the case for the orange roughy fishery in the deep-water coral study.

Alternative tools were considered in the project that model the probability density of fishers' location choice either as a parametric function of factors, such as MPA regulation, vessel type and characteristics, gear, port, distance from port or catch or in a non-parametric way from data on fisher's location to come up with predictions of the same probability density. The outcomes could be used to parameterise fishers' behaviour in a dynamic model. This was envisaged but could not be done in the course of the project for both lack of data availability and lack of time.

Empirical assessment of public preferences

Statistical models were implemented to describe user preferences with respect to environmental protection measures for the deep-sea coral case study. This work is quite unique within PROTECT as it is related to estimating and modelling *non-use* benefits, in contrast to fisheries management issues prevailing in the other case studies. It is also original as there are few such empirical studies concerning marine biodiversity conservation. The technique selected was choice experiments, which was applied to the case study with the aim of measuring the preferences of the Irish general public for the protection of deep-sea cold-water corals using MPAs in the Irish Sea and the associated non-use values.

[36] Jensen 2001, Kaupinnen 2008
[37] Kaupinnen 2008
[38] Gauger 2008

Implementing such data collections is quite time- and resource consuming as the population of interest is very large (the general public). However, the Willingness To Pay (WTP) figures generated are relatively easy to understand by non-scientists and other users, they are sensitive to human activity, tightly linked in space and time to the activity in question, relatively easy to measure, and measurable for the area where they may be used. Further, the WTP figures generated facilitate the monitoring and incorporation of stakeholder group concerns and interests into the management process, the determination of the impacts of management decisions on stakeholders, and the demonstration of the value of the MPA to the public and decision-makers. They also permit the quantification of the economic value of those attributes of MPAs that don't have traditional market expression for incorporation in cost benefit analysis and, with further development, other socio-economic or bio-economic models of MPAs.

Theoretical economic modelling

Two economic models were developed wihin the coral case study. First, the production function approach was developed, attempting to quantify and analyse the linkages between deep-water *Lophelia* coral reefs seen as both a habitat for fish and an area for redfish exploitation. The basic assumption underlying this approach is that, if a coral ground serves as a habitat for a commercial fishery, then this *ecosystem service* benefits the fishery. The model uses landings and price, effort and cost data from a Norwegian resource, as data was not available in the Irish case study-related fisheries.

Second, the HABFISH model describes linkages between a non-renewable (coral with extremely slow growth) and a renewable resource (fish resource), and the effects of economic interactions between these two resources. This work is original in that so far most marine management has not taken non-renewable ocean resources into account. Because these models help to formalize and understand central questions and processes, they form the basis for future modelling utilizing real data e.g. on effort, fisheries impact on habitat and coral reef ecology.

Model requirements for MPA assessment

In order to be used for MPA assessment, the underlying model should be sufficiently detailed to capture the essence of fisheries dynamics with respect to the scenarios investigated, i.e. spatially-explicit models are definitely required for both population and exploitation components. MPA consequences in mixed fisheries cannot be understood if spatial issues are not taken into account. Seasonal features also often need to be explicitly modelled when relevant. In mixed fisheries, the exploitation model should contain the main components of fishing effort: gear, time spent fishing and fishers' behaviour at both the trip scale and year scale. Failing to account for these components restricts the range of policy options and associated fishers' responses that can be investigated. In addition, considering components of fishing effort is needed to account for costs that are specific to e.g. gears, fuel or crew salaries, and thus to build bio-economic models for policy evaluation. Regarding management modelling, as acknowledged in the literature, fishers' response should be modelled as well and the testing of combined policies should be made possible. The mixed fisheries models constructed within PROTECT comply with most of these requirements. The single-species sandeel population model was designed in a very particular setting of environmental conditions and exploitation, and is therefore fully appropriate for this type of short-lived resource exploited by a single-species fishery. However, assessing the ecosystem consequences of this fishery could benefit from ecosystem models including predation interactions.

Grounding the models in real data

Parameterisation of complex models is genrally quite difficult. One way to circumvent this issue to some extent is to ensure that parameters may be estimated independently of the model and in a consistent way with respect to model equations. This approach is not fully rigorous from a statistical standpoint, but it is pragmatic. This is particularly appropriate for exploitation-related parameters in mixed fisheries. In ISIS-Fish, the choice of the exploitation model was based on both realism and consistency with the kind of information available to estimate corresponding parameters in documented fisheries (e.g. commercial logbook data, fisher's interviews, observer data, etc). Likewise, the spatial resolution of ISIS-Fish may be adapted to the level of knowledge and data availability to facilitate integration of available information about the fishery. Further, the model may be calibrated to fit observed data.

Computer development and performance issues: think generic

The dynamic models above are all spatially explicit and thus complex. As most complex models, they require a lot of computer programming, and may face performance problems during simulations. Therefore, it seems wise to develop tools that are to some extent generic, so that human resources can be allocated to model construction and parameterization rather than computer programming and debugging. Development of the tool should rely on professional computer scientists as far as possible to prevent and solve performance issues.

Facilitating the use and reuse of modelling tools, and incorporating uncertainty in model output

In addition to desirable model features and performance, policy-screening tools should display qualities linked to their utilization. They should be flexible enough to incorporate improved knowledge about the fishery and changes in some model assumptions. In the same line of thought, facilities for obtaining results that are robust to uncertainties should be integrated into any tool, as numerous simulations are required for policy screening. Simulations should involve combinations of policy designs, parameter values, and model assumptions to encompass a plausible range of "states of nature" for the fishery, and thereby warrant that results are not too dependent on certain parameter values and assumptions. Accommodating all these features results in computer development that is costly in terms of both effort and time. Therefore, a tool should be applicable to several fisheries. For example, ISIS-Fish addresses each of these issues: i) a database is attached to the model, so that changes in fishery description are easy and several fisheries may be entered; ii) several components of the model may be interactively coded and saved, e.g. growth, reproduction, selectivity and fishers' response; iii) user interfaces for running sensitivity analyses and simulation designs have been developed; and iv) the software is freely available[39]. The user's manual and contextual help were improved within PROTECT to facilitate the use of ISIS-Fish.

Modelling and adaptive MPA management

Simulation models are indispensable tools to support adaptive management, in the case of implemented MPAs. In that it allows evaluating a range of scenarios against the present state of nature corresponding to the present MPA zoning under the current human pressures. The comparison of scenarios enables to adapt the regulation of uses to better reach the management objectives. Ideally, this should be possible with all the uses, but as the link between the pressure of a given use and the impact of this use upon the ecosystem is mostly quantified for fishing, this approach remains to develop for other uses.

The second kind of modelling that can support adaptive management relates to the quantitative assessment of MPA effects from monitoring data. In this case, modelling consists of statistical modelling.

[39] http/www.ifremer.fr/ISIS-Fish ; http://isis-fish.labs.libre-entreprise.org/

Once the link is established between the diagnostic resulting from the assessment and the management actions to undertake, such assessments may be used to assist decision process regarding the adaptation of management.

Data needs and priorities for more efficient MPA evaluations

Implementing modelling tools inevitably brings back the question of data collection. At this point it should be underlined that the objectives of PROTECT, made explicit in the concrete management-related questions to be addressed in each case study, led the group to look at data that are not routinely used for stock assessment and fisheries studies, but that are invaluable when it comes to MPA assessment as they provide information on key processes affecting MPA performance. Based on the modelling exercises carried out in PROTECT, the following priority areas for data collection were identified:

- Data on young stages: larval dispersal, recruitment processes, use of hydrodynamic modelling, studies of habitat-fish relationships: Necessary for delineating critical habitats, population areas, and linkages between spawning areas and nursery areas;
- Data on population connectivity, fish movements: Necessary to characterise and quantify exchange rates between population areas;
- Vessel Monitoring System data, fishers interviews, geo-referenced logbook data: Necessary for characterizing effort distribution and dynamics, particularly in its spatial component;
- Information on the impact of fisheries on benthic habitats. In the deep-water coral case study, the impact assessment was limited by the lack of knowledge on the impact of fisheries on coral reefs.
- Information on other uses of marine ecosystems that may interfere with fisheries: Necessary as there are often conflicting sea uses in and around MPAs, potentially influencing the MPA effects. The development of an infrastructure for sharing spatial environmental data through the EU INSPIRE directive will advance progress towards an integrated marine spatial planning.
- Detailed information about fishermen's cost structures in order to undertake more detailed bioeconomic modelling, and collection of information related to performing socioeconomic valuations through modelling.

Challenges for the future in MPA modelling

Improvement in statistical experimental design

For the empirical assessments of MPA effects, improvements in statistical experimental design are highly needed. Designs involving data before and after MPA establishment, within and outside the MPA (BACI designs) and with a sufficient number of replicates are still insufficiently developed. There are also issues pertaining to MPA design and monitoring. For instance, MPAs are increasingly envisaged under the form of networks, which implies both local and regional scaling for sampling designs.

Taking habitat variability into account in experimental design

Habitat patchiness is a crucial source of spatial variability for fish communities[40]. Ignoring habitat when assessing MPA effects results in increased residual variability and lower statistical power. Sampling designs should account for habitat, which should be monitored at the same time as fish communities[41],[42].

[40] Sale 1998
[41] Stewart-Oaten and Bence 2001
[42] García-Charton et al. 2000

Adapting an ecosystem approach to evaluate MPA effects
Indeed, effects are mostly evaluated for a single species or species group and for a single variable, e.g. density or biomass, at a time. Consequently, an overall diagnostic about MPA effects cannot be established.

Dynamic modelling
Here it is important to develop models that are realistic enough but do not have too many parameters, and which are calibrated from real data. Models are needed that make explicit the spatial dynamics of population and exploitation at the scale of MPA designs, including the seasonal scale when relevant (e.g. for temporary restrictions on fishing). Models should account for mixed fisheries and for fishers' response to MPAs. They should allow for thorough investigations of MPA designs including permanent versus temporary MPAs, partial restrictions of fishing activities, and reserve networks. They should also provide for other management measures, as MPAs are not the only management tool used in a given fishery.

Data for model calibration
In order to be able to calibrate models against real data, appropriate information is needed at the scale of the ecosystem and fisheries. Knowing the spatial dynamics of different developmental stages of populations, including early stages, is necessary, although often poorly known. The need for better data on the spatial dynamics of exploitation should also be emphasized. Conventional fisheries statistics provide information with good spatial and temporal coverage, although their spatial resolution may be limited[43]. High-resolution spatial data on exploitation can be obtained through vessel monitoring systems[44] and fishers' interviews. In any case, the model should be used in order to account for uncertainties, whether through simulation designs[45] or other techniques, e.g. risk analysis. These modelling issues underpin the construction of model-based indicators, as reliable model outputs require models that are grounded in real data.

Economic and social models
Regarding economic and social effects of MPAs on fishing and other human activities, previous work reviewing field analyses of economic and social effects of MPA and bio-economic models[46],[47] have shown that most dynamic models considered focused on fisheries issues: quantification of effects of MPA implementation on catch, revenues and biomass. Most models have been theoretical, pointing at the lack of empirical field data that may contribute to the parameterisation of dynamic models and to empirical assessment.

[43] Verdoit et al. 2003
[44] Murawski et al. 2005
[45] e.g. Drouineau et al. 2006
[46] Pelletier and Mahévas 2005
[47] Pelletier et al. 2005

PROTECT case study studies and their results

The Baltic Case Study

Brief description of the ecological and geographical setting

The upper trophic levels in the Central Baltic are dominated by cod (*Gadus morhua*) as the top predator and sprat (*Sprattus sprattus*) and herring (*Clupea harengus*) as its most important prey. A fragile and highly dynamic balance exists between these species and environmental conditions. Biological interactions and fisheries have recently led to a sprat-dominated system, i.e. with cod populations at a historically low level and sprat populations at a high level. The decline of the Baltic cod population in the recent two decades has been caused by a combination of high fishing pressure and environmentally driven recruitment failure[48],[49].

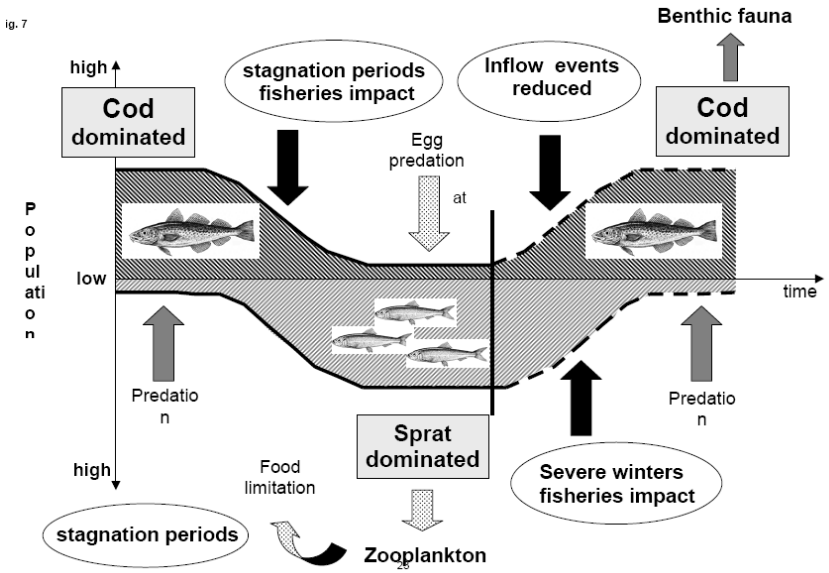

Figure 10. Regime shift from a cod to a sprat dominated system (Köster et al. 2003)

Decreased predation pressure by the cod stock, in combination with high reproductive success and relatively low fishing mortalities, resulted in the second half of the 1990s in a drastically enlarged population of sprat, a species that in turn feeds on the eggs of cod. These two developments are considered a "regime shift" in the upper trophic levels, from a cod-dominated to a sprat-dominated system[50] (see Fig. 10).

One of the most significant human activities occurring in the Baltic Sea is commercial fishing for especially Baltic cod (*Gadus morhua*), as well as herring (*Clupea harengus*), sprat (*Sprattus sprattus*) and salmon (*Salmo salar L.*). Due to high fishing pressure and unfavourable environmental conditions, the size of the cod population, however, is at an historical low level and has in recent years been considered outside "*biologically safe limits*" by the International Council for the Exploration of the Sea (ICES 2007), a threshold where the sustainability of the stock can no longer be ensured. However, despite targeted industrial fishery on sprat, the sprat stock in the Central Baltic Sea is still on a very high level.

Photo: T.K. Sørensen

In addition, as a result of adverse environmental conditions in the more eastern basins (e.g. Gdansk Deep and Gotland Basin), the Bornholm Basin

[48] MacKenzie et al. 2000

[49] Köster et al. 2003

[50] Köster et al. 2003

(ICES Subdivision 25) to the east of Bornholm has been the only major, active spawning ground where the Baltic cod is able to reproduce successfully[51].
The poor status of the cod population suggests that, in addition to the detrimental effects caused by environmental conditions, the present fisheries management regime is inefficient in facilitating stock recovery. A complete collapse of the Baltic cod stock would have considerable implications not only for the ecological balance of the Baltic Sea but also the livelihoods of those dependent on cod fishing. Thus, there is an urgent need for more effective management tools, where efficient MPAs may have an important role to play.

Baltic cod use separate locations and habitats for spawning, larval development, juvenile and adult feeding[52],[53],[54] (Fig. 11). Such a complex life history requires successful and intact temporal and spatial coherence between these locations to integrate the whole life cycle and produce abundant generations, as a consequence posing a great challenge to the design, implementation and management of MPAs for cod conservation in the Baltic Sea.

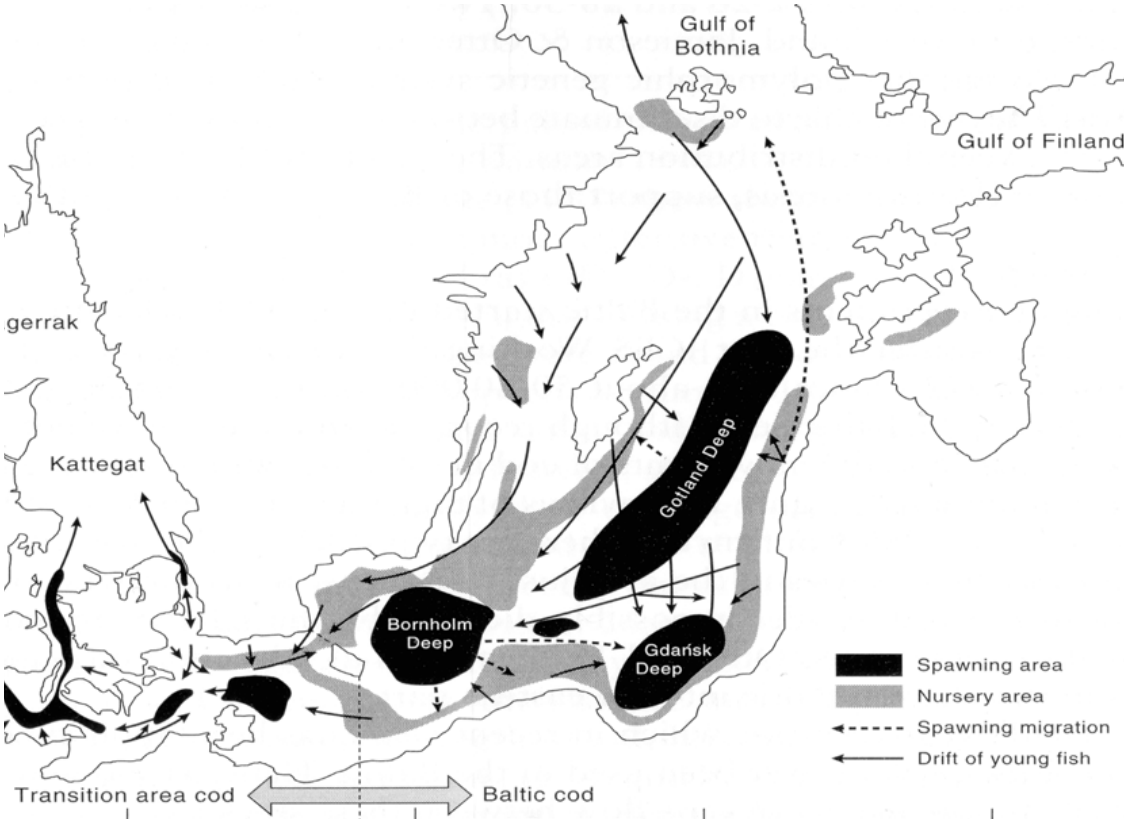

Figure 11. Distribution of spawning and nursery areas of cod in the Baltic Sea (redrawn after Bagge et al.[55]). At present the Bornholm Basin (to the east of Bornholm), as a result of unfavourable environmental conditions, is the only, major, active cod spawing area in the Baltic.

[51] Hinrichsen et al. 2007
[52] Hinrichsen et al. 2007
[53] Hinrichsen et al. 2009
[54] Köster et al. 2005
[55] Bagge et al. 1994

Recent cod fisheries closures in the Baltic Sea

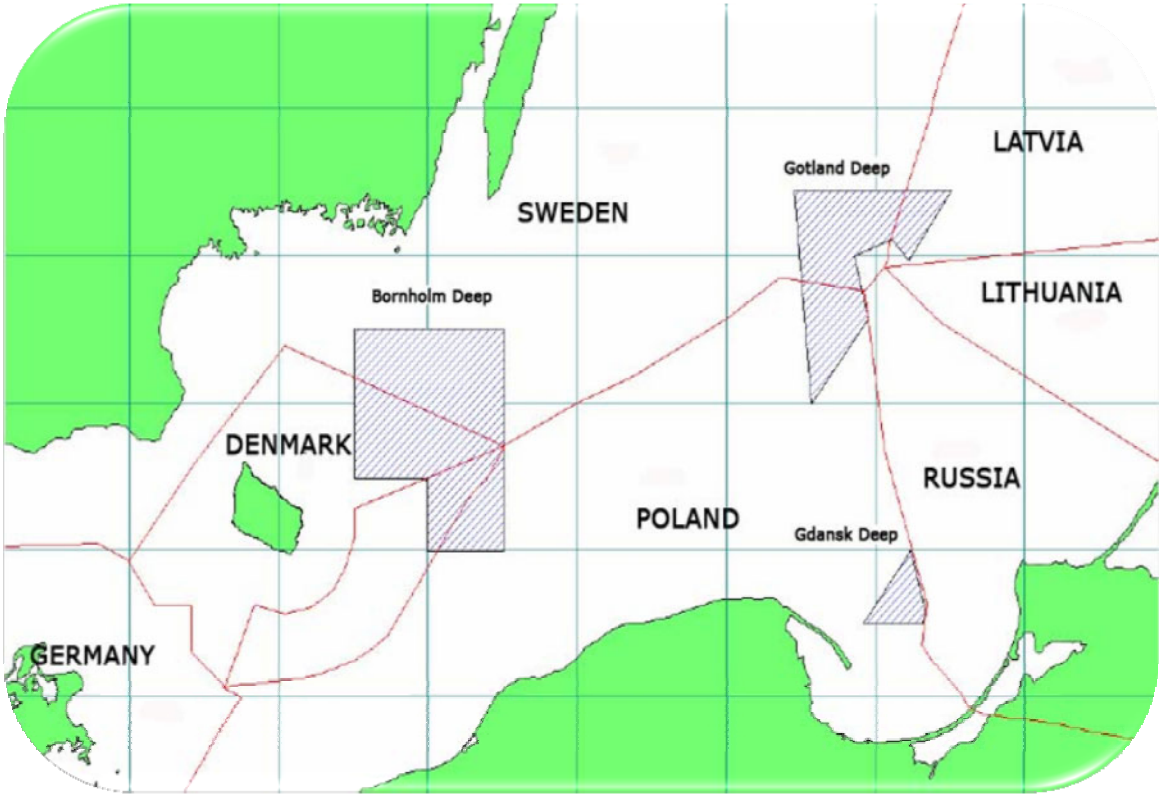

Fig. 12. Three year-round MPAs enforced in (clockwise from left) the Bornholm Basin, Gdansk and Gotland Deep in 2005. In 2006, these MPAs were enforced temporally.

MPAs to assist recovery of the depleted Eastern Baltic cod stock have been used as part of management plans for some years in the Baltic Sea (see e.g. Fig 12). The closures currently in place are the result of an evolving sequence of seasonal and permanent MPAs. A first regulation that banned targeted cod fishery in the Baltic Sea during the summer months was enforced in 1995, i.e. a seasonal MPA. The duration of this closure was subsequently modified from year to year. The summer bans were awccompanied with a springtime closure of targeted cod fishery in the Bornholm Deep, the main spawning area of the stock (spawning closure). In 2004, the Bornholm Deep closure was enforced earlier (in mid-April) and was extended spatially further to the east. In January 2005, three closures were enforced in the Baltic Sea (see Fig. 12). They banned all fisheries year-round in the main spawning areas of the eastern Baltic cod, i.e. permanent MPAs. In 2006, a temporal MPA network enforced in the same three areas replaced the year-round MPA network. In 2007 the EU made a new proposal of a closure design, but this configuration was never implemented.

Evaluations of the enforced MPAs by ICES[56] however concluded that all closures enforced in 1995-2003 were insufficient in reducing fishing mortality and hence in rebuilding the Eastern Baltic cod stock. The summer ban in 1995 had no significant positive impacts on the stock, mainly because the main cod catches in the Baltic Sea were taken from September to April, with in particular the trawl fishery exploiting pre-

[56] *ICES Baltic Fisheries Assessment Working Group* (ICES 1999) and the *ICES Study Group on Closed Spawning Areas of Eastern Baltic Cod* (ICES 2004)

spawning concentrations of cod in late winter and spring. Similarly, the relatively small "spawning closure" in the Bornholm Deep had little effect on the stock. Furthermore, the closed areas enforced in 1995-2003 in the Bornholm Deep were according to the ICES evaluations not large enough to ensure adequate coverage of potential areas with favourable hydrographical conditions for spawning. The extension of the closed area in the Bornholm Deep was not able to increase egg production and survival because the spatial extension covered only the eastern waters of the Deep where under normal circumstances the hydrographical conditions are not favourable. Therefore, the reason for the failure of past MPAs may have been a suboptimal spatial-temporal design, not taking into account the available knowledge on ecosystem functioning.

Baltic case study: GOIS & Monitoring strategies

GOIS

In order to develop a monitoring strategy for evaluating the success of potential MPAs in restoring the Baltic cod stock, GOIS tables were developed for the Baltic case study. In addition to goals, objectives, indices and success criteria, observation and modelling methods were entered into a table, i.e. methods which are already in use or may be used in the future (esp. models developed in the BCS like ISIS-Fish, PNN and BEMCOM) to evaluate the efficacy of MPAS.

Due to the highly migratory behaviour of cod in and out of the spawning areas, and strong dispersal of early life-stages due to the circulation, no spatially-explicit monitoring was considered. The strategy of the CS to judge on the success of the MPA is visible along the definition of the goals.

The primary goal is to *Restore the Baltic cod stock*. Different indicators have been chosen to describe the success of a potential MPA, involving fishing pressure, stock structure and reproductive success.

A secondary goal *Re-establish a (more) balanced ecosystem* refers to potential ecosystem effects of an increased cod stock. This goal is formulated under the assumption that a larger cod stock would decrease the sprat stock which further would release the predation pressure on the copepod *Pseudocalanus acuspes*. These kinds of trophic interactions have been observed for the Central Baltic ecosystem[57],[58]. Indicators related to this goal cover ratios of the dominant species of the fish and zooplankton communities, as well as herring condition being dependent on both their competitors (sprat) and zooplankton abundance[59].

The above described strategy for evaluating the success of a potential MPA is based on the primary assumption that a reduction in fishing effort by means of a closed area can assist the cod stock in increasing and the following cascading effects to occur. However, the magnitude of the effect will depend on the level of recruitment.

Enhanced Baltic cod recruitment success, which would be the primary mechanism through which the stock status could be enhanced is (as other important components of the ecosystem as well) strongly dependent on the environmental conditions. Thus the level of stock increase eventually depends on the prevailing environmental conditions[60,61].

[57] Möllmann and Köster 2002, Möllmann et al. 2008b
[58] Möllmann et al. 2008b
[59] Möllmann et al. 2005
[60] Köster et al. 2005
[61] Röckmann et al. 2007

Moreover, if increased recruitment has occurred in parallel to establishing an MPA AND enhanced environmental conditions, it would be difficult to estimate the relative contribution of both effects. Hence, it is suggested to conduct a baseline monitoring of the biotic and abiotic environment to potentially evaluate the relative effect of the MPA on the cod stock and the whole ecosystem (see Annex I).

As the closed area has been implemented through the Common Fisheries Policy it is assumed that anoverarching goal of a potential Baltic MPA would be to *Obtain sustainable fishing communities and to maintain livelihoods*. A monitoring of this goal would be through indices of the profitability of the fisheries themselves and of the state of the fishing communities (See Annex I).

Reviewing the existing monitoring activities has lead to the conclusion that most of the indices are already regularly observed since the Baltic Sea is a highly monitored ecosystem. However, data are collected under a variety of programmes for specific purposes. There is often little data exchange between different monitoring programmes and institutions involved. Currently, in the open sea Baltic monitoring programmes are focused on the effects of eutrophication and hazardous substances (HELCOM COMBINE) as well as on fishery management (European Council regulation 1543/2000). Major Baltic Sea status assessments are the annual fish stock assessments conducted by ICES working groups, and the HELCOM assessments of eutrophication and biodiversity, the later covering longer time periods and are planned to be updated in 2009 and 2010, respectively. Additional monitoring requirements are created by the EU Habitats and Birds directives and in the future also by the upcoming EU Marine Strategy.

For a reliable monitoring of the potential effect of MPAs for the Baltic cod stock and the whole ecosystem, the present existing monitoring efforts should go into one “ecosystem monitoring programme”.

As a first step most of the biological data needed for an MPA evaluation are available in a database produced by the ICES/ HELCOM Working Group on Integrated Assessment of the Baltic Sea WGIAB[62]. WGIAB produced the first ecosystem analysis for the Central Baltic Sea covering all trophic levels as well as the hydro climatic and chemical environment[63]. WGIAB established a data flow from the different samplings into a common ICES/HELCOM indicator database. This database is well suited for the evaluation of the success of potential MPAs. However, a deficit to be overcome in the future is the collection of bio-economical data, which is largely unavailable for the area.

Monitoring compliance

Control and enforcement in the Baltic Sea cod, herring and sprat fishery has suffered from considerable time delay (2–3 years) from violation to detection. As a result, harvests should ideally be monitored through the use of real time vessel monitoring systems (VMS) which have already been used in the Baltic Sea on vessels exceeding 15 metres overall length. VMS monitoring could also be used for verification of landings and fishing ground prior to an entry into a landing port. This kind of online monitoring would exclude the time delay and hence, increase enforcement and rule compliance with an aim to reduce overexploitation of the stocks.

Baltic case study: Modelling approaches and results

A series of models and modelling techniques was used in the Baltic case study, both numerical/statistical models to generate basic knowledge and parameters required for MPA simulations, and MPA simulation

[62] ICES 2007
[63] Möllmann et al. 2008a

models used to evaluate the ecological and economic effects of various MPA scenarios[64]. Among the former type were a 3d-hydrodynamic circulation model, which was e.g. used to specify nursery habitats of the Eastern Baltic cod population, and a Multispecies Virtual Population Analysis (MSVPA), which reconstructed initial population sizes to start the simulations stock-recruitment relationships used as basis for the regeneration functions. Models to simulate the ecological and economic effects of potential MPAs were specifically: i) a simple model of the cod population forced by environmental scenarios, ii) the more complex spatial fishery simulation model ISIS-Fish, iii) fleet movement models and iv) bio-economic models, which were used to analyze the feedback effects between human activity and natural resources.

A simple model of the Baltic cod population forced by environmental scenarios

In order to test the implications of the establishment of MPAs in the Baltic Sea, a model was applied to simulate the stock development over a 50-year time period using different management policies and a variety of environmental conditions. This model did not consider the dynamic responses of the fishery, i.e. how the fishery would respond to the management changes e.g. by reallocation of fishing effort. The investigated management policies thus reduced fishing mortality and ranged from a moratorium on the Eastern Baltic cod fishery via the establishment of a permanent or a seasonal MPA in ICES subdivision (SD) 25 (Bornholm Basin) to a fishing as usual scenario. The environmental conditions incorporated were based on the size of the area with environmental conditions allowing for reproduction (also called the reproductive volume RV) and comprise a best case and a worst case of reproductive conditions, and two more realistic scenarios, where it was assumed that a historic series of RV-sizes reoccurs over the simulation period.

The results show a strong dependence of stock dynamics on the environmental conditions. If fishing continues as usual, the model projects stock extinction by the year 2020 under prevailing environmental conditions. The models also project that if fishing mortality is reduced either directly or by implementation of an MPA, the stock benefits from an increase in stock size and an improved age structure. A seasonal closure of the ICES Sub-division SD 25 appears to be sufficient to prevent the Eastern Baltic cod stock from falling below safe biological limits.

The model was further used to test the long-term implications of different management policies on the cod stock and the fishery. To this end the model was applied in 50-year simulation analyses. Under the presented environmental scenarios, a stock collapse cannot be prevented, but only postponed by the establishment of an MPA in the Bornholm Basin. The simulation results showed that a significant reduction in fishing mortality is necessary for achieving high long-term economic yields.

Spatial fishery simulation model ISIS-Fish in the Baltic Sea

A more detailed approach to evaluate the performance of MPAs used the spatially explicit fisheries simulation model ISIS-Fish[65]. This model combined an age-structured, spatial population model with a multi-fleet exploitation module and a management module in a single model environment. Different production regimes of the stock were considered, based on past observed situations and on results from hydrodynamic models. Different MPA scenarios were simulated over 20 years, each under favourable and unfavourable conditions for cod reproduction: a) a baseline scenario without an MPA which was used to show the effect of misreporting and discarding on stock development, b) different MPA scenarios, including closed seasons and large, year-round spawning closures on the main cod spawning grounds.

[64] Kraus et al 2009
[65] Kraus et al 2009

The ISIS model is a sophisticated modelling approach, suitable to evaluate the complex consequences of different MPA options. As for all models, however, it is important to understand what it aims to achieve, as well as its constraints. Some of the important constraints of the model used here is that the ISIS fish model for the Baltic:
a) does not allow for any build-up of biomass within the permanent closures,
b) calculates reproduction based on spawning stock biomass , but it does not differentiate between reproductive output of large and small females,
c) does not deal with spatial differences in discards of juveniles,

The output of the model should be viewed in light of these constraints. These constraints have their roots in the fact that the Baltic cod closures (both the actual implemented closures and the potential designs modelled in PROTECT) were not designed to build up cod biomass or restore age structure, but rather to enhance reproductive output of the stock (spawning closures). This makes this case different from the "mainstream" MPA, where the build up and perhaps export of biomass commonly is a main goal.

The results show the serious consequences of misreporting: the effect of misreporting was most prominent under adverse environmental conditions as the spawning stock biomass (SSB) continued to decline to levels below 50.000 tonnes. Without misreporting the stock would slowly recover, but still well below the present biomass limit reference point of 160.000 tonnes. Assuming favourable environmental conditions resulted in stock recovery irrespective of the correction for discard and misreporting.

All different MPA scenarios showed positive effects on the stock development, but their effects differed. The 2007 closure scenario resulted in a similar SSB as the 1995 scenario, i.e. around 110.000 tones. The proposal for spawning closures of the EU-Commission for 2006 performed worse: under the adverse environment scenario SSB increased slightly, but only to an absolute value of SSB around 50.000 tonnes, which is still considerably lower than the present B_{lim}. Also under favourable environmental conditions, the effects of this closure scenario were negligible compared to the baseline scenario, indicating that the majority of the fleets could displace their effort beyond the closure boundaries. The 1995 and 2007 closure scenarios under favourable environment both led to SSB levels ~50% higher than the baseline scenario.

All implemented MPA scenarios comprised a combination of small scale spawning closures and large-scale seasonal fishing bans to the directed cod fishery. Additional simulations to disentangle these effects were conducted with only the spawning closures being implemented. SSB development for the 2007 scenario with only the spawning closures implemented did not differ from the baseline scenario and the large spawning closure suggestion by the Commission only showed a limited positive effect. Thus, the spawning closures alone are not sufficient to recover the stock, because the fleet displaced the fishing effort to other areas.

If closed seasons were implemented, stronger positive effects on SSB were detected. This simulation showed that despite the strong and obvious influence of environmental conditions, large scale closed seasons effectively reduced the effort and thus fishing mortality as there was no possibility for the fleets to compensate for catch losses during closure times by spatial effort displacement. Thus, effort reduction appears to be the major driver for stock recovery. An MPA which is is designed specifically to provide undisturbed spawning by the implementation of spatially restricted spawning closures, may not ensure such an effort reduction. If so, an effective, coinciding effort management regime may be a viable complement or alternative to the presently applied MPAs in the Baltic Sea.

Spawning closures will not necessarily allow build-up of fish biomass within the closed areas, and thus the positive effects demonstrated for no-take areas, such as increased reproduction and restoration of ecosystem function, will not necessarily occur. The results of the PROTECT project indicate that spawning

closures are efficient only if they decrease fishery mortality as a whole. For Baltic cod fisheries spawning closures will be inefficient if they are the only managament instrument, as the fish will simply be caught during other seasons or in other places. Put simply, MPAs of limited spatial scale are not likely to be efficient in decreasing overall fishing mortality for a mobile species such as cod if otherwise nested in a Total Allowable Catch (TAC) regulated fisheries management regime. In order to be efficient, such a Baltic cod MPA would need to be of a size so large that a substantial decrease in overall fishing mortality is ensured.

Baltic Sea fleet movement models

Using temporal and spatial effort distributions of the Swedish and Polish fisheries, the effect of MPAs on movements of the cod targeted fleet in the Bornholm Deep area (SD25) were evaluated using random utility models (RUM) and alternatively non-parametric neural network models. The results are illustrations of the importance of considering the effects of fleet and effort displacement. Polish and Swedish cod fishers in 1996-2004 could offset MPA induced catch losses during the non-closed seasons through spatial and temporal displacement of their fishing activity. Efforts increased during the autumn-winter and early spring seasons and in the reopened spawning area in the Bornholm Deep. Thereafter, the year-round MPA network introduced in 2005 induced higher efforts in the non-closed areas. That is, fishers had an incentive to "race to fish" a lower TAC and weekly quotas in a smaller area.

Bio-economic modelling in the Baltic

A bioeconomic model (BEMCOM) was set up in order to analyse the consequences of marine protected areas in the Baltic Sea. Focus was on assessing stock development of Baltic cod (eastern and western stock), but bycatches of other species were included in order to evaluate total profit of the fleets in question.

Two scenarios were investigated, both run over a seven-year time period, and it was assumed that the fleet size did not change during the entire period:

1. The first scenario was a business-as-usual case, where it was assumed that the current regulation in the Baltic Sea continued, thus the current closed areas in the Baltic Sea continue to be in place.
2. Because fishing continued around the borders of these closures, thus taking any spill-over of cod, the second scenario considered extended closures around the Bornholm and Gotland Deeps.

The results from the two scenarios shows that the value of net present profits in the business-as-usual case will be 6,020 million DKK compared with 4,303 million DKK in the case with extended closures, i.e. a difference in profits of approx. 28%. This is not a surprising result, because vessels during closures are excluded from fishing areas with high catch and CPUE levels around the deep basins, and are thus forced to fish in less attractive grounds. Fishing in less attractive areas means that the average size of fishes caught decreases, and that more effort is needed to catch the same amount of adult legal sized fish, which in turn leads to lowered net profits and more discards. However, the development in spawning stock biomass is positively influenced by extending the closed areas as depicted in the second scenario, but the increase is not large enough to offset the negative economic consequences for the fishermen in the seven-year time frame of the present model.

Based on the analysed scenario, extending the marine protected areas would be beneficial for the recovery of the cod stock, but economically negative for the fleet, at least in the short term. However, it must be noted that this conclusion depends on the assumptions and restrictions made.

Main conclusions from the Baltic case study

The Baltic Sea case study is an illustration of the use of closures to regulate a fishery on a stock, which is a Total Allowable Catch (TAC) managed fishery and strongly dependent on environmental conditions. It is also an example of the use of closures for protecting a migratory stock that is under intense fishing pressure, and where the analysis of displacement of effort (in time and/or space) is essential for predicting if the MPA will meet its goals or not.

The work in the Baltic case study resulted in a number of conclusions important for a potential future implementation of MPAs under similar circumstances:

- For a fish population such as Eastern Baltic cod that is strongly dependent on the environmental conditions for succesful spawning and recruitment, the intesity of the benefits that a given MPA may have is to a large extent dependent on the overall state of the environment;

- It is important to note that the Baltic cod closures (both the actual implemented closures and the potential designs modelled in PROTECT) were not designed to build up cod biomass or restore age structure, but rather to protect an essential cod habitat to enhance reproductive output of the stock. This makes the Baltic case study different from some more "mainstream" MPAs, where the build up and perhaps export of biomass commonly is a main goal.

- For a highly mobile species such as Eastern Baltic cod, evaluating the effects only within the MPA is difficult, hence the overall performance of the stock may be a better measure of the efficiency of the MPA; This includes a shift of goals and targets from the build-up of biomass in the MPA to a more ambitious goal of contributing to an overall stock recovery (on its own, or as a part of a broader suite of management interventions).

- Simulations for various MPA scenarios demonstrated that under continuously adverse environmental conditions, closed seasons to the cod directed fishery in the whole Central Baltic were most effective in restoring the stock, while only closing spawning areas was not effective. However, none of the implemented closures was able to restore the stock to safe levels (B_{lim}) within 20 years of simulation under unfavourable conditions. Under favourable environmental conditions stock recovery occurred irrespective of the MPA design;

- For the recovery of the eastern Baltic cod stock, an effective effort regulation system may be an alternative or a supplement to a combination of closed seasons and small scale spawning closures.

- Modelling the spatial-temporal effort displacement as a reaction to the closures indicated that fishermen are likely to offset catch losses induced by the summer ban/closed seasons by increasing catches during non-closed seasons in autumn-winter and early spring, as well as by increasing effort along the spatially restricted effort MPA borders, potentially preventing a positive MPA-effect;

- A bioeconomic model showed that the development in spawning stock biomass was positively influenced by extending the present closed areas. However, the increase in biomass was not large enough to offset negative economic consequences for the fishermen, at least not during the modelled 7-year period. An extended MPA may therefore contribute to meeting the suggested goals of restoring the cod stock, and thus possibly restoring the ecosystem, but it is not likely to contribute in this timeframe to meeting the socioeconomic goal of economically sustainable fishing

communities. For this to be achieved, other means of effort management and reduction would be necessary.

The North Sea case study

Brief description of the ecological and geographical setting

The energy flow in ecosystems with abundant stocks of small pelagic fish is often characterized by a bottleneck middle trophic level (a "wasp-waist" system). Sandeels (to a very large extent of the genus *Ammodytes*) constitute an important component of food webs in the North Atlantic and may be considered to be a bottleneck intermediate trophic link between secondary producers and larger predators such as fish, seabird species, and marine mammals. In the North Sea, sandeels are among the most abundant fish species and support the largest single species fishery[66]. Sandeels are species characterised by juvenile and adult life stages resident on certain sandbanks coupled to specific areas of sediment with dispersal to other areas confined to a drifting larval stage[67,68]. This life strategy makes local sandeel populations potentially vulnerable to a directed fishery.

Previous closures of the sandeel fishery

In 2000, the Firth of Forth area of the UK northeast coast was closed for the sandeel fishery[69,65] (Fig. 13), because of concerns that the fishery in previous years reduced the sandeel population below a level where this affected breeding success of certain seabirds and hence potentially other top predators. The Firth of Forth study focuses on the sandeel fisheries effects on this specific part of the North Sea ecosystem. The sandeel fishery on sand banks in the Firth of Forth area (the FF area) of the Scottish East cost significantly increased in 1992, after a number of years with exploratory fishing efforts in the area. In 1993 landings in the FF area peaked at more than 100.000 tonnes of sandeel and subsequently declined.

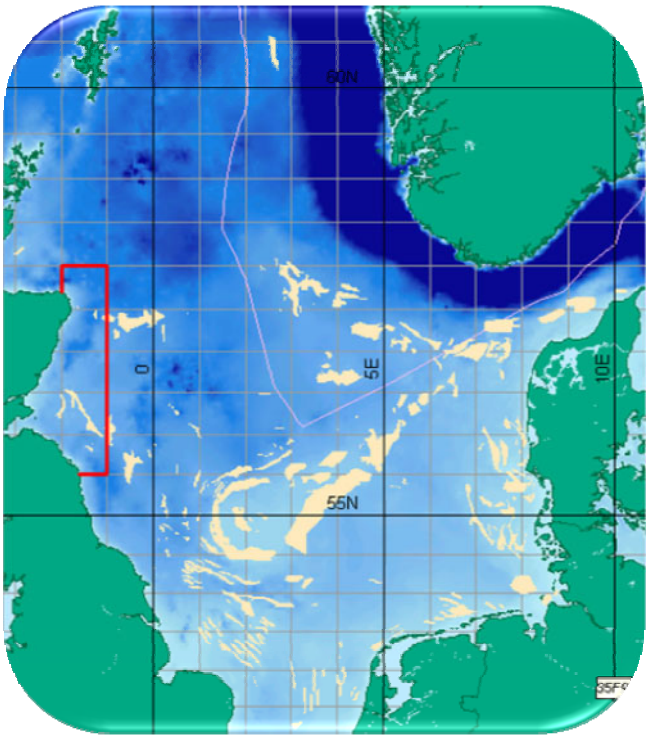

Figure 13: Map of North Sea potential sandeel habitats (yellow) with an indication of the closed area of Firth of Forth (red line) (H. Jensen, DTU Aqua).

The FF area is important for a number of seabirds that breed in the area and some of these seabird species are highly dependent on sandeels as a food source during the breeding season[70,71]. The sandeel fishery in the FF area occurs within the foraging range of some of the sandeel-eating seabirds, and as the increase in sandeel fishing in the area coincided with a decline in breeding success of some of the seabird species[72,73], the sandeel fishery became a matter of concern.

[66] ICES 2003
[67] Boulcott et al. 2007
[68] Christensen et al. 2008
[69] Daunt et al. 2008
[70] Frederiksen et al. 2008
[71] Daunt et al. 2008

Figure 14. A nesting colony of black-legged kittiwakes (*Rissa tridactyla)*. Source: Tom Vezo/Minden Pictures/National Geographic Stock

The UK called for a moratorium on sandeel fishing adjacent to seabird colonies along the UK coast and in response the EU requested advice from ICES. An ICES Study Group was convened in 1999 in response to the EU request for advice. The ICES study group noted that there were indications of a negative effect of the Firth of Forth fishery on the sandeel stock in 1993, and that this coincided with a low breeding success of some of the seabird species that breed in the FF area, especially kittiwakes (see Fig. 14). The ICES study group recommended that the sandeel fishery west of 1° W in the north-western North Sea should be closed to sandeel fishing, because breeding success of kittiwakes at this time was below the limit required to maintain viable colonies (<0.5 fledged chicks per well-built nest). The ICES study group further suggested that the closure should stay in force until kittiwake breeding success exceeded 0.7 fledged chicks per well-built nest. The intention was that kittiwake breeding success would provide a sensitive indicator of sandeel availability to other sandeel-dependent predators. The EU agreed with the ICES advice and closed the fishery in 2000 (Fig. 13), after which the sandeel fishery has remained closed, except for a small commercial monitoring fishery. No other fisheries were affected by the ban. However the Commission did not accept the use of kittiwake breeding success as an index for re-opening the fishery and no alternative methodology has been suggested.

North Sea Plaice

Closing an area to fishery undoubtedly protects fish and other organisms within this area, but any benefits from protection of fish may quickly be reduced to zero if they are harvested as soon as they leave the protected area. To capture the tendency of a fish species to move around and to infer the resulting distribution area, PROTECT examined and modelled the key processes driving migration and dispersal.

The aim was to evaluate the effects of size and location of marine protected areas (MPAs) on a population of non-sessile animals and on its fisheries. With North Sea Plaice in mind, PROTECT looked at potential effects of area protection on survival, distribution and fishing yield. Management scenarios were examined, ranging from no closure of the fishery to a closure of the entire North Sea. These results were then evaluated in relation to existing closures such as the North Sea Plaice Box.

Photo: T.K. Sørensen

[72] Frederiksen et al. 2004
[73] Frederiksen et al. 2008

Objectives of the North Sea case study

The North Sea case study focuses on ecological implications of MPA introduction for the sandeel, but also includes an additional modelling analysis of fisheries closures to a migratory fish species, plaice (*Pleuronectes platessa*). The work in the North Sea case study provides two stages of MPA design and selection:

- An analysis of MPA application: the Firth of Forth area of the Scottish East coast has been closed to sandeel fishery from year 2000 (except for a limited monitoring fishery) for conservation of sandeel availability to the ecosystem;
- Analyses focusing on model simulations of the potential effects of MPA site selection and network design: defined sandeel fishing banks in the North Sea approximately south of 60˚ and north of 53˚ (effects on sandeel) and proposals for protected areas in the North Sea (effects on plaice).

The case study on mid trophic level "wasp-waist" ecosystems puts focus on areas where North Sea sandeel potentially is a key link between lower trophic levels and top predators. The hydrodynamically determined larval sandeel transport, growth, and survival at each bank in such sandeel areas is one key recruitment mechanism, and the possible negative density dependent effects of age 1 sandeel on the 0-group is another.

The idea is that overall sustainability of the populations of both sandeel and its predators can be achieved through the maintenance of permanent or rotating MPAs for protection of local spawning aggregations, which ensure sources of larval recruitment to nearby areas. The impact of such protected local populations on sandeel population dynamics, trophic transfer rates, effects on top predators and the fishery are key issues in this case.

North Sea case study: GOIS and monitoring strategies

The North Sea case study provides analyses of MPA effects on an important mid-trophic sand bank resident species with a larval dispersion phase, i.e. sandeels. Sandeels have a well-defined optimal habitat that has a large and medium scale patchy distribution in the North Sea (see Fig. 15) and robust analyses of the connectivity between habitat elements.

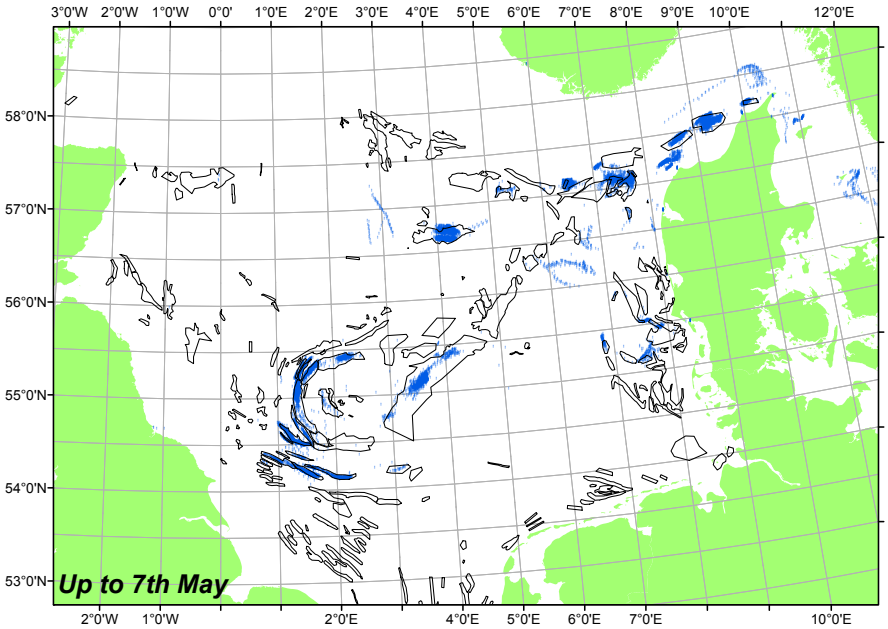

Figure 15. Known sandeel fishing grounds (black polygons) and year 2007 VMS data up to 7th May from Danish vessels fishing sandeels. Light blue dots represent all activity (fishing and steaming etc.) and dark blue dots represent sandeel fishing (ship velocity between 1-5 knots logged between 4am to 9pm). Every dot represent one hour of activity. (H. Jensen, DTU Aqua)

The Firth of Forth sandeel fishery closure (Fig. 13) is dedicated to population conservation, where the exclusion from the area of the sandeel targeting fishery segment is implemented of concern for the ecosystem. There are no official defined goals or targets for this MPA.

The elements analysed within the PROTECT project thus relate to the sandeel population dynamics and interaction with the ecosystem and the fishery. The sandeel recruitment, growth and survival is analysed on a local scale; the community of predatory fish is monitored and its dynamics analysed; and the breeding success and feeding ecology of seabirds in the area is studied.

GOIS

In the following a short overview of the primary goals and specific objectives of MPAs for sandeels is presented including correspondning indices and success criteria..

The primary goal of sandeel MPAs is to design and employ MPAs to help sustain sandeel populations in a healthy state. The specific objective is to use MPAs in fisheries management as a tool to:

a. Avoid overexploitation and local depletion of the North Sea sandeel stocks,
b. Restore depleted sandeel aggregations,
c. Improve stock resilience,
d. And ensure a reproductive potential through viable key stocks.

The success criteria to judge if the objectives are met are, that:

a. SSB is above Bpa and local stock abundance is above local target
b. Previously occupied habitats are recolonised
c. The age structure of sandeels is extended to include more than present level of mature individuals
d. Juvenile sandeels are available at major sandeel habitats and recruitment failure is avoided

Other goals for this MPA are for the benefit of higher trophic levels, to avoid negative ecosystem effects of fisheries displacement and socio-economic goals.

See Annex I for a complete GOIS table developed for the PROTECT North Sea case study.

Monitoring strategies for the North Sea case study

For the Firth of Forth site there are several ongoing monitoring programs in place:

- VMS: Highly valuable information about effort allocation and distribution
- Contracted fishing vessels: Highly valuable information about the sandeel vital statistics (life tables etc.)
- Scottish trawl survey covering fish predators and sandeels
- Scottish acoustic survey giving estimate of actively foraging sandeels
- Combined Index of trawl, acoustics and sediment-grab samples: Rather uncertain estimates of older age classes, no reliable information on recruiting year-class.
- CEH monitoring of seabird foraging performance
- CEH and JNCC monitoring of seabird breeding success
- Observations of marine mammals

Similarly, for the larger North Sea areas covered by the case study, several existing monitoring programmes were used:

- VMS
- Sampling trawl hauls from fishing vessels
- Dredge sampling of buried sandeels in winter
- Ichthyoplankton sampling at sandeel fishing banks
- CPR (continuous plankton recorder)
- Surveys of seabirds at sea (ESAS database)

- Marine mammal census

Sandeel monitoring needs

However, for comprehensive planning and evaluation of a system of North Sea MPAs, some additional new monitoring systems are needed:

- Grid of in year zooplankton samples for assimilation into biophysical models
- Electronic logbook for fishing information

The scientific monitoring fishery provides important information about the stock dynamics of sandeels, from the information about age composition of sandeels in the catches and the catch rate that is used as an index of sandeels stock size. Such data is essential in an analysis of the stock dynamics of sandeels. However, because of poor sampling in years with low stock size and due to the emergence behaviour of sandeels that is highly variable, information from a monitoring fishery that only measures abundance of sandeels in the water column must be combined with sampling of sandeels in the seabed, preferably at times when whole of the population resides in the sediment (i.e. during most of winter)(see Fig. 16). Methods have been applied to combine information about sandeel abundance in the sediment and in the seabed, but the approach used only provided uncertain estimates about the stock size of older sandeels and no reliable information about the stock size of the recruiting year class. However, the timing of the benthic sampling programme did not ensure that all sandeels were in the seabed when sampling took place. Different techniques are presently under review in order to find out which method is most suitable for providing a survey-based index of sandeel abundance, and ICES will evaluate the different sources of information. Once a suitable approach has been defined such a method should be implemented in the FF MPA area as a supplement to the ongoing monitoring fishery, or a commercial fishery in case the area is reopened to sandeel fishery.

Fig. 16: Above: swimming sandeels. Below: buried sandeel. Photos: J. Behrens.

The time series of seabird population size, foraging pattern, and breeding success, should be continued, in order to be able to identify early warnings about changes in the environment, including changes in the availability of the main seabird prey species. The same kind of information should be made available for marine mammals.

Monitoring fleet responses and compliance

Monitoring fleet responses, including compliance, is especially challenging with MPAs situated far offshore. The most likely tools for this are the use of VMS and/or logbooks. This is discussed in a separate section on VMS data in this report.

North Sea case study: Modelling approaches and results

The core models (e.g. SPAM[74]) for the North Sea sandeel case may be considered as intermediate between *empirical approaches* and *dynamic modelling* in that they use both methods in conjunction to investigate MPA effects. Fisheries economic effects were investigated in a dynamic model (BEMCOM) formulated around the basic biological parameters and an initialisation and equilibration period from SPAM.

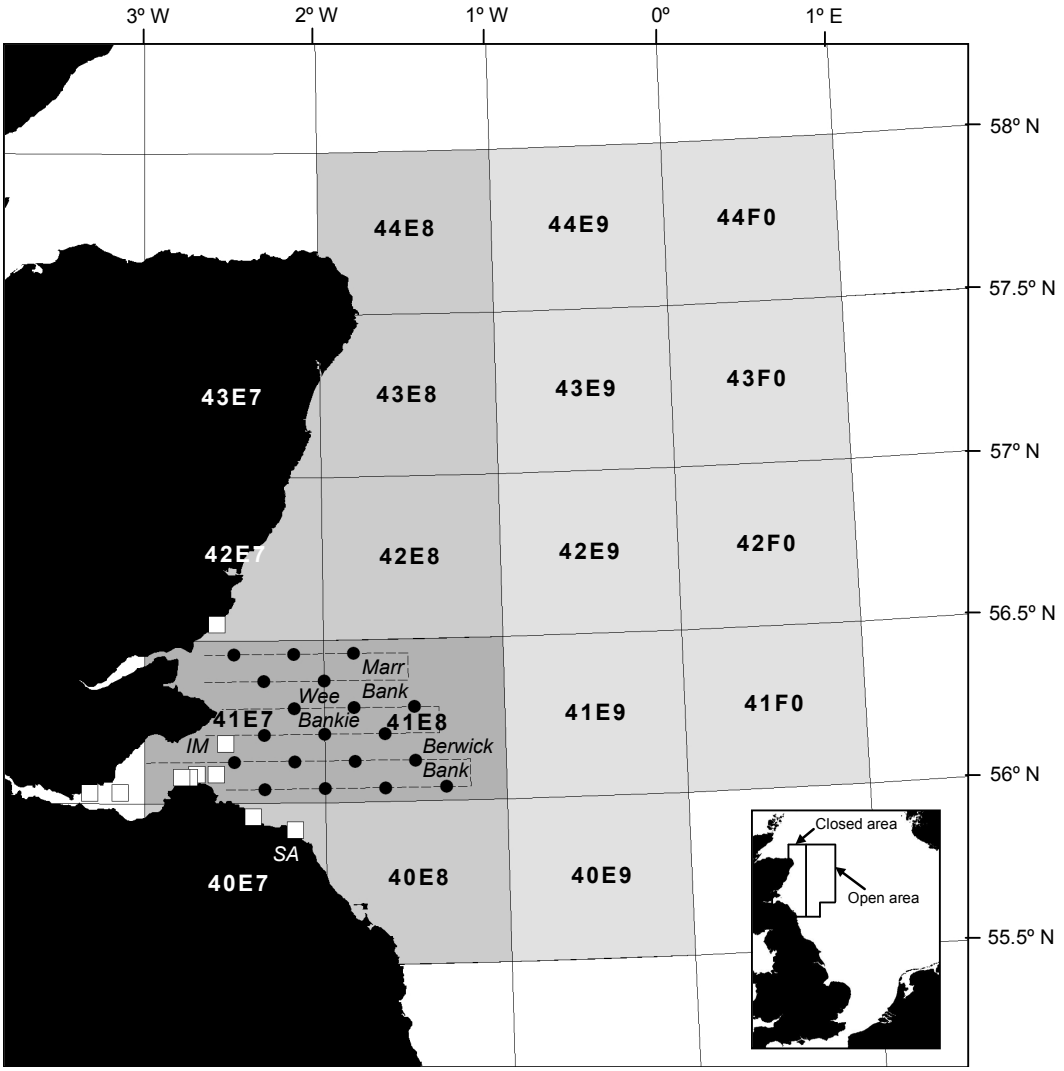

Fig. 17. Map showing the location of 18 ICES rectangles for which Danish sandeel fishery catch data were examined. The three shades of grey represent (from darkest to lightest): a) the "study area" (ICES rectangles 41E7 and 41E8) in which seabird and sandeel surveys were made; b) the seven rectangles which, together with 41E7 and 41E8, were closed to sandeel fishermen from 2000 (the "remaining closed area"); c) the nine rectangles east of the closed area (the "open area"). The at-sea seabird and acoustic survey transects (dotted line) and demersal trawl stations (black circles) are shown. The source colonies of birds that were predominantly feeding in the study area are shown as white squares, including the two colonies that provided data on breeding success (*IM* = Isle of May; *SA* = St Abbs).

[74] Christensen et al. 2009

Empirical modelling using BACI design testing

Empirical approaches were used to analyse the effects of the sandeel closed areas in the North Sea on sea birds via trophic interactions. This relied on a large data set that fits in a BACI design[75] (see Fig. 17). Only one seabird species, the surface feeding black legged Kittiwake was significantly affected by the closure of the Firth of Forth area.

Another anaysis showed that there are marked differences in age specific egg production between regional spawning aggregations in the North Sea, reflecting different population growth rates between aggregations. Given the regional differences in productivity, sandeels in the Firth of Forth region may be more susceptible to growth over-fishing than other regions, with those from the Fisher region least susceptible. However, data on population development before and after the Firth of Forth closure from a survey based model and from analyses of the fishery and the following monitoring fishery are contradictory and with the present stage of analysis inconclusive. To overcome this obstacle, a total analysis of the sandeel population including fisheries monitoring and a continued trawl & acoustic survey series would be required.

For the North Sea sandeel case study, closures are aimed at conserving or restoring resources. The empirical assessment of the Firth of Forth provides a local diagnostic for selected indicators like breeding success of black legged Kittiwake, but cannot encompass changes at the fisheries scale.

Connectivity among sandeel areas

Present sandeel stock-assessment models treat the North Sea sandeel populations as one single homogeneous population or, at most, two populations. These stock-assessment models neither predict stock variations sufficiently well nor provide a satisfactory starting point for linking population dynamics to underlying oceanographic and biological processes that are major drivers for the population dynamics of many fish species including sandeels. In PROTECT, coupling hydrodynamic models for assessing connectivity among sandeel areas with population growth and fisheries models to simulate different MPA scenarios was an important step.

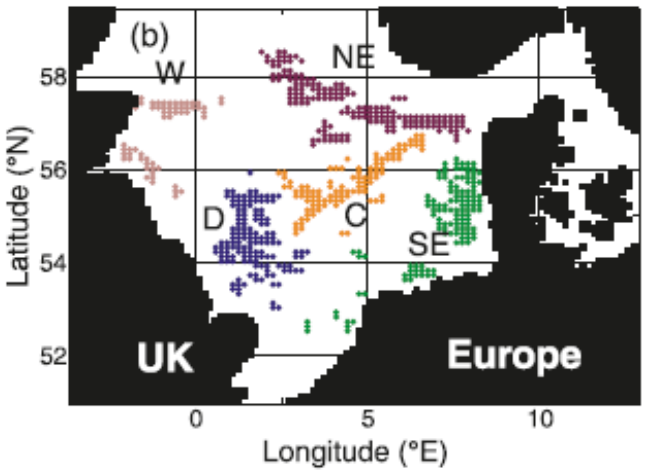

Figure 18. Suitable sandeel banks in the central and southern North Sea divided into five major systems.

A model framework for optimising an MPA network for sandeels in the North Sea has been constructed in PROTECT[76] but specific solutions will depend on the objectives set by managers.

The connectivity between sandeel banks at the North Sea wide scale was early in the project demonstrated by selecting five major regions and analysing transport patterns within and between them (see Fig. 18). Connectivity between identified sandeel habitats was analysed based on the mapped sandeel banks resolved at the hydrographical grid scale as sources of egg production. The SLAM output of transport survival probability from hydrographical data and a sandeel larval

[75] Frederiksen et al. 2008
[76] Christensen et al. 2009

development model was then used with different expressions of connectivity. The preliminary results indicate that the major separation between sandeel habitats exists between a northern and southern system separating at a line north of Tail-end and south of Inner Shoal, as well as clusters of connectivty on smaller scales.

For the Firth of Forth a specific bio-physical simulation analysis of sandeel larval dispersal was performed. The origin of recruits to the Firth of Forth sub-population confirmed the retentive nature of the area and supported that sandeel recruitment in the area is mostly dependent on local production with some potential immigration from spawning areas as far as the Moray Firth and Orkney. The results have implications for the management of the sandeel stocks off the east coast of Scotland. The justification for the closure of the sandeel fishery in the area was the notion that the sandeel sub-stock was largely local and therefore generally responsible for recruitment in the area. The model simulations were consistent with this assumption.

An inference from the present results is that a mosaic of MPAs at an optimal scale distance will enhance connectivity and favour a wide distribution of the North Sea sandeel stock as well as the chances for recolonisation of presently depleted banks in the northern region. This will benefit a sustainable fishery as well as the trophic dependencies in the ecosystem.

Effects of MPA size: MPA simulation scenarios

In a series of analyses with smaller size MPAs[77], the fishery in ICES statistical rectangle 37F2 at Dogger Bank was simulated to be closed (see Fig. 19), and the influence on sandeel stocks within the MPA and the adjacent habitat regions as well the entire North Sea was investigated.

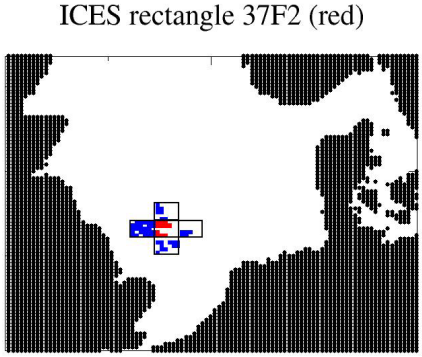

Figure 19. Target area (red) of MPA scenario simulation.

According to the simulations, the sandeel stock inside the MPA responded immediately to the effort closure, whereas the adjacent regions have a response lag of 2–3 years. On a regional scale, the total sandeel population build-up induced by closing ICES rectangle 37F2 would take place within approximately ten years when stock levels are within bounds of natural fluctuations, while the full effect of the closed area requires approximately 30 years. Due to sandeel life cycle duration combined with indirect effects of dispersal rate on population build up there is time lag in the recovery period and the development in total yield.

The long-term MPA effect on the local stocks is a 10–50% stock increase, mostly within the MPA. In the case of an MPA in a productive sandeel area of the size of an ICES square, spill over effects to more distant habitat regions outweigh the loss of local fishing opportunities with the total southern North Sea yield increasing by 16% based on a crude assumption of effort response. This is caused by larval spill over to more distant habitat regions, which cumulatively increase yield. The distance of larval spill over influence is in the order of 100–150 km. However, density dependent damping of spill over production per area was obvious in the simulations of an MPA of the relatively large size of an ICES rectangle. It is possible that several smaller MPAs scattered over larger areas will do a better job of maximising long term sustainable fisheries yield and at the same time avoid local depletion and favour trophic linkage in the ecosystem.

[77] Christensen et al. 2009

Bioeconomic modelling in the North Sea case study

A detailed bioeconomic analysis of the consequences of closing the Dogger area for sandeel fishery was carried out using the BEMCOM coupled to the SPAM model. The baseline simulation shows a more or less constant fishing pattern during the eight year period with Dogger being by far the most important region for the total value of the sandeel fishery. Closing the Dogger will increase spawning biomass (SSB) in this region but to some degree decrease SSB in the two adjacent areas due to a slight reallocation of effort. The total profit will decrease with about 21% primarily due to reduced total effort with very little reallocation to other areas or species.

Overall, it can be concluded from the bio-economic analysis that closure of Dogger Bank will improve the stock on this habitat, but will be countered by a slight decrease in stocks on other areas due especially to some limited MPA-induced reallocation of effort to these sites. Furthermore, as the CPUE is comparatively very high in the Dogger Bank fishing grounds, a closure of this site would have negative consequences for the economies of those fishing there.

Adaptive management in North Sea case study

The closure of the sandeel fishery in Firth of Forth area is in theory subject to recurring revision by the EC. There are no set rules for specific adaptation following evaluations of this MPA. The ICES study group convened in 1999 suggested that kittiwake breeding success could be used as a sensitive indicator of sandeel availability to other sandeel-reliant predators, and that the closure should stay in force until kittiwake breeding success exceeded 0.7 fledged chicks per well-built nest. However, this suggestion was not accepted by the Commission, and no alternative method has yet been established that can be used for managing the sandeel fishery in the area. The closure was reviewed for the Commission in 2001 but no further reports have been requested.

The present regulation of the North Sea sandeel fishery by a real time management regime is in effect adaptive to the overall sandeel biomass. A low incoming year-class (age 1) will stop the fishery at an early stage and thereby leave a sufficient amount of sandeels to keep the spawning stock biomass above critical levels for recruitment. The effect of this management regime has not been quantified in relation to risk of local depletion, but is unlikely to provide sufficient protection against local depletion of sandeels due to fishing.

The North Sea sandeel case study has developed a model tool for sandeel fishery management system that evaluates a dynamic mosaic of sandeel MPAs covering potential sources of recruitment to the ecosystem and the fishing banks. This provides in essence an adaptive management tool that considers all relevant biophysical interactions affecting the sandeel lifecycle in the North Sea and acts on predicted fishing opportunities and identified ecosystem risks.

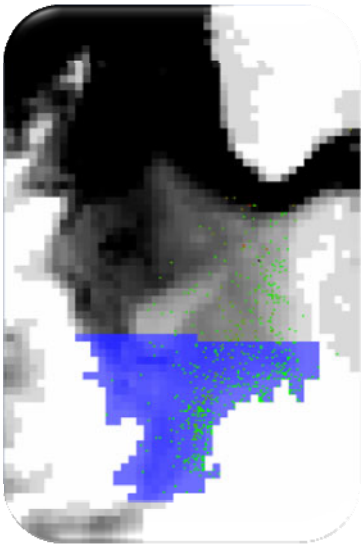

Figure 20. Spatial distribution of the population, scenario= 25% of North Sea closed, as derived from the simulation model (source: PROTECT report by Deerenberg et al. 2006).

North Sea plaice modelling

Conceptually, the North Sea plaice model consists of two layers: a physical and a biological one. The physical layer represents the North Sea (including the Wadden Sea) as a rectangular grid. Each grid cell has relevant physical characteristics, such as mean depth, position, size and temperature. The biological layer contains the plaice, reacting to their physical environment. The model is individual based, that is: the

characteristics of the individual fish are modelled. The emergent properties of the population are determined by the sum of all individuals, not by imposing trends on abundance and distribution on the collection of all individuals.

The plaice model was used to investigate MPA scenarios and relate modelled plaice migrations to the design of the North Sea Plaice box which has been implemented since 1989 to protect nursery areas for flatfish such as plaice and sole (see Fig. 20). Management scenarios were examined that represent a wide range of MPA configurations (incl. no MPA).

In all scenarios in which the closed area was relatively small (incl. current configuration of the Plaice box) no considerable effect was detected by the model. However, closing a substantial part of the North Sea (25%) did indeed have a considerable effect; stock abundance increases by 50%, mean individual weight increases by 100%, and stock biomass increases by 200%. Since the 25% closed area was situated in the southern North Sea where plaice fisheries are concentrated, the catch in numbers is reduced by 60%. The increased survival, however, results in a higher average weight, and catch in weight is only reduced by 40%. The scenario in which the entire North Sea was closed for all fishing resulted in a recovery of the stock, abundance nearly doubling, and biomass increasing nearly five-fold.

Main conclusions from the North Sea case study

Area-based management appears to be viable as one tool to manage the North Sea ecosystem, the sandeel population and the fishery. PROTECT has developed important methods to develop and evaluate MPAs in the North Sea.

- The North Sea case study provides examples where a fishery may be regulated through spatial closures, both for the conservation of the fish stock and for the benefit of other parts of the ecosystem (in these cases birds and other predators on sandeels and most likely other migratory fish species). In effect the Firth of Forth closure is an example of a true ecosystem approach to area-based fisheries management.

- The sandeel work is an illustration of how to design a network of dynamic MPAs that may be reconfigured from year to year depending on the state of the ecosystem.

- The sandeel work also shows how connectivity among MPAs can be operationally analysed to underpin MPA site selection and designation of MPA *networks*. It also highlights the importance of specific habitats for sandeel populations, i.e. one specific habitat can not simply be replaced by another. This not only has implications for MPA site selction but is also of critical value in relation to consideration of the location of other activities at sea such as windfarms. As the sandeel is dependent on specific sediment conditions, activities taking place upstream of habitats may be altered by e.g. sediment plumes.

- A major conclusion from this study is that stock self-regulation must be included when the efficiency of MPAs are assessed by modelling. For the lesser sandeel, self-regulation is expected to partially counteract the benefits of a fishing sanctuary.

- The combined SPAM and BEMCOM model can furthermore conclude that closure of one bank (the Dogger bank) will improve the sandeel stock on this bank, but reduce it on others due to reallocation of effort. Furthermore, the profitability of the sandeel fleet will be negatively influenced by these closures. However, in the case of an MPA in a productive sandeel area of the

size of an ICES square, spill over effects to more distant habitat regions outweigh the loss of local fishing opportunities with the total southern North Sea yield increasing by 16% based on a crude assumption of effort response. This is caused by larval spill over to more distant habitat regions, which cumulatively increase yield.

- The plaice work is an illustration of the importance of one key aspect of behaviour (migration) affecting the required scale of MPAs. The major conclusion from this study is that MPAs as a tool for fisheries management of migratory species such as plaice requires MPAs of considerable size (about 25% of the total North Sea) to achieve substantial effects on population and catch.

The Deep Sea Coral case study

Brief description of the ecological and geographical setting

While deep-water corals have been known to occur since the last century, their extent and potential importance as a key structural element in the European deep-water biotope has only recently become apparent. Advances in side-scan and multi-beam mapping technology combined with improved *in situ* exploration capabilities (principally Remotely Operated Vehicles (ROV) and other imaging platforms) have significantly changed our knowledge of both the extent and the components of this biotope.

Figure 21. *Lophelia pertusa* coral. Photo: P.B. Mortensen, IMR Norway

Coral ecosystems are slow growing, fragile and vulnerable to the impacts of deep-water fisheries and the development activities of the offshore industries. Trawling have already impacted (Fig. 25) between one third and a half of known deep-water coral habitats in Norwegian waters[78]. There is scientific evidence that certain fish species of commercial importance aggregate around cold-water coral (CWC) reefs[79,80]. This may imply that CWC reefs are an important habitat for supporting certain species[81]. If CWC can be empirically linked to a commercial species then it is likely that coral depletion may have a harmful effect on the fishing industry[82].

In Ireland (Fig. 22, 23), there is now evidence of major damage to deep-water corals linked to a recent expansion of the Irish deep-water fishery particularly for orange roughy[83]. This fishery uses trawls fitted with robust rock hopping gear and employs a high risk fishing technique, which is potentially very destructive to coral habitats. The combination of the new knowledge on coral distribution and the increased risk of threat to this habitat lead to the question if coral sites should be protected as soon as possible, while they are still in pristine condition. In 2000, the Irish Coral Reef Taskforce (ICRT) was set up to support the implementation of appropriate conservation measures. The ICRT is made up of scientists, government officials, legal advisors and stakeholders. The group has worked to develop a strategy for the conservation of coral ecosystems in the Porcupine and Rockall areas (Fig. 23). The coral case study in PROTECT has been built on the work of the ICRT and

Figure 22. Cold-water coral reefs/mounds of Ireland (red dots) and fishing grounds (blue) in Irish waters. The black line is the 200-mile limit.

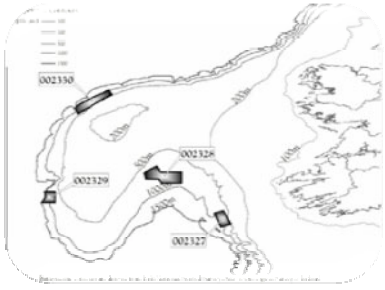

Figure 23. Location of the four offshore coral SACs (Natura 2000) off the west coast of Ireland.

[78] Fosså et al., 2002
[79] Fosså et al, 2002
[80] Husbø et al. 2002
[81] Armstrong 2007
[82] Armstrong & Falk-Petersen 2008
[83] Grehan et al., 2004

recognizes that the development of MPAs as a tool for the conservation of coral ecosystems in the North East Atlantic is supported by bodies such as the OSPAR Commission and by environmental groups.

In Norway, deep-water coral reefs are distributed along the whole coast of Norway from the Tisler reef in Skagerrak close to the Swedish border in the south, to the east of Finnmark county in the north. The species is found in most fjords, on the continental shelf and along the shelf break mostly at 200-400 m depth. The highest densities and largest continuous reefs occur along the continental break and on the edges of shelf-crossing trenches and moraine formations. Fishermen's interviews and direct observation have led to the conclusion that between a third and a half of the total reef area of Norway has been damaged.

Previous closures of fisheries affecting corals

In Europe offshore MPAs have a very short history relative to their more coastal counterparts. Correspondingly, there is an urgent need to determine to what extent inshore experiences in the designation, implementation and bio-economic assessment of MPAs can be used in the deep-sea. Given the distance from shore of offshore MPAs, certain factors are of greater importance, such as enforcement and compliance issues, to ensure the long-term success of offshore protected areas. In August 2003 the European Commission, under the revised CFP, banned trawling from the Darwin Mounds area (west of Scotland)[84] and can be expected to ban trawling from other ecologically sensitive areas in the future. The future success of permanent trawling bans to protect such areas will require co-operation from the fishing industry and improved surveillance, enforcement of compliance and assessment of the degree to which the trawling ban has lead to an amelioration in the ecology of the area under closure. Close integration with coral habitat protective measures linked to the implementation of the EU Habitats Directive will also be required[85].

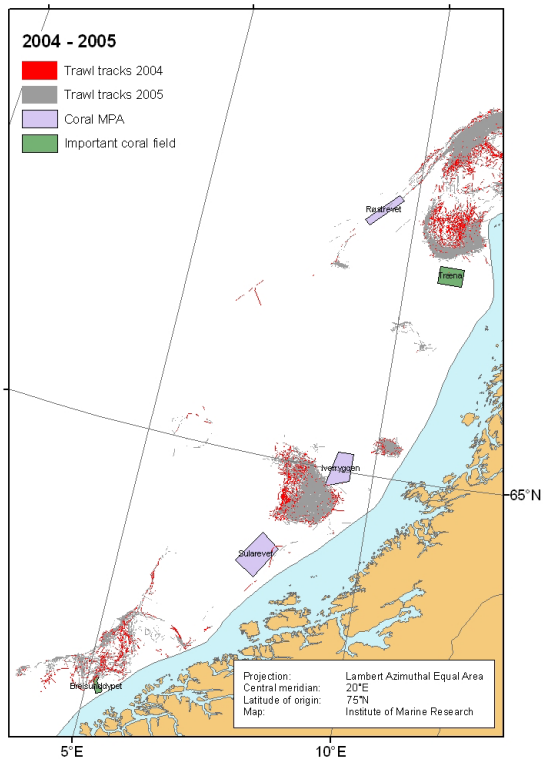

Figure 24. Trawl tracks on the mid Norwegian shelf from 2004 and 2005. Coral MPAs and important coral fields as well as the 12 nautical mile line are shown.

In Norwegian waters, as a consequence of damage caused by fishing activities to coral reefs, a number of areas have been closed on the Norwegian continental shelf to fishing by towed gear to prevent further damage to relatively pristine areas[86,87] (Fig. 24). The Sula Reef outside of the Trondheim Fjord was the first cold-water coral reef area to be protected in European waters in 1999. Norway has since taken a number of legal initiatives to protect other cold-water coral reefs[88] and in 2003 alone, two further reefs, Tisler and the world's largest, the Røst Reef (35 km long and 3 km wide) were protected.

[84] Commission Regulation (EC) No 1475/2003
[85] Long 2009
[86] Armstrong & van den Hove 2007
[87] Fosså & Skjoldal (in press)
[88] Fosså et al., 2002

Purpose of the work done in the coral case study

The main objectives of this case study are to:

- Examine the legislative basis for management of fisheries activities in support of offshore MPAs
- Develop monitoring and management tools for offshore MPAs.
- Carry out economic valuation studies and develop bio-economic models to assess the likely socio-economic impact for fisheries of implementing offshore MPAs

Deep sea coral case study: GOIS & Monitoring strategies

GOIS

The GOIS tables developed in PROTECT in the deep sea coral case study include examples of goals for both no-take areas and areas where some fishing activities are allowed. The also contain both biophysical and socio-economic goals. Furthermore monitoring goals related to specifically allowed activities are listed. All types of goals were prioritized in primary, secondary and tertiary goals. Secondary and tertiary goals increase in their level of specificity.

The primary biophysical goals:

a. Ensure the structural integrity of cold-water coral habitat,
b. Protect living populations of Lophelia pertusa and ensure contributions of local genetic diversity to Lophelia gene pool,
c. Protect associated biodiversity and ecosystem function (including fish populations).

Socio-economic primary goals listed include:

a. Livelihoods enhanced or maintained,
b. State compliance with EU and international obligations and maintenance of international standing,
c. Maintain as scientific reference area and increase scientific knowledge to ensure long-term dividend of research investment is realised,
d. Environmental awareness and knowledge enhanced.

Activity related goals include:

a. Ensure the structural integrity of cold-water coral habitat,
b. Protect living populations of Lophelia pertusa and ensure contributions of local genetic diversity to *Lophelia* gene pool.

Indices and related success criteria for the Deep Sea Corals CS can be found in Appendix 1c. Note however, that in the case of cold-water corals, basic research is still at an elementary stage and some of the potential indices that could be used to monitor the success of management objectives have yet to be fully worked out. This means that the table can be used to guide and prioritise future research in support of management objectives.

MPAs set up to protect cold-water coral reefs can either be no-take zones (no extractive activities allowed) or allow for some extractive activities (e.g. fishing using static gear, or only pelagic trawling). The goals for these two types of MPAs will probably be similar, but some of the objectives, indicators and success criteria may differ. Both types of MPAs were analysed in PROTECT. The goals were divided into:

1) Biophysical

- Ensure the structural integrity of cold water coral habitats
- Protect living populations of *Lophelia pertusa* and ensure contributions of genetic diversity to *Lophelia* gene pool
- Protect associated biodiversity and ecosystem function (including fish populations)

2) Socioeconomic

- Livelihoods enhanced or maintained
- State compliance with EU and international obligations and maintenance of international standing
- Maintain as scientific reference area and increase scientific knowledge to ensure that long-term dividend of research investment is realised
- Environmental awareness and knowledge enhanced

The coral GOIS procedure was useful for identifying a suite of 'generic' MPA goals and 'success criteria'. Even a casual glance at the results suggests that the choice of indicators developed in the project to use for monitoring, particularly offshore, will be very cost dependent. An example is the use of VMS to monitor the frequency of fishing vessel activity in an MPA. When no fishing activity is permitted in the MPA, VMS can be cost effectively used to demonstrate compliance. Allowing derogations for some types of fishing (e.g. pelagic fishing) reduces the effectiveness of VMS as fishing activity will be registered. For control purposes, the type of fishing activity will require periodic checks by fisheries patrols and thus lead to higher costs for the Member State charged with enforcement. Equally, the GOIS work also revealed the lack of suitable measurable performance indicators and defined success criteria. This means that the Table can be used to guide and prioritise future research in support of management objectives.

Monitoring of compliance

In the deep sea coral case study, monitoring has been heavily focussed on the spatial monitoring of management compliance, i.e. using VMS, of fisheries and their compliance in relation to MPAs for deep sea corals.

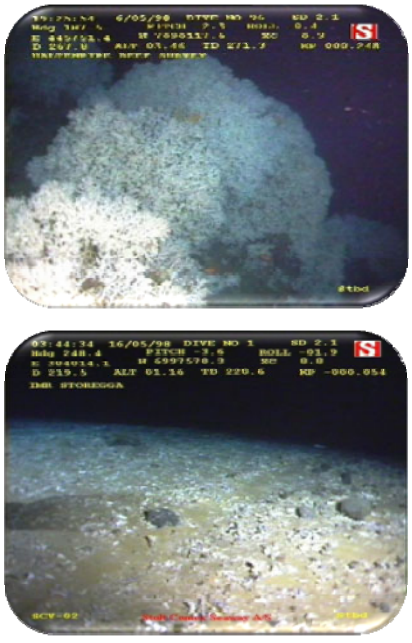

Figure 25. Pristine and damaged corals. Institute of Marine Research, Norway

VMS data was available for all countries fishing in Irish waters and this provided a general impression of fleet activity. However, for the majority (80%) of vessels fishing in Irish waters there was no information concerning vessel speed, thereby preventing an interpretation of those vessels likely to be fishing and those merely steaming through the area. For 20% of the fleet, the distribution of vessels travelling at more than and less than 6 knots was made available to the group, assuming that those moving at >6 knots were not fishing. This analysis showed that the main concentrations of VMS returns comprised those vessels moving at less than 6 knots, and therefore assumed to represent the distribution of the major fisheries.

Further analysis of these data will require a more detailed understanding of the speed and operation of a range of gears in these waters than is currently available. For example,

Spanish longline vessels are understood to set their lines at a speed of 10–12 knots, and haul them at less than half that speed. The simple analysis described above would therefore exclude such fishing operations and affect the interpretation of the data.

In the absence of more detailed analysis, all VMS data have been used to ensure that the fleets of all Member States are included. However, in addition to the risk of presenting areas where vessels are only travelling, not fishing, as described above, fleet distribution patterns may also be biased by the differences in reporting frequency of vessels from different Member States. The extent to which this creates a visual impression of artificially high levels of fishing activity is unknown.

VMS to monitor coral MPAs in Norway

PROTECT work has shown that established coral MPAs in Norwegian waters seem to be respected by the trawling fleet. There is not much trawling along the shelf edge where the Røst Reef is located or in the Sula area, but there is evidence of heavy trawling near the Iverryggen closure. In the 1990's, trawlers started to fish northeast of the traditionally used trawl ground that corresponds to the area trawled in 2004 and 2005. The hilly area to the northeast that corresponds to the now closed area, contains considerable amounts of coral reefs. Some of the reefs were trawled down as the trawlers worked their way uphill. Damage on the reefs was documented in 1999 and an MPA was established in 2000.

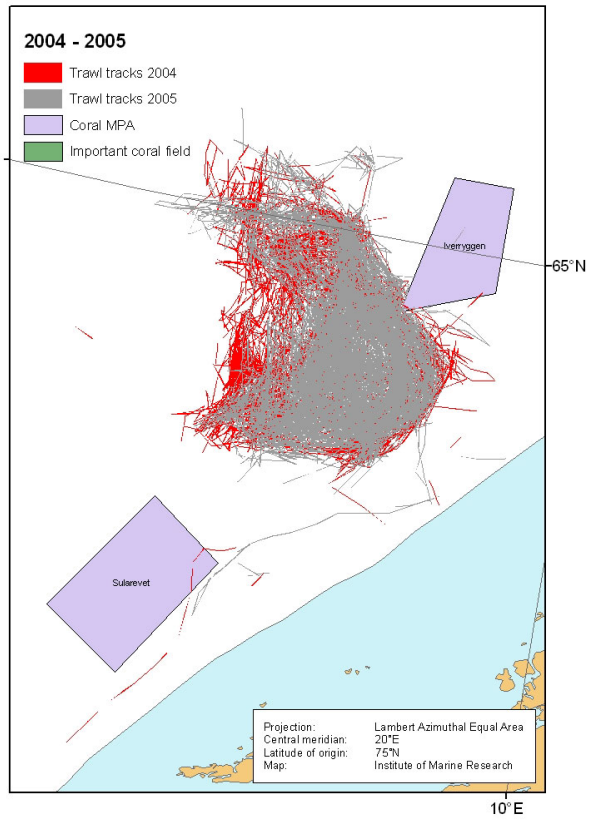

Figure 26: Trawl tracks in 2004 and 2005 in the vicinity of the Sula (left) and Iverryggen (right) MPAs.

The VMS data (see Fig. 26) shows that the fishing activity occurs outside the coral MPA although they come as close as possible to the border in the southwest. The direction of the bottom current in Iverryggen is not known, but the heavy trawling very close to the MPA can potentially have a significant impact. This should be followed up by measurement of the bottom current and monitoring of the particle concentration in the water in combination with an assessment of the condition of the reefs with emphasis on possible sediment particle loads.

This example shows how the VMS clearly identifies the changed fishing pattern where an MPA has been established. Unfortunately we do not have VMS data before the area was closed, but we know they trawled there because many fishermen reported the activity to IMR and in addition we documented severe coral damage on video (e.g. Fig. 25).

Deep sea coral case study: Modelling approaches and results

In the coral case study, modelling approaches were used to:

1. Investigate a bio-economic model with renewable and non-renewable interaction, where the non-renewable resource (cold-water corals) enters into the growth function of the renewable resource

(commercial fish species). Non-use values of the corals were also to be included in the model description.

2. Explore management involving gear restrictions/marine reserves/transferable habitat quotas, applied to the model in 1.
3. Design an applied model using a specific fishery in the proximity of corals; test and simulate management options.
4. Apply choice models to assess public preferences with respect to environmental preservation for the deep-sea coral case study.

Coral/Fish Production Function Approach

Data from the Norwegian redfish (*Sebastes marinus*) fisheries was used to employ a production function approach in order to explore the linkages between coral and fish. Furthermore, a theoretical bioeconomic model named HABFISH was designed in order to assess how optimal management is affected by different coral-fish interactions.

The results indicate that reduction in deep water coral has affected redfish harvest along the Norwegian coast. The statistical results were significant for as low reductions in coral coverage as 5%. This indicates that coral protection may indeed be of interest from a fisheries perspective.

Figure 27. Redfish and coral. Photo: Institute of Marine Research, Norway

The bio-economic modelling of the Norwegian redfish (*Sebastes marinus*) fishery show that there is a strong link between coral occurrence and redfish catches (Fig. 27), indicating that destruction of coral habitats would be harmful to the fish stocks, but also to the fishery. The analyses also show that the effect of fishery closures (MPAs) on the economy of fisheries depends on whether the corals are an *essential* or a *preferred* habitat for the redfish. If MPAs may contribute to preventing the damage to corals, then the importance of MPAs to the fishery is obvious if the habitat is essential for the redfish. However, if the coral reefs habitat is preferred (rather than essential), the situation is more complex, and MPA areas may act either as sources or sinks, depending on the circumstances. MPAs may then be beneficial to the economy of the fishery if fishing with non-destructive techniques is allowed inside the MPA, while this is not necessarily the case if the MPA is a no-take area.

The above results are of course subject to there being no non-use values connected to coral. In order to assess this, choice modelling was carried out (see below).

Empirical assessment of public preferences: choice modelling

Statistical models were implemented to describe user preferences with respect to environment preservation for the deep-sea coral case study[89]. This work is quite original in the project as it is related to estimating and modelling non-use benefits, in contrast to fisheries management issues prevailing in the other case studies. It is also original as there are few such empirical studies concerning marine biodiversity conservation.

[89] Glenn et al. (accepted)

The technique selected was choice experiments, which was applied to the case study with the aim of measuring the preferences of the Irish general public for the protection of deep-sea cold-water corals using MPAs in the Irish Sea and the associated non-use values. The mechanism and aim of CE is to estimate the structure of an individual's preferences by establishing the relative importance of different attributes as incorporated in a set of alternatives presented in a questionnaire format.

The results clearly show which individual objective the respondents prefer. The preferred combinations of attributes were in order, to:

1. ban trawling in an MPA that would include all areas where corals are thought to exist with no personal tax imposed,
2. ban trawling in an MPA covering all known corals with a personal tax imposed of €1 p.a.,
3. to ban all fishing in an MPA covering all areas where corals are thought to exist with a personal tax imposed of €1 p.a.

In terms of the probabilities attached to the individual attributes, the most preferred policy options were in order to (1) ban trawling, (2) protect all areas where corals are thought to exist, and (3) pay a ring-fenced personal tax of €1 p.a. Unfortunately, the attribute of COST in the model was not statistically significant, undermining the determination of part-worths for the attributes and levels, and the estimation of a willingness to pay (WTP). However, a €1 annual tax for a population of 3.2 million (2006) aged 18 years and over is sizeable. Table 4 contains the respondents' level of agreement (percentages) on attitudinal questions regarding corals, fisheries and coral conservation.

Table 4. Respondent's level of agreement (percentages) on attitudinal questions regarding corals and coral conservation.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
a) Before filling in this survey I was unaware of the Irish cold-water corals	8.1	13.8	7.6	34.9	35.4
b) I have never come across deep sea fish such as Orange Roughy, Grenadier and Black Scabbard	6.2	7.4	3.1	37.5	45.6
c) I have an interest in commercial fishing	37.6	17.0	25.2	11.9	8.0
d) I have little or no interest in the marine environment	28.3	35.4	16.2	8.5	11.4
e) I think that the Irish public have a responsibility for the protection of the marine environment in Irish waters	3.1	1.9	2.9	30.6	61.2
f) The Government should do more to protect the interests of Irish fishermen and fishing communities	2.4	2.9	9.8	31.2	53.6
g) The Government should do more to protect the Irish marine environment	1.9	0	2.6	32.5	62.7
h) I think that trawling can be a sustainable method of fishing	17.9	27.3	34.0	17.0	3.6
i) Banning all fishing is the only way to protect cold-water coral ecosystems and the animals that depend on them.	13.5	41.1	22.0	12.8	10.4
j) I would be willing to pay more for fish that is managed and caught from cold-water coral areas in an environmentally responsible way?	2.4	5.9	15.2	55.1	21.1
k) Cold-water corals should be protected because they provide direct uses such as raw materials for biomedical industry, essential fish habitat and as a carbon sink that	0.5	1.2	10.8	42.0	45.3

support climate change.					
l) Cold-water corals should be protected so that I can personally have the option to use or see them in the future	3.1	6.9	28.6	36.2	25.1
m) Cold-water corals should be protected for the benefit of my children and future generations	0.5	0.5	9.0	41.9	47.9
n) Cold-water corals should be protected because they represent a unique and fragile ecosystem which has a right to exist, although I don't intend to use or see them,	0.7	4.0	11.1	43.6	40.3

The findings of this study provide advocates of coral MPAs stated endorsement of their actions. They also enable policy makers to estimate the level of support for different management options and potentially use the results as controls within a modelling context.

Main conclusions from the Deep Sea Coral Case study

- The coral case study serves as an example of MPAs where the conservation of biodiversity may be the main goal. The Norwegian redfish example shows that such MPAs, despite having negative impacts on fishing opportunities, may have equal importance for the protection of fish stocks too. The coral case study is also an example of the legal, practical and economic challenges of establishing MPAs offshore.

- However, choice experiment survey showed that commercial fishermen are not the only stakeholders with an interest in deep sea coral reefs. The resources protected by MPAs often have a potentially larger non-use value than use (market) value. This non-use value requires determination to help balance the costs and benefits of MPA implementation.

- The surveyed part of the Irish public was in favour of the protection of cold-water corals. The preferences and political endorsement lay with selective exclusion of trawling rather than the designation of a no-take zone, which endorses the applicability of the findings of the Norwegian redfish modelling. The stance of the Irish electorate in terms of the area of reefs protected was, however, more precautionary and all-inclusive, for which they were prepared to pay personally. The findings of this study also provide advocates of MPA designation for the corals stated endorsement of their actions. It is also feasible for policy makers to estimate the level of support for various combinations of the management options or use the results as controls within a modelling context. Reference to environmental valuation techniques and particularly, choice experiments is a critical part of pre-project evaluation.

- Good data to describe the distribution of international fishing fleet in the waters of Member States are essential if the interests of the fishing industry are to be properly represented in the management of Natura 2000 sites. Further efforts must be made to include fishing gear type and vessel speed with all VMS records, and make them available for scientific analysis. Logbook data describing the catch by fleet and country will be necessary to assess the implications of these fleets on the conservation features.

- Although there is more work required to provide complete datasets describing the distribution of fleets, and more detailed information on the conservation features and reef-associated species, sufficient information has been made available to assess the impact of fisheries on each of the proposed sites.

- A more detailed understanding of the speed and operation of a range of gears in these waters than is currently available. For example, Spanish longline vessels are understood to set their lines at a speed of 10–12 knots, and haul them at less than half that speed. The simple analysis described above would therefore exclude such fishing operations and affect the interpretation of the data.

- In the case of the Norwegian coral MPAs on the continental shelf the use of VMS has proven very helpful both to scientists and managers. The scientists can use the information to evaluate the ecological condition and impact from fishing activities in an area and the managers can use the data as a tool in the process of identifying conflicts and consequences for the fisheries of a closure. It was also concluded that the trawlers respect the established coral MPAs and that VMS is a very effective method to monitor compliance. The high degree of compliance can be a result of the fishermen knowing that they are surveyed and that the vessels can be identified.

PROTECT general framework for establishing and managing MPAs

PROTECT has covered many aspects of the complex issues related to the establishment, management, monitoring and evaluation of MPAs, and some of these aspects have been related to very specific settings and situations. In this section we aim to broadly analyse the results from PROTECT in relation to a *generic* adaptive planning and management framework (figure 28). The framework was discussed and developed throughout the project lifespan, based on several other frameworks available in the literature. It is important to understand that any step of the framework can and should be revisited if new knowledge or new goals emerge in relation to a given MPA.

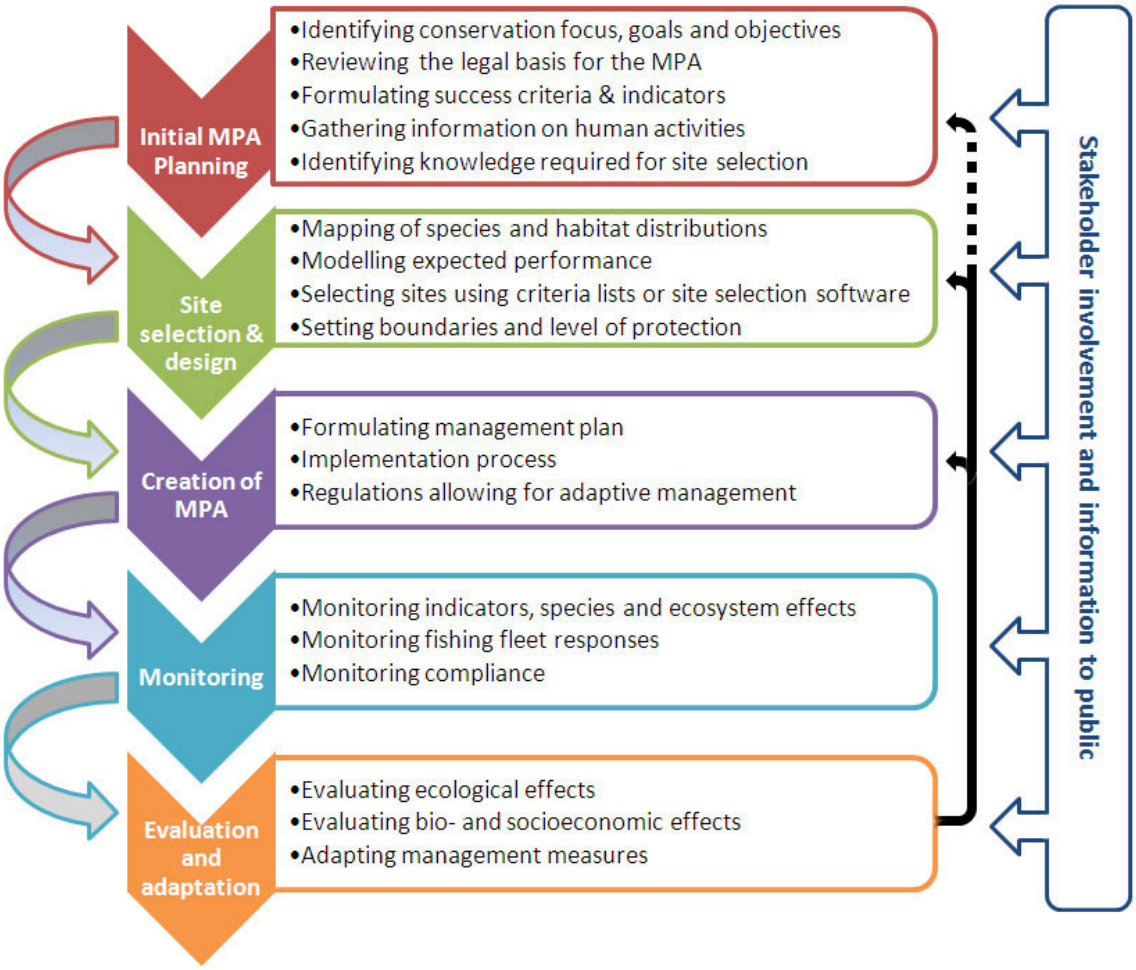

Fig.28. The PROTECT planning framework for developing and managing MPAs

Initial MPA planning

Identifying conservation and resource management focus

The general purpose of an MPA must be determined as the intuitive first step in the life of any MPA. The general approach will vary greatly depending on whether an MPA is viewed as either a fisheries management measure or a tool for conservation and protection of biodiversity and/or certain features in the sea.

However, in some cases the differences between the two approaches become blurred, i.e. in cases where certain marine features play an essential role in the life cycles of target fish species. For instance, deep-sea coral reefs are the focus of much attention among the conservation community while also serving as important fish habitats, supporting fisheries in the vicinity of reefs. Sandbanks are among the habitats listed in the Natura 2000 habitats directive and MPAs have been designated to protect them (albeit no management is yet in place). Coincidentally these sandbanks constitute highly essential habitats for sandeels in the North Sea.

One of the fundamental obstacles that must be overcome in such situations is the disentanglement or determination of sectoral jurisdiction, i.e. who is in charge of what? If the overarching purpose of an MPA is not sharply defined by management bodies and policy makers it can not be expected that stakeholders will understand the reason for its implementation, let alone support such an initiative. In recent years a growing number of European MPA initiatives have been rooted in an ecosystem approach to fisheries management, signalling a gradual shift from a strict fish/ecosystem division towards greater integration between sectors and a better understanding of the interdependence between healthy ecosystems and sustainable fisheries.

Formulating goals and objectives, success criteria and indicators

Any form of resource managment or biodiversity conservation plan originates from some sort of vision of what should ultimately be achieved. Translating this commonly rather vague vision into more concrete goals and objectives is not an easy task but must nonetheless be the first stage of MPA implementation to promote its success. The process of goal setting is commonly a political process (see above), closely linked to stakeholder expectations. It is therefore a good idea to involve stakeholders in the very first steps of MPA implementation. Failure to do so, e.g. with the view of saving time, usually results in lost time in the long run.

In the PROTECT case studies, it became very clear that evaluation of MPA success and/or failure is impossible without clearly formulated goals and objectives. Without goals and objectives it is not possible to formulate success criteria and related indicators (see below).

At the start of the project, goals and objectives for the different case study MPAs were either very vague or not formulated at all. PROTECT experiences show that the time spent working with goals and objectives was well worth it, and it is therefore a strong recommendation for any MPA process to allow for substantial time devoted to this stage. A common view at an early stage among managers and stakeholders regarding goals, objectives and general expectations will greatly facilitate the later process.

Success criteria are the concrete measures of success for a given MPA. These must be determined in the initial stages of MPA development and not, as has often been the case, many years after implementation. As it is not practically nor financially feasible to measure everything at sea, strategically formulated indicators must be developed to measure the level of success that an MPA is acheiving. Clearly formulated success criteria and indicators of success are of course tightly linked to goals and objectives, and are equally essential for designing monitoring programmes. Without clearly defined goals, objectives and success criteria and indicators it is in principle (and practice) unfeasible to determine or monitor whether or not an MPA has accomplished what it was set out to accomplish or what can be altered to improve its performance. This has also been evident in relation to coinciding evaluations of existing closed areas implemented under the Common Fisheries Policy for which no clear goals, objectives and success criteria had been formulated prior to their establishment. The actual variables measured can be decided in a process involving stakeholders, but as success criteria and corresponding indicators are more technically detailed than goals and objectives, the process of their formulation may be the responsibility of the management organisation in collaboration with scientists and stakeholders.

In PROTECT, it rapidly became obvious that it is easy to formulate many and ambitious goals and objectives, which then require a large number of sucess criteria resulting in potentially very costly monitoring programmes. Formulating success criteria early in the MPA implementation process may thus have a sobering effect on the ambitions of the MPA, and sometimes the result is that the goals and objectives may need to be reformulated.

Reviewing the legal basis for the MPA

Regardless of the purpose of an MPA, it should stand on a solid legal foundation. According to PROTECT, an MPA is *any marine area set aside under legislation or other effective means to protect marine values.* By stating that MPAs must be set aside under legislation *or any other effective means*, the definition does not exclude voluntary agreements such as a code of conduct among fishermen, etc. One example of this is a Scottish voluntary system of real-time area closures that in 2007 was introduced with the co-operation of the Scottish fishing industry as an effective means of protecting concentrations of cod.

Giving any generic advice on the legal basis of MPAs is difficult, however, as the legal setting will vary from case to case and diverse legislation governs MPA designation and the jurisdiction thereof. Jennings (2009)[90] argues that MPA designation would be simplified by pre-arranged and pre-negotiated agreements among all relevant authorities, elaborating that agreements could specify how to make trade-offs among objectives, interpret scientific advice, ensure effective engagement among authorities and stakeholders, deal with appeals and support progressive improvement.

Gathering information on human activities

It is difficult to imagine implementing an MPA without collecting biological data on the resource and/or the biodiversity of the site. However, an MPA is an intervention in the utilisation of the sea and its resources and it is therefore equally important to gather data on human use, human-induced threats, human resources, social setting, governance structure, and other socio-economic data. A baseline invetory of the biological resources is essential. In a similar fashion, data for a governance baseline should be collected before the MPA is implemented.

In the PROTECT project difficulties were experienced in finding the essential socio-economic background information. Socio-economic data of relevance to MPAs typically suffers in two respects: Firstly, existing data often lacks consistency in space and time with any MPA proposed, such that limitations are encountered in drawing specific conclusions. This is notably true for fishing activities, which are rarely geographically confined. Secondly, there are large gaps in the types of data available, requiring dedicated collection, as in the case of the determination of the non-use value of an MPA and public/political endorsement of the management alternatives. Primary data collection is often required, yet not always undertaken due to a perception that it is too expensive or unnecessary. Expanding the discussions on goals, objectives and success criteria to include both biological and socio-economic aspects may help to balance the monitoring needs.

Identifying knowledge required for site selection

Knowledge required for site selection includes physical and ecological criteria, evaluation of human pressures and behavioural responses by the fishery to management and changes in the ecosystem, social acceptance and management constraints within the area where an MPA must be implemented. Obviously, site selection depends on the objectives of the MPA, which in turn dictates the kind of knowledge needed

[90] Jennings 2009

for site selection. In all three PROTECT case studies, site selection were important parts of the analyses. Both data collection and modelling were used to identify the knowledge required for this. The obvious criteria of quantifying the importance of sites as being essential habitats for the target organisms of protection may be supplemented with the role of specific sites in connectivity for the dispersion and colonisation of other potential sites in the region. This connectivity may have importance both with respect to completing individual life cycles in motile and migrating species and in a longer perspective providing protected sources of larval dispersal in sessile and more resident species.

For fisheries management related objectives the reduction of fishing mortality may be a primary MPA goal. In such cases site specific information about migration rates and mixing of size and age classes is of importance for selection of MPAs that will decrease overall catches and/or discarding.

To optimise sustainable yields and reduce the adverse effects of fishery/effort displacement, information about site specific resource distribution, production and catch rates to calculate costs and earnings is important in modelling fishery behaviour in bio-economic scenarios with different MPA design and selection.

The use of Choice Experiments within environmental economics facilitates the identification of public preferences and willingness to pay for specific MPA alternatives, including among other things the spatial scope thereof. The statistical significance of the attribute area, along with that for the attribute pertaining to the extent of exclusion, arising from the model for the coral case study demonstrates strong public preferences in this respect. As previously noted, such public preferences underpin the political support, resource, economic endorsement and public cooperation required for an effective MPA. The outputs of choice experiments can also potentially serve as controls within subsequent modelling that permits the setting of maximum and minimums for certain parameters.

Site selection & MPA design

Mapping of species and habitat distributions in potential areas

If several areas are candidates for MPA designation, then obviously the distribution of the target species will be one of the things that are important to map, and to compare among candidate areas. The better the knowledge of species distributions, the greater the opportunity to properly design the MPA (e.g., in terms of size, borders, regulations, zoning). In PROTECT case studies the focal species differed: in both the Baltic case study and the North Sea case study, the distribution of the commercial target species was the primary study object to map, while in the coral case the mapping of coral habitats was the most important subject for the MPA analysis.

Modelling the expected performance of planned and implemented MPAs

The location of an MPA can obviously affect its effectiveness and its consequences for the environment and resource use (including fishery). Modelling the effects of the MPA in different alternative sites (or sizes, borders etc.) can therefore aid in selecting one site over another already in the implementation phase. All three case studies in PROTECT show examples of this.

Selecting sites using criteria lists or site selection software

When selecting sites for MPAs with many goals or target species, as is commonly the case for MPAs designed for conservation purposes, criteria lists or dedicated decision support software is commonly used.

In the case of e.g. the Great Barrier Reef Marine Park (e.g. Day 2008)[91], site selection decision support software was used to determine optimal zoning of sub-sites within the MPA. The resulting configurations of zones was subsequently utilised in stakeholder consultations. The result ended up looking substantially different once socio-economic considerations and stakeholder consultations were complete.

In all three PROTECT case studies the focus has been on one target species (and to varying degrees on the role of that species in ecosystem and for the society). As a result, the use of criteria lists and dedicated software was less relevant.

For the Baltic case study, no criteria list or dedicated software was used for the implementation of the MPAs for Baltic cod. However, one of the main outputs from the case study is the efficiency of different MPA scenarios on the stock development as tested with the ISIS-Fish Model, which can be said to fill this function. Sites of potential sandeel MPAs in the North Sea were modelled and selected according to case study specific objectives (see North Sea GOIS), where criteria may encompass minimising risks to local population depletion and maximising sustainable exploitation of the sandeel subpopulations.

Setting boundaries and level of protection

Setting the boundaries is an important issue. Boundaries can influence not only what is included in the MPA, but also who or what is excluded from the MPA. This is relevant both for the target species and for the users of the area. The configuration of boundaries may influence the ease of compliance, and the cost of monitoring compliance.

Behaviour of fishermen (i.e. the displacement of fishing effort) relative to the MPA boundaries was analysed in the Baltic case study, revealing strong boundary effects where some categories of fishermen were more affected by their MPA than others. There was intense fishing along the boundaries of the MPA, as is commonly found in MPA studies (the "fishing the line phenomenon"). In many cases this is an expected and even planned outcome of an MPA designation, but may have strong negative effects if the boundary is situated in the wrong place, so that the intensified fishing effort takes place in an area that actually should be included in the MPA. Optimal boundaries for new MPAs for the sandeel in the North Sea should consider the natural habitat limitations for lesser sandeel, the level of connectivity between habitats, the selected objectives e.g. benefits for the sandeel population and thereby their influence on the ecosystem and the livelihood of the fishers. In the Irish coral example, the influence of the boundaries and the geographical shape of MPAs was shown to be important for monitoring of compliance, as discussed more in depth in the section on the use of VMS data.

Boundaries of course also have strong socioeconomic and other societal implications. To engender political support for legislation, supportive data is essential, including scientific and socio-economic data and evidence of public/electorate support for the measures proposed. Boundaries and the level of protection are two of the elements of MPAs that were targeted in the choice experiment study with the results demonstrating public support and willingness to pay for the largest area of protection offered and the level of exclusion set at the exclusion of trawling. Such evidence helps politicians legitimise actions that may prove unpopular to other stakeholder groups (e.g. fishermen).

[91] Day 2008

Establishment of MPAs

Formulating the management plan

There are many publications and more or less established practices on how to formulate a management plan. A management plan must reflect both the natural and the political setting, and therefore differs from case to case. In PROTECT, the legal setting was similar among the three case studies, but with different emphasis on conservation vs. resource managment, and on the interactions between different policies (e.g. the common fisheries policy, the habitats directive, and national laws).

Implementation process

None of the PROTECT case studies have studied the actual implementation of an MPA, and therefore PROTECT does not add any case specific knowledge in this particular stage of the process. Nonetheless it can be stated that transparency has been one aspect of European MPA implementation that may be improved greatly. During implementation of MPAs it is essential that the purpose and expected benefits of the implementation of a given MPA is widely communicated and clear to affected sectors and to society as a whole. In some cases such as e.g. the Shetland Box (see PROTECT MPA Review), it has been debated whether the closure has been established on a socio-economic foundation or on the basis of fisheries biology.

Regulations allowing for adaptive management

In simplified terms, adaptive management requires a set of goals of what should be acheived, a monitoring system to follow what is happening, a system to evaluate the results and finally some form of management/governance system to make the necessary adjustment to the MPA management plan. This may sound simple, but in reality this has seldom been explicitly laid out in MPAs in Europe so far. The case studies in PROTECT are no exceptions. Although the three MPA systems all contain important elements of adaptive management, it is not explicitly formulated in such terms in any management plans. Nor is it very transparent to an outsider. That said, the management of fish resources have a long history of something similar to adaptive management. If the management of fisheries has not been very successful (judging form the present state of many stocks), it is not necessarily caused by a lack of adaptive measures, but perhaps rather that the management responses have not been in proportion to the effects measured. It has so far been rather uncommon to incorporate adaptive management within nature conservation MPA initiatives, but this is rapidly changing. With the creation of new MPAs and corresponding management plans a golden opportunity arises to include truly adaptive measures into the managment plans.

Modelling to evaluate MPA effects

As argued throughout this report, the PROTECT project strongly encourages systematic evaluations of MPAs. Evaluation requires observations of outcomes of the MPA management regulations, i.e. some form of monitoring. Monitoring is expensive and time-consuming, and therefore monitoring should be directed toward site specific formulated goals and objectives and not a general monitoring framework. Monitoring should therefore be linked as closely as possible to the indicators related to the goals, objectives and success criteria of the MPA (see above). Monitoring is also linked functionally with indicators, as much of the indicators of the efficiency of MPA to attain management objectives rely on statistical assessments (statistical models) and/or dynamic models. Modelling results (in terms of indicators built from monitoring data) can help to improve monitoring protocols, since assessment is the main goal of monitoring.

PROTECT has made large efforts in evaluating MPAs of different nature. This includes the collation on a vast amount of information, which is presently incorporated into the final version of a meta-database. This information facilitated the extensive modelling work of protect and has been used for developing monitoring strategies. The major conclusion that emerged from developing case study specific monitoring

strategies and comparing them in PROTECT is, however, that generic principles for MPA monitoring strategies are difficult to define. Each ecosystem and/or target species needs a specially designed monitoring scheme accounting for its special characteristics. A further clear result was the need for a better monitoring of the socio-economy of involved communities and of the compliance of the implemented closures.

Evaluation and adaptive management of MPAs

Evaluating ecological effects

The management criteria and monitoring systems put in place for an MPA are case specific. However, analysis of the effects of any MPA is likely to require certain fundamental knowledge of fisheries and ecosystems independent of the specific case. Common data-types are likely to be a common feature (e.g. baseline information from before and after the MPA was established), and such data can be analysed using a standardized suite of methodologies. The ideal experimental design, to test conclusively whether MPAs have a particular ecological effect relative to their original goals, would involve monitoring regimes at multiple localities that include surveys before and after MPA establishment. It is important to note that different species will respond to protection in different ways, and at differing rates. Comparisons of 'before vs. after' and 'inside vs. outside', need to take such factors into account.

An important messsage from PROTECT is that modelling may have an important role to play in the evaluation of MPAs.The main area of improvement for modelling approaches lies in the development of models that achieve a trade-off between parsimony and complexity, and are parameterized and calibrated against real data. More specifically, models are needed that explicit the spatial dynamics of population and exploitation at the scale of MPA design, including the seasonal scale if relevant (e.g. for temporary MPAs). Models should account for mixed fisheries (multi-species multi-fleet fisheries), and for fishers' response to MPA. Models should allow for thorough investigations of MPA designs including permanent versus temporary MPAs, partial restrictions of fishing activities, and reserve networks. They should also provide for other management measures, as MPA are not the only management tool used in a given fishery. Concerning empirical assessments of MPA effects, experimental design is a major area of improvement. Properly replicated Before-After-Control-Impact (BACI) designs are still insufficiently developed.

Evaluating bio- and socio-economic effects

The socio-economic side of the efficacy of an MPA is of crucial importance for the acceptance of a closure and hence the compliance of the fishery. These kind of monitoring activities need, however to be further developed. The use of GOIS tables makes it easier to define appropriate MPA goals and 'success criteria'. Goals are to be set for both biophysical, socio-economic and governance purposes and contribute to identify significant data and monitoring gaps.

A weak point in all case studies dealt with in PROTECT is the relatively paucity of monitoring activities for socio-economic data. Monitoring compliance was not incorporated in the monitoring strategies. It is in the future best conducted using VMS-data, depending on its legal availability.

A common feature of the PROTECT case studies is that they all deal with the *direct use value* of the marine resources, typically in the form of 'consumptive' outputs (e.g. fish) but in some instance 'non-consumptive' benefits (ecotourism linked to seal watching).

Adapting management measures

If an MPA is not performing as expected due to changes in human uses, technology, ecosystems etc., it is crucial that MPAs and their management are evaluated on a cyclical basis and are reconfigured accordingly to adapt to such changes. For instance, 'non-stationary' of natural ecosystems has been a confounding factor, influencing the apparent success or failure of closure areas, including the southern North Sea 'Plaice box'. Alternatively, MPAs may become "white elephants" that merely obstruct human uses of the sea without the resulting benefits that justify such substantial trade-offs.

Simulation models are indispensable tools to support adaptive management, in the case of implemented MPAs. It allows the evaluation of a range of scenarios against the present state of nature corresponding to the present MPA zoning under the current human pressures. The comparison of scenarios enables adjustments in the regulation of uses to better reach the management objectives. Ideally, this should be possible with all the uses, but as the link between the pressure of a given use and the impact of this use upon the ecosystem is more highly quantified for fishing, this approach requires more development for the other uses.

The second kind of modelling that can support adaptive management relates to the quantitative assessment of MPA effects from monitoring data. In this case, modelling consists of statistical modelling. Once the link is established between the diagnostic resulting from the assessment and the management actions to undertake, such assessments may be used to assist decision making for the adaptation of management.

Stakeholder involvement & information to the public

Stakeholder involvement is important during all stages in the implementation, management, and evaluation of MPAs. There are several reasons for stakeholder involvement, among them:

1. *It is a part of a democratic process*: People that are affected by actions such as the implementation of an MPA should also have a chance to influence such actions. In particular, the formulation of goals, objectives and success criteria is a stage where stakeholders should be involved more often than is common today.
2. *It commonly makes the implementation process run more smoothly:* it may be tempting to think that running the process without the time-consuming stakeholder involvement process would be a faster and more efficient process. It is an experience by several PROTECT partners that this is not the case – failure to involve stakeholders early in the process will make the process much more difficult in the later stages of MPA implementation.
3. *It may leed to better management actions*: Stakeholder often have important knowledge to add to the management process, and incorporating the practical views of stakeholders will make compliance to regulations more likely. For instance, meetings held with the fishing industry have led to concrete suggestions for how to improve the methodology used in the North Sea case study for sampling of sandeels in the seabed as well as in the water column.
4. *Assistance in monitoring:* Contrary to periodic monitoring programmes, stakeholders are often in "the field" on a daily basis and are able to detect and report short or long-term changes in the marine environment that may lead to higher adaptiveness in MPA management. Real-time closure of fish spawning grounds or nursery areas are one example of such participatory monitoring.
5. *Society's role in balancing management trade-offs:* The public is the largest of all stakeholders and sometimes the most difficult to engage in relation to specific MPAs. However, if efforts are made to gain insight to the views of the general public, management measures which may be detrimental to one affected sector may in some cases be justified by large-scale support from other parts of society.

PROTECT has been a research project, so the purpose has not been to establish any specific MPA. As a result, PROTECT has not dealt with stakeholder involvement in the context of any formal MPA designation process.

Nonetheless, as stakeholder involvement is important to MPA efficiency, a number of PROTECT activities has consulted stakeholders and analysed their viewpoints. Most of the areas studied in PROTECT are offshore sites, and the number of stakeholder groups involved are therefore smaller than is common for coastal MPAs. Stakeholder involvement has been included in PROTECT to acknowledge e.g. the value and knowledge that rests in the collective experience of (in this case) fishermen. Considering the time they spend fishing in the same marine areas in which scientists are planning to establish MPAs or networks of MPAs, their knowledge is important to the aim of defining MPA sites that efficiently meet the goals while at the same time having minimal negative socio-economic effects on the fishery. For instance, of four different marine reserve proposals considered in an initiative in California, the proposal designed by fishermen was considered by Klein et al[92] more efficient than the proposals designed by other stakeholder groups at representing biodiversity and minimizing impact to the fishing industry, thus highlighting the necessity of using comprehensive information on fishing effort to design MPA networks.

The Baltic Sea case study conducted three separate consultation meetings with Danish, Polish and Swedish fishers during 2007 to collect fishermen's knowledge and views. The resulting information is useful in understanding past conflicts surrounding MPAs in the Baltic, and for identifying likely sources of agreement and disagreement in the future. It is common that bottom-up support is required for the successful implementation of MPAs, and for all other management measures as well[93].

One PROTECT partner had direct responsibility for surveillence and enforcement of offshore deep-sea coral MPAs. His insight into what is actually feasible to enforce in an offshore situation and how regulations should be designed to be realistic and effective, has been invaluable. It can be debated if enforcement agencies should be seen as a stakeholder, but the experience from PROTECT underlines that the early involvement and input of the very people that have the responsibility to enforce regulations can potentially circumvent future management and control issues and problems.

PROTECT has also gauged the views of perhaps the most important stakeholder, the general public,in the Irish coral case study. Two potentially quite powerful stakeholders in the creation and ongoing management of MPAs are politicians and the electorate they serve. One way to incorporate the public/electorate in a meaningful and value-added way within the MPA decision-making process is through stated preference techniques within environmental valuation. Within the coral case study, the choice experiment study served this purpose. In eliciting the Irish public's preferences and willingness to pay in support of various management alternatives for coral reef MPAs, it not only established preferences for and the value placed on the MPA per se, it has informed decision-makers as to the acceptability of different management options and provides evidence of legitimacy for political action.

A re-occuring observation during the PROTECT project has been how all stages of the implementation of an MPA are connected to the goals and objectives of the MPA, and how changes in these should lead to changes in regulations, monitoring and enforcement (and perhaps by necessity also the other way around). This confirms our view that stakeholders should be involved in as many aspects as possible in the MPA implementation process, in particular if the process has the ambition to lead to a system of adaptive management. As a result, the stakeholder component in the MPA framework above is not inserted at

[92] Klein et al. 2008
[93] Hilborn et al. 2004

specific stage in the implementation process, but rather should be ubiquitous throughout every stage in the process.

Lessons learned

As is clearly evident in the case study descriptions and the results of PROTECT work, no two marine areas are alike regarding their legal, political and societal setting, ecology or corresponding patterns of utilisation of marine resources. As a consequence, no two MPAs will ever be alike, and there exists no quick fix for MPA site selection, design, implementation, monitoring and evaluation. The necessity to tailor MPA approaches to a given site becomes crystal clear from the very beginning in the development of goals, objectives, indicators and success criteria for a given MPA and is ubiquitous throughout the entire process of site selction, monitoring, evaluation, etc. What may initially seem intuitive becomes a challenge once the MPA evolves from being conceptual to something operational and measurable for which society has high expectations.

Many lessons have been learned in the PROTECT project that apply to the three case study sites and these have been listed at the end of each case study section. However, many lessons have been learned that can be lifted to a more generic level and applied in relation to MPAs elsewhere:

- **The use of GOIS tables within PROTECT has proven very insightful**
  GOIS (Goals-Objectives-Indicators-Success Criteria) tables were used within the context of the PROTECT project for mapping hypothetical monitoring programmes and for matching indicators to the aims and objectives of the MPAs concerned. The GOIS format does not accommodate any stray thinking or substantial gaps and are therefore an excellent tool for adding needed focus to management planning. PROTECT recommends that GOIS tables be applied not only to new MPA designations but also to MPAs already in place, many of which do not have clearly formulated goals, objectives, indicators or success criteria upon which evaluations must be based.

- **Clearly stated goals and objectives will be cost-efficient**
  Most closures had been established without clearly stated objectives, making it exceedingly difficult to evaluate the effectiveness, regardless of the amount of evidence that might be available. To facilitate future evaluation of closed areas it is recommended that when a closed area is established, explicit consideration be given to its objectives and ways of measuring whether or not those objectives have been met. If possible, these measures should be based on pre-existing data series. This will minimise extra costs of monitoring and place any future changes in environmental or other conditions in context. It will also ensure that the reasons for establishing the MPA are transparent and evaluations of success become easier.

- **Size is not everything. Proper site selection is.**
  MPAs do not necessarily become more effective with size, while improper site selection will likely render an MPA ineffective. In the North Sea case study it was described how optimal site selection for relatively small sandeel closures, while creating adverse impacts on the sandeel fishery on a local scale, could provide substantial increases in the total sandeel population on a North Sea scale. This has implications regarding the role of sandeel sandbank habitats that go far beyond national boundaries. In relation to wider maritime spatial planning this implies that e.g. windfarms established in the waters of one nation may have severe consequences for a given fishery in the entire North Sea. Optimal site selection also reduces the area needed for establishment of MPAs or MPA networks and with adaptive management and monitoring MPA network configurations can shift appropriately with changes in the ecosystem.

- **MPA design should be adapted to the life cycles and migratory behaviour of the target species**
  Fish species have complex life cycles and rarely spend all of their life or even all of the year in one place. Some species are more stationary and some are highly migratory. For stationary species small MPAs might work, but for migratory species MPAs may need to be very big or consist of a network of MPAs.

- **MPA boundaries may need to be 'adaptive' as species distributions change with time**
  The Baltic cod and the North Sea plaice are examples of stocks whose geographical distribution has changed over time. For MPAs to efficiently protect similar stocks, the MPA boundaries may need to be adaptive to changes in the ecosystem and cyclical evaluations should be in place to evaluate the appropriateness of the MPAs boundaries relative to the distribution of the main focal species.

- **The fishery benefits of MPAs are not guaranteed**,
  MPAs are only one of many available tools to manage the marine environment and fisheries. Although MPAs have in recent years gained momentum and political support it is crucial to note that MPAs in some cases may not be the best tool. In other cases MPAs may only prove beneficial if used *in parallel* with other fisheries management measures such as effort control/reduction. In cases where management of a certain fishery is based on Total Allowable Catch, effort may simply shift in time and space, i.e. effectively reducing potential benefits gained through MPA establishment.

- **There is no single monitoring strategy that is appropriate for all kinds of MPAs.**
  Monitoring strategies are dependent on the ecological and socioeconomic setting of an MPA, and on the goals and targets formulated for the MPA. A major conclusion that emerged from developing case study specific monitoring strategies and comparing them in PROTECT is that generic principles for MPA monitoring strategies are difficult to define. Each ecosystem and/or target species needs a specially designed monitoring scheme accounting for their special characteristics. Due to the fundamentally different nature of the three case studies, the monitoring schemes needed to be different. Hence the Baltic case study found it difficult to apply a spatially-resolved monitoring for potentially detecting positive effects of fishing closures inside the MPA compared to outside, as the high mobility of Baltic cod makes the detection of such an effect unlikely. It was therefore decided to develop an ecosystem-based monitoring scheme including monitoring of lower trophic levels, which are connected to the cod stock via trophic interactions. In contrast to the Baltic case, the North Sea case study focused on a relatively enclosed area and a semi-mobile benthic-pelagic forage fish and the effect of its availability to local seabird populations. In this case and certainly in the case of sessile species such as corals, more local approaches to MPA monitoring can be applied.

- **The PROTECT case studies have demonstrated the difficulty but also some methods to disentangle the effects of a closure and environmental change**
  This is especially true for the highly variable habitats of the Baltic and North Sea. Baltic cod and North Sea sandeel are strongly dependent on the abiotic and biotic environment. This is accounted for in these case studies by the extensive use of coupled biophysical models. In terms of monitoring, the importance of the variable environment is incorporated in the Baltic case by a special monitoring programme for the environment.

- **A weak point in all case studies is the lack of monitoring of socio-economic effects**

  As the socio-economic side of the efficacy of an MPA is of crucial importance for the acceptance of a closure and hence the compliance of the fishery, this kind of monitoring activity need to be further developed. Monitoring compliance is not incorporated in the present monitoring strategies. It is in the future best conducted using VMS-data, depending on its legal availability.

- **Modelling can assist in the analysis of both planned and existing MPAs**

  By MPA modelling, we here mean quantitative modelling tools that enable direct or indirect assessment of the performance of planned or existing MPAs. Modelling tools for MPA assessment are usually classified as belonging to either empirical or dynamic modelling approaches. Empirical approaches may provide an indication of the impact of MPAs on the ecosystem and resources; they are also needed for devising and assessing sampling designs for monitoring programmes. Dynamic models enable exploring the consequences of MPA designs and other management policies.

- **The experimental design of MPA studies must be improved**

  Concerning empirical assessments of MPA effects, experimental design is a major area in need of improvement. Properly replicated Before-After-Control-Impact (BACI) designs are still insufficiently developed. A second area of improvement relates to habitat considerations. Ideally habitat should be monitored at the same time as fish communities, because habitats are a crucial source of spatial variation for fish communities. A third area of improvement lies in more holistic approaches to evaluate MPA effects. Effects are mostly evaluated from univariate approaches, i.e. for a single species or species group, and for a single variable (e.g. density or biomass) at the time. Consequently, an overall description of MPA effects cannot be established, nor can the performances of different factors be formally compared.

- **Models must be realistic**

  With regard to dynamic modelling, the main area of improvement lies in the development of models that achieve a trade-off between parsimony and complexity, and are parameterized and calibrated against real data. Models are needed that explicit the spatial dynamics of population and exploitation at the scale of MPA design, including the seasonal scale when relevant (e.g. for temporary restrictions on fishing). Models should account for mixed fisheries and for fishers' response to MPA. They should allow for thorough investigations of MPA designs including permanent versus temporary MPAs, partial restrictions of fishing activities, and reserve networks. They should also provide for other management measures, as MPAs are usually used in combination with other management tools.

- **Input data for the models is still a problem, but there are solutions**

  In order to be able to calibrate models against real data, appropriate information is needed at the scale of the ecosystem and fisheries. Knowing the spatial dynamics of population demographic stages, including early stages, are necessary. Some of these aspects are poorly known, as are the spatial dynamics of exploitation. Conventional fisheries statistics provide information with good spatial and seasonal coverage, but their interpretation may be difficult and spatial resolution may be limited. Additional information can be obtained through vessel monitoring systems and fishers' interviews. In any case, the model should be used in order to account for uncertainties, whether through simulation designs or other techniques e.g. risk analysis. These modelling issues underpin the construction of model-based indicators, as reliable model outputs require models that are grounded in real data.

- **PROTECT has demonstrated the value of economic approaches to the design and implementation of MPAs**

  The potential usefulness of environmental valuation techniques as a tool of MPA design and implementation was evaluated. Discrete Choice experiments demonstrated theoretical and practical qualities that make it a highly valuable tool. It quantifies the non-use value/benefit attached to MPA protection essential for inclusion in the cost-benefit analyses that increasingly accompany MPA designation.

- **A Choice experiment revealed widespread public support for the creation of MPAs for the protection of Irish deep-water corals**

  The preferences of the monitored part of the Irish public lay with the protection of all areas thought by scientists to hold cold-water coral reefs, the banning of trawling (as distinct from all fishing) within those areas, and a personal annual ring-fenced tax of €1 to support the MPAs. This is a substantial political endorsement of the action being pursued in Ireland for protection of corals.

References

Introduction

1. http://www.mpa-eu.net/
2. http://eur-lex.europa.eu/
3. Pedersen, S.A., Fock, H., Krause, J., Pusch, C., Sell, A.L., Böttcher, U., Rogers, S.I., Sköld, M., Skov, H., Podolska, M., Piet, G.J. and Rice, J.C. 2009. Natura 2000 sites and fisheries in German offshore waters. ICES J. mar. Sci. 2009 66: 155-169; doi:10.1093/icesjms/fsn193
4. Ihttp://eur-lex.europa.eu/
5. Ibid
6. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0604:FIN:EN:PDF
7. http://www.nafo.int/about/frames/media.html
8. COM (2008) 187 final. The role of the CFP in implementing an ecosystem approach to marine management.

MPA Goals, Objectives, Indicators & Success Criteria

9. Pomeroy, R.S., Parks, J.E., Watson, L.W., (2004). How is your MPA doing? A guidebook of natural and social indicators for evaluating marine protected area effectiveness. IUCN – Gland, Switzerland and Cambridge, UK. 216pp; see www.effectivempa.noaa.gov/guidebook/guidebook.html
10. Ward, TJ (2004) *Marine Protected Areas in Fisheries*: *Design* and *Performance Issues.* ***In:*** Aquatic Protected Areas as Fisheries Management Tools. (J. Brooke Shipley, editor) American Fisheries Society Symposium [Am. Fish. Soc. Symp.]. Vol. 42, pp. 37-61
11. Ward, TJ (2004) *Marine Protected Areas in Fisheries*: *Design* and *Performance Issues.* ***In:*** Aquatic Protected Areas as Fisheries Management Tools. (J. Brooke Shipley, editor) American Fisheries Society Symposium [Am. Fish. Soc. Symp.]. Vol. 42, pp. 37-61
12. Agardy, T. (2000). Information needs for Marine Protected Areas: Scientific and societal. *Bulletin of Marine Science* 66: 875–888
13. Kay, R., and J. Alder. (1999). *Coastal planning and management.* London: E and F Spoon
14. Margolius, R.A. & Salafsky, N. (1998). Measure of success: designing, managing and monitoring conservation and development projects. Island Press, Washington DC, USA.
15. Ward, TJ (2004) *Marine Protected Areas in Fisheries*: *Design* and *Performance Issues.* ***In:*** Aquatic Protected Areas as Fisheries Management Tools. (J. Brooke Shipley, editor) American Fisheries Society Symposium [Am. Fish. Soc. Symp.]. Vol. 42, pp. 37-61
16. Botsford, L.W., Castilla, J.C., Peterson, C.H. (2003) Principles for the design of marine reserves. Ecological Applications, 13(Supplement): S25-31.
17. SGMOS-07-03 Evaluation of closed area schemes. Subgroup on management of stocks (SGMOS), of the scientific, technical and economic committee for fisheries (STECF), 5-9 november 2007 in Ispra.
18. Pomeroy, R.S., Parks, J.E., Watson, L.W., (2004). How is your MPA doing? A guidebook of natural and social indicators for evaluating marine protected area effectiveness. IUCN – Gland, Switzerland and Cambridge, UK. 216pp; see www.effectivempa.noaa.gov/guidebook/guidebook.html
19. Jennings, S. 2009. The role of marine protected areas in environmental management. – ICES Journal of Marine Science, 66: 16–21.2009
20. Ibid
21. Ibid
22. Ibid

Monitoring of MPAs

23. Houde, E. (chair), Committee on the Evaluation, Design, and Monitoring of Marine Reserves and Protected Areas in the United States, Ocean Studies Board, Commission on Geosciences,

Environment, and Resources, National Research Council (2001) Marine Protected Areas: Tools for sustaining ocean ecosystems. National Academy Press, Washington, D.C., 272pp.
24. Allison G.W., Lubchenco J., Carr M.H. (1998) Marine reserves are necessary but not sufficient for marine conservation. *Ecological Applications*, 8, 79-92
25. Syms C. and Carr M.H. (2002) *International clearinghouse for MPA effectiveness measures: A conceptual design*. Prepared for the Commission on Environmental Cooperation as a template for information compilation and dissemination to resource managers. www.piscoweb.org/files/mpa_handouts/MPA_Evaluation_guidelines.pdf
26. Stewart-Oaten A. and Bence J.R. (2001) Temporal and spatial variation in environmental impact assessment. *Ecological Monographs*, 71: 305-339
27. Syms C. and Carr M.H. (2002) *International clearinghouse for MPA effectiveness measures: A conceptual design*. Prepared for the Commission on Environmental Cooperation as a template for information compilation and dissemination to resource managers. www.piscoweb.org/files/mpa_handouts/MPA_Evaluation_guidelines.pdf
28. Möllmann, C., Diekmann, R., Müller-Karulis, B., Kornilovs, G., Plikshs, M. and Axe, P. 2008b. The evolution of an ecosystem under atmospheric and anthropogenic pressure – the case of the Central Baltic Sea. Global Change Biology (submitted manuscript)
29. Daunt, F., Wanless, S., Greenstreet, S.P.R., Jensen, H., Hamer, K.C. & Harris, M.P. (2008) The impact of the sandeel fishery closure in the northwestern North Sea on seabird food consumption, distribution and productivity. Canadian Journal of Fisheries and Aquatic Sciences 65: 362-381
30. Frederiksen M., Jensen H., Daunt F., Mavor R.A., Wanless S. (2008) Differential effects of a local industrial sand lance fishery on seabird breeding performance. Ecological Applications, 18: 701-710

The importance of high-resolution fisheries data, e.g. from logbooks and VMS for the evaluation of MPAs and other management measures

31. EUCOA (2007) Notices From European Institutions and Bodies Court of Auditors SPECIAL REPORT No 7/2007 on the control, inspection and sanction systems relating to the rules on conservation of Community fisheries resources together with the Commission's replies (pursuant to Article 248(4) second paragraph, EC) (2007/C 317/01) [online]
URL http://eca.europa.eu/portal/pls/portal/docs/1/673627.PDF Last accessed 17 Mar 2008
32. Nielsen, J.R. & Mathiesen, C. 2003. Important factors influencing rule compliance in fisheries: lessons from Denmark. Marine Policy Vol. 27, issue 5. pp. 409-416
33. Dinmore, T. A., Duplisea, D. E., Rackham, B. D., Maxwell, D. L., and Jennings, S. 2003. Impact of a large-scale area closure on patterns of fishing disturbance and the consequences for benthic communities. – ICES Journal of Marine Science, 60: 371–380
34. Bergman, M. J. N., and van Santbrink, J. W. 2000. Mortality in megafaunal benthic populations caused by trawl fisheries on the Dutch continental shelf in the North Sea in 1994. ICES Journal of Marine Science, 57: 1321–1331

PROTECT Modelling to evaluate MPA effects

35. Pelletier et al (PROTECT WP 5 report)
36. Jensen H. 2001. Settlement dynamics in the lesser sandeel Ammodytes marinus in the North Sea. PhD Thesis, University of Aberdeen.
37. Kauppinen E. 2008. Age estimation and growth of lesser sandeel (Ammodytes marinus) larvae. University of Joensuu, Faculty of Biosciences. MSc Thesis 27p

38. Gauger, M. (2008). Otoliths as indicators of good and poor conditions for sandeel 0-group recruitment in the North Sea. MSc Thesis, 118p. University of Hamburg, Institute for Hydrobiology and Fisheries Science.
39. http/www.ifremer.fr/ISIS-Fish ; http://isis-fish.labs.libre-entreprise.org/
40. Sale, P.F., 1998. Appropriate Spatial Scales for Studies of Reef-Fish Ecology. *Australian Journal of Ecology* 23 (3), 202-208.
41. Stewart-Oaten A., Bence J.R., 2001. Temporal and spatial variation in environmental impact assessment. Ecological Monograph 71, 305-339
42. Garcia-Charton J.A., Williams I.D., Pérez Ruzafa A., Milazzo M., Chemello R., Marcos C., Kitsos M.S., Koukouras A., Riggio S., 2000. Evaluating the ecological effects of Mediterranean protected areas : habitat, scale and the natural variability of ecosystems. Environmental Conservation 27, 159-178.
43. Verdoit M., Pelletier D., Bellail R., 2003. Are commercial logbook and scientific CPUE data useful for characterizing the spatial and seasonal distribution of exploited populations? The case of the Celtic Sea whiting. *Aquatic Living Resources* 16, 467-485
44. Murawski S.A., Wigley S.E., Fogarty M.J., Rago P.J., Mountain D.G., 2005. Effort distribution and catch patterns adjacent to temperate MPAs. *ICES Journal of Marine Science* 62, 1150-1167
45. Drouineau, H., S. Mahévas, D. Pelletier, B. Beliaeff. 2006. Assessing the impact of marine protected areas on the hake-nephrops fishery of the Bay of Biscay using ISIS-Fish. *Aquatic Living Resources* 19, 15-29
46. Pelletier D., Mahévas S., 2005. Spatially-explicit fisheries simulation models for policy evaluation. *Fish and Fisheries* 6, 1-43
47. Pelletier D., Garcia-Charton J.A., Ferraris J., David G., Thébaud O., Letourneur Y., Claudet J., Amand M., Kulbicki M., Galzin R., 2005. Designing indicators for evaluating the impact of Marine Protected Areas on coral reef ecosystems : a multidisciplinary standpoint. *Aquatic Living Resources* 18, 15-33

The PROTECT case study studies and their results:
The Baltic Case Study

48. MacKenzie, B. R., Hinrichsen, H-H., Plikshs, M., Wieland, K. and Zezera, A. S. 2000. Quantifying environmental heterogeneity: habitat size necessary for successful development of cod *Gadus morhua* eggs in the Baltic Sea. Marine Ecology Progress Series, 193: 143-156
49. Köster, F.W., Möllmann, C., Neuenfeldt, S., Vinther, M., St John, M.A., Tomkiewicz, J., Voss, R., Hinrichsen, H.H., Kraus, G., and Schnack, D. 2003. Fish stock development in the Central Baltic Sea (1996–2000) in relation to variability in the environment. ICES Marine Science Symposia, 219: 294-306
50. Ibid
51. Hinrichsen, H.-H., Voss, R., Wieland, K., Koester, F., Andersen, K. H., Margonski, P. (2007) Spatial and temporal heterogeneity of the cod spawning environment in the Bornholm Basin, Baltic Sea. Mar. Ecol. Prog. Ser., 345: 245-254.
52. Ibid
53. Hinrichsen, H.-H., Kraus, G., Böttcher, U. and Köster, F. 2009. Identifying eastern Baltic cod nursery grounds using hydrodynamic modelling: knowledge for the design of Marine Protected Areas. ICES J. mar. Sci. 2009 66: 101-108; doi:10.1093/icesjms/fsn207
54. Köster, F.W., Möllmann, C., Hinrichsen, H.-H., Wieland, K., Tomkiewicz, J., Kraus, G., Voss, R., Makarchouk, A., MacKenzie, B.R., St. John, M.A., Schnack, D., Rohlf, N., Linkowski, T., and Beyer, J.E. 2005. Baltic cod recruitment – impact of climate variability on key processes. ICES J. Mar. Sci., 62: 1408-1225.
55. Bagge et al. 1994: The Baltic cod. Dana. Charlottenlund [DANA]. Vol. 10, pp. 1-28
56. ICES 1999. Report of the ICES Baltic Fisheries Assessment Working Group. ICES CM 1999/ACFM:15

57. Möllmann, C. and Köster, F.W. 2002. Population dynamics of calanoid copepods and the implications of their predation by clupeid fish in the Central Baltic Sea. Journal of Plankton Research, 24: 959-977.
58. Möllmann, C., Müller-Karulis, B., Kornilovs, G. and St. John, M.A. 2008b. Effects of climate and overfishing on zooplankton dynamics and ecosystem structure regime shifts, trophic cascade and feedback loops in a simple ecosystem. ICES Journal of Marine Science, doi:10.1093/icesjms/fsm197
59. Möllmann, C., Kornilovs, G., Fetter, M. and Köster, F. W. 2005. Climate, zooplankton and pelagic fish growth in the Central Baltic Sea. ICES Journal of Marine Science, 62: 1270-1280.
60. Köster, F.W., Möllmann, C., Hinrichsen, H.-H., Wieland, K., Tomkiewicz, J., Kraus, G., Voss, R., Makarchouk, A., MacKenzie, B.R., St. John, M.A., Schnack, D., Rohlf, N., Linkowski, T., and Beyer, J.E. 2005. Baltic cod recruitment – impact of climate variability on key processes. ICES J. Mar. Sci., 62: 1408-1225.
61. Röckmann, C., St. John, M.A., Schneider, U.A. and Tol, R.S.J. (2007) Testing the implications of a permanent or seasonal marine reserve on the population dynamics of Eastern Baltic cod under varying environmental conditions. Fisheries Research 85 (1-2), 1-13.
62. ICES 2007. Report of the ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea. ICES C.M. 2007\BCC:01.
63. Möllmann, C., Diekmann, R., Müller-Karulis, B., Kornilovs, G., Plikshs, M. and Axe, P. 2008. The evolution of an ecosystem under atmospheric and anthropogenic pressure – the case of the Central Baltic Sea. Global Change Biology (submitted).
64. Kraus G, Pelletier D, Dubreuil J, Möllmann C, Hinrichsen H, Bastardie F, Vermard Y, and Mahévas Y (2009) A model-based evaluation of Marine Protected Areas: the example of eastern Baltic cod (Gadus morhua callarias L.). ICES J. Mar. Sci. 66: 109 - 121
65. Ibid

The North Sea case study

66. ICES 2003. Report of the Working Group on Ecosystem Effects of Fishing Activities. ICES Headquarters, Copenhagen, 1-8 April 2003. ICES CM 2003/ACE:05.
67. Boulcott,P., Wright, P.J., Gibb, F.M., Jensen, H. , Gibb, I.M.(2007): Regional variation in maturation of sandeels in the North Sea. Ices Journal of Marine Science, 64: 369-376.
68. Christensen, A., Jensen, H., Mosegaard, H., St John, M. and Schrum, C. 2008. Sandeel (Ammodytes marinus) larval transport patterns in the North Sea from an individual-based hydrodynamic egg and larval model. Can. J. Fish. Aquat. Sci. Vol. 65: 1498-1511.
69. Daunt, F., Wanless, S., Greenstreet, S.P.R., Jensen, H., Hamer, K.C. & Harris, M.P. (2008) The impact of the sandeel fishery closure in the northwestern North Sea on seabird food consumption, distribution and productivity. Canadian Journal of Fisheries and Aquatic Sciences 65: 362-381
70. Frederiksen M., Jensen. H., Daunt F., Mavor R.A., and Wanless S. 2008. Differential effects of a local industrial sand lance fishery on seabird breeding performance. Ecological Applications, 18(3), 2008, pp. 701–710
71. Daunt, F., Wanless, S., Greenstreet, S.P.R., Jensen, H., Hamer, K.C. & Harris, M.P. (2008) The impact of the sandeel fishery closure in the northwestern North Sea on seabird food consumption, distribution and productivity. Canadian Journal of Fisheries and Aquatic Sciences 65: 362-381
72. Frederiksen, M., Wanless, S., Harris, M.P., Rothery, P. & Wilson, L.J. (2004) The role of industrial fisheries and oceanographic change in the decline of North Sea black-legged kittiwakes. Journal of Applied Ecology, 41, 1129-1139
73. Frederiksen M., Jensen. H., Daunt F., Mavor R.A., and Wanless S. 2008. Differential effects of a local industrial sand lance fishery on seabird breeding performance. Ecological Applications, 18(3), 2008, pp. 701–710

74. Christensen, A., Mosegaard, H. and Jensen, H. 2009. Spatially resolved fish population analysis for designing MPAs: influence on inside and neighbouring habitats. ICES J. mar. Sci. 2009 66: 56-63; doi:10.1093/icesjms/fsn191
75. Frederiksen M., Jensen H., Daunt F., Mavor R.A., Wanless S. (2008) Differential effects of a local industrial sand lance fishery on seabird breeding performance. Ecological Applications, 18: 701-710
76. Christensen, A., Mosegaard, H. and Jensen, H. 2009. Spatially resolved fish population analysis for designing MPAs: influence on inside and neighbouring habitats. ICES J. mar. Sci. 2009 66: 56-63; doi:10.1093/icesjms/fsn191
77. Ibid

The Deep Sea Coral case study

78. Fosså, J.H., P.B. Mortensen & D.M. Furevik 2002. The deep-water coral *Lophelia* pertusa in Norwegian waters: distribution and fishery impacts. Hydrobiologia 471, 1-12
79. Ibid
80. Husbø, Å., L. Nøttestad, J.H. Fosså, D.M. Furevik & S.B. Jørgensen. 2002. Distribution and abundance of fish in deep-sea coral habitats. Hydrobiologia 471, 91-99
81. Armstrong, C.W. 2007. A note on the ecological–economic modelling of marine reserves in fisheries. Ecological Economics Volume 62, Issue 2, 20 April 2007, Pp. 242-250
82. Armstrong, C.W. & Falk-Petersen, J. 2008. Habitat Fisheries – a missing link. ICES Journal of Marine Science 65, 2008.
83. Grehan, A. J., Unnithan, V., Olu, K. and Opderbecke, J. 2004a. Fishing impacts on Irish deep-water coral reefs: making a case for coral conservation. In: J. Thomas & P. Barnes (eds) Proceeding from the Symposium on the Effects of Fishing Activities on Benthic Habitats: Linking Geology, Biology, Socioeconomics and Management, American Fisheries Society, Bethesda, Maryland, USA. pp. 819-832
84. Commission Regulation (EC) No 1475/2003
85. Long, R. (2009) "Natura 2000 sites and fisheries management in Ireland: The deep-water coral sites" in China Ocean Law Review (forthcoming edition No. I (2009))
86. Armstrong, C.W. & van den Hove, S. 2007. The formation of policy for the protection of cold-water coral off the coast of Norway. Marine Policy 32, 66-73.
87. Fosså, J.H. and H.R. Skjoldal (in press). Conservation of cold-water coral reefs in Norway. In: R.Q. Grafton, R. Hilborn, D. Squires, M. Tait and M. Williams (eds). Handbook of Marine Fisheries Conservation and Management. Oxford University Press.
88. Fosså, J.H., P.B. Mortensen & D.M. Furevik 2002. The deep-water coral *Lophelia* pertusa in Norwegian waters: distribution and fishery impacts. Hydrobiologia 471, 1-12
89. Glenn, H., Wattage, P. Mardle, S. Van Rensburg, T. Grehan, A. and N. Foley (accepted). Marine Protected Areas – Substantiating their Worth. Marine Policy.

The work of PROTECT in relation to a general framework for establishing and managing MPAs

90. Jennings, S. 2009. The role of marine protected areas in environmental management. – ICES Journal of Marine Science, 66: 16–21.2009
91. Day, J. 2008. The need and practice of monitoring, evaluating and adapting marine planning and management—lessons from the Great Barrier Reef. Marine Policy Volume 32, Issue 5, September 2008, Pages 823-831.
92. Klein C.J, Steinbeck, C, Scholz A.J.m Possingham, H.P. 2008.Effectiveness of marine reserve networks in representing biodiversity and minimizing impact to fishermen: a comparison of two approaches used in California. Conservation letters 1: 44-51

93. Hilborn, R., Stokes, K., Maguire, J.-J., Smith, T., Botsford, L.W., Mangel, M., Orensanz, J., Parma, A., Rice, J., Bell, J., Cochrane, K.L., Garcia, S., Hall, S.J., Kirkwood, G.P., Sainsbury, K., Stefansson, G., Walters, C. 2004. When can marine reserves improve fisheries management? Ocean & Coastal Management, 47: 197–205

Annex I Case-specific GOIS tables and lessons learned

GOIS table for MPAs, identifying goals, objectives, indices and success criteria for the Baltic Sea Case Study.

MPA Goals in the Baltic Sea	Specific objectives of MPAs	Indices	Observation-Method	Success Criteria
To restore the Baltic cod stock	Reduced fishing effort	Effort	Log-books and VMS	Effort leading to fishing mortality (F) below $F_{PA;}$ and below status quo
	Reduced fishing mortality	F, Effort Catch , CPUE	Observation (Landings)	F below $F_{PA;}$ Catch/CPUE > recent without MPA catch
	Improved spawning stock	SSB Mean length Demographic structure Age-at maturity	BITS and other surveys	Reverse decline, SSB above B_{lim} > without MPA, inside > outside
	Reduced juvenile mortality	Juvenile discarding rate Juvenile abundance indices	Discard observing BITS	Overall discard rate lower Juvenile abundance > before
	Improved recruitment (age2)	R/SSB total abundance (TA)/recruit abundance (RA)	BITS	R/SSB > mean 1989-2005 (regime 2*) TA/RA > mean 1989-2005 (regime 2*)
To re-establish a (more) balanced ecosystem in the Central Baltic	Balanced cod (c) and sprat (s) abundance	Ratio of cod (C) to sprat (S) abundance	BITS, BIAS[3]	C/S > mean 1989-2005 (regime 2*)
	Balanced zooplankton community	Ratio of *Pseudocalanus* (P) and *Acartia* (A)	Seasonal net sampling	P/A > mean 1989-2005 (regime 2*)
	Increased herring growth	Herring condition	Landings/BIAS	Herring condition > mean 1989-2005 (regime 2*)
To obtain sustainable fishing communities and to	Obtaining a profitable fisheries	Profits	Interviews, Accountings	Profits compared to asset value should be at least as high as market rent

maintain livelihoods	Securing employment in local fishing communities	Employment and number of vessels	Interviews, Accountings	Crew payment should be above opportunity payment. Change in number of vessels must be within specified limits.
	Equal distribution of monetary benefits between fishing communities	Profits and employment	Interviews, Accountings	Comparison of pre and post MPA distribution of profits and employment within specified limits.

GOIS table for MPAs, identifying goals, objectives, indices and success criteria for the North Sea Case Study.

MPA goals (primary, secondary and tertiary)	Specific objectives of the MPA	Indices to be measured	Success Criteria	Monitoring*	Modelling**
1) Design and employ MPAs to help sustain sandeel populations in a healthy state	Manage fishery to avoid overexploitation of the North Sea sandeel stocks	• Index of SSB	• Observed SSB above Bpa	1	1
	Improve stock resilience (age structure, recruitment variability, genetic/phenotypic variability)	• SSB, numbers at age, maturity at size and age • recruitment	• SSB recovered to above Bpa • Age structure extended to include more than present level of mature individuals • Avoidance of recruitment failure i.e. not below the bottom quartile observed	1	2
	Avoid local depletion of sandeel aggregations	• Abundance indices from fishery driven surveying • Abundance from Scientific surveys (FF & Dogger)	• Local stock abundance above local target (median observed)	23 5	1+y+z
	Restore depleted sandeel subpopulations within available habitats	• Fishery and survey driven distribution mapping	• Recolonisation of previously occupied habitats (in relation defined sandeel habitat see map HJ)	23	1+z
	Key stocks remain viable as sources of recruitment	• Fishery and survey driven distribution of juveniles from direct sampling • sandeels in predator stomachs • CPR index of larvae	• Juveniles available at major sandeel habitats	3	1+z
2) for the benefit of higher trophic levels	Avoid bottom up driven declines in sandeel dependent predators: Seabird populations	• No of fledged chicks per Kittiwake nest = breeding success • Proportion weight of sandeels in diet of breeding kittiwakes	• Breeding success of black legged kittiwake > 3 year median of 0.7 chicks per nest per year • More than 80 % sandeels in kittiwake diet	6 7	1 1
	Abundance and distribution of marine	• Adult common seal counts in NS/WC haul out	• Distribution and abundance should not decline in North Sea haul out sites	8	1

	mammals	sites • Proportion weight of sandeels in diet of common/habour seals	compared to non North Sea sites 3) • Level of sandeels in common seal diet should not decline	9	1
	Abundance and distribution of sandeel eating fish	• Survey based index of condition (Fulton) in whiting	• Higher condition of whiting in Q3 inside MPA than in the rest of the North Sea	5	1
3) To avoid negative ecosystem effects of fisheries displacement	Minimise physical displacement of sandeel fishery to previously unfished areas	• Observed fishing effort and target species from VMS + logbook databases	• No new areas of sandeel fishery are observed	2	1+3
		?	?		
4) Socio-economic goals: Maximise net benefit to society of sandeel protection through direct and indirect effects	to ensure long term stability of yields and profits within the sandeel fishing industry	• Profit divided by capital value compared to government bond	• Keep the rent in the sandeel fishing industry to be at least at a level similar to government bonds	a	3
	to ensure fishing society sustainable livelihood	• Number of crew personnel • Number of processing industry employees • Sum of wages in fishing and in processing	• Keep sector specific employment (fishing and processing) at or above present level • Keep sector specific total wage bill (fishing and processing) at or above present level	a x	3
	Maintain possibilities for wildlife based recreational activities e.g. wildlife centres, tours, boat trips	• Number of people employed in wildlife based recreational activities • Visitation to wildlife centres etc. • Hits on relevant websites • Spend on activities • Memberships of relevant interest groups	• Maintain or increase current level of people employed in the wildlife based recreational activities • Maintain or increase current level of people participating in and spending money in wildlife based recreational activities • Increase in campaign related local membership of wildlife NGOs	x y y	1

	Avoid damage to, maintain or improve resources/ecosystem attributes according to what society value	• Match of performance of indices (as identified above) corresponding to society values concerning preferences and priorities of resources and ecosystem attributes	• Management actions match what society wants based on a survey before and after establishment of an MPA	y	4
	Avoid negative effects on Aquaculture sustainability through maintaining high quality low price and influence on availability of fish meal/oil	• Price and quality (lipid composition and toxin content)	• No increase in price or reduction in quality of fish meal/oil after establishment of an MPA	x	3
5) Governmental goals: Benefits to society should outweigh costs of exploitation and monitoring	MPA design and monitoring systems should allow decisions on cost/benefit strategies	• Societal understanding and acceptance of MPA based management	• Weighted evaluation of all relevant success criteria		

The reference to MPAs at different levels of objectives may vary, thus the primary goal 1) sustainable sandeel populations was addressed at the North Sea scale, whereas focus on 2) benefits to higher trophic levels had most of its focus on the existing MPAs at Firth of Forth and Shetland. 3) and 4) have both local and North Sea implications. 5) This goal is suggested to be developed further together with managers for future applications.

** Monitoring:*
1 Existing monitoring of the fishery on an ICES rectangle basis + logbook data on landings on an ICES rectangle basis
2 Existing monitoring of the fishery on a trawl haul basis + individual estimated haul weight
3 Dredge surveys (either by research vessels or in collaboration with fishers)
4 MIK larval surveys in collaboration with fishers
5 scientific surveys by research vessels catching predators and sandeels
6 observations of seabirds in colonies
7 scientific studies of seabird feeding ecology
8 observations of seals at haul out sites
9 scientific studies of seal feeding ecology
a existing monitoring of economic data from industry
x New collation of data needed
y New investigation needed: e.g. interview

***Modelling :*
1 statistical analysis in relation to references e.g. before/after inside/outside effects
2 WGNSSK stock assessment

3 Bioeconomic model (e.g. BEMCOM)
4 socio-economic valuation tools
x new statistical analysis needed
y new bank specific stock assessment methods needed !!
z new integrated hydrodynamic - population dynamic model needed (e.g. SLAM + SPAM)s

GOIS table for MPAs, identifying goals, objectives, indices and success criteria for the Coral Case Study.

MPA goals (primary, secondary and tertiary)	Specific objectives of the MPA	Indices to be measured (necessary to judge success)	Success (management) criteria
BIOPHYSICAL GOALS; NO TAKE			
Primary Goal (1) Ensure the structural integrity of cold water coral habitat	Prevent all activities which cause abrasion and physical damage	Biological: Statistical comparison of percentage cover using visual inspections of coral – before and after (BACI)	Coral percentage cover to remain within percentage cover values calculated for reference sites
		Fisheries: Frequency of vessel activity in MPA as shown by VMS	Vessel entry into area = 0
		Other Activities: Level of compliance with terms of scientific research permits issued for study in MPA	Compliance with terms of permit = 100 %
		Licensed granted for oil and gas exploration/exploitation	Licenses = 0
		Number of seafloor structures/platforms constructed including associated groundworks in coral fields	Seafloor construction /platforms = 0
		Number of instances of dumping/lost fishing gear	Instances = 0
		Number of instances of ship related pollution effects including wrecks/spills and intentional discharge	Instances = 0
		Number of instances of ship related pollution	Instances = 0

		effects including wrecks/spills and intentional discharge	

Secondary Goal (1) Restore degraded habitat	Prevent all activities which cause abrasion and physical damage to permit recovery	Document presence of coral re-growth in impacted areas	Instances of re-growth > 0
	Cut down recovery time through possible interventions such as artificial reefs /transplantations with due regard to population genetic considerations	Document presence of coral re-growth in impacted areas	Instances of re-growth > 0
Tertiary Goal (1) Maintain potential as carbon sink/reservoir		Visually assess the structural integrity of reefs and diversity of associated mega-fauna along monitoring transects.	Structural integrity of reefs and associated mega-fauna above OSPAR EcoQO reference levels. Reference levels not established.
Primary Goal (2) Protect living populations of *Lophelia* pertusa and ensure contributions of local genetic diversity to *Lophelia* gene pool	Prevent all activities which cause unnatural mortality to *Lophelia* populations. Ensure contribution of local genetic diversity to *Lophelia* gene pool.	Calculate proportion of living to dead coral using video or photographic stills	Proportion of living to dead coral maintained at natural levels* for *Lophelia* as estimated** from multiple reference sites. *Natural levels defined in time and space to allow for natural shifts linked, for example, to climate change; ** Reference limits not defined - methodology to be developed.
	Maintain environmental quality	Measure relevant oceanographic variables	Environmental parameters remain at

	at levels sufficient to ensure natural viability of living coral polyps within reference limits	including temporal variation of quantity and quality of suspended particulates in the locality of the reef	natural levels. Threshold not defined - research required
Primary Goal (3) Protect associated biodiversity and ecosystem function (including fish populations)	Losses to associated biodiversity and ecosystem function prevented, maintenance of trophic structure complexity ensured	Visually assess the structural integrity of reefs and diversity of associated mega-fauna along monitoring transects.	Structural integrity of reefs and associated mega-fauna above OSPAR EcoQO reference levels. Reference levels not established.

Secondary Goal (3) Restore degraded coral habitat areas to level sufficient to support natural associated faunal assemblages (including fish species) similar to those found in non-degraded habitat	Prevent all activities which cause abrasion and physical damage to permit recovery	Document presence of coral re-growth in impacted areas	Instances of re-growth > 0
	Cut down recovery time through possible interventions such as artificial reefs /transplantations with due regard to population genetic considerations.	Document presence of coral re-growth in impacted areas	Instances of re-growth > 0
SOCIO-ECONOMIC GOALS: NO-TAKE			
Primary Goal (1) Livelihoods enhanced or maintained	Ensure the option value (reservoir) of coral habitat for potential biodiscovery	Visually assess the structural integrity of reefs and diversity of associated mega-fauna along monitoring transects.	Structural integrity of reefs and associated mega-fauna above OSPAR EcoQO reference levels. Reference levels not established.
	Maintain contribution of coral habitat supporting local populations of exploiTable fish stocks (refuge and stock reservoir etc.)	Census exploitable fish stocks in locality of coral habitat.	Fish populations of commercial species maintained or enhanced

Primary Goal (2) State compliance with EU and international obligations and maintenance of international standing	Ensure that the State is compliant and not subject to EU penalties or private lawsuits. Economic imperative of not drawing down fines or engendering lawsuits.	Number of notified breaches of EU and international obligations with fiscal penalties	Number of breaches with fiscal penalties = 0
Primary Goal (3) Maintain as scientific reference area and increase scientific knowledge to ensure long-term dividend of research investment is realised	Scientific understanding increased through research and standardised monitoring approaches – future link with Marine Strategy objectives.	Instigate long-term sampling and monitoring programme with standardised sample design.	Long-term data-sets collected are robust and amenable to time series analysis.
Secondary Goal (1) Increase understanding of climate change processes	Undertake paleo-climate studies	Develop appropriate coral skeletal isotopic proxies	Improved understanding of climate change
Primary Goal (4) Environmental awareness and knowledge enhanced	Level of scientific knowledge held by the public increased	Monitor public exposure to available new science related information through public questionaires	Questionaires reveal increase in public awareness and knowledge of coral reefs over time
Tertiary Goal (1) Ensure non-monetary benefits	Aesthetic value enhanced or maintained (education, tourism)	Visually assess the structural integrity of reefs and diversity of associated mega-fauna along monitoring transects.	Structural integrity of reefs and associated mega-fauna above OSPAR EcoQO reference levels. Reference levels not established.

ACTIVITY SPECIFIC MONITORING: STATIC GEAR FISHING			
Primary Goal (1) Ensure the structural integrity of cold water coral habitat	Prevent all activities which cause abrasion and physical damage	Biological: Statistical comparison of percentage cover using visual inspections of coral – before and after (BACI)	Coral percentage cover to remain within percentage cover values calculated for reference sites
		Fisheries: Frequency of vessel activity in MPA as shown by VMS	Vessel entry into area = 0
		Other Activities: Level of compliance with terms of scientific research permits issued for study in MPA	Compliance with terms of permit = 100 %
		Number of instances of dumping/lost fishing gear	Instances = 0
		Number of instances of ship related pollution effects including wrecks/spills and intentional discharge	Instances = 0
		Document presence of coral re-growth in impacted areas	Instances of re-growth > 0
	Cut down recovery time through possible interventions such as artificial reefs /transplantations with due regard to population genetic considerations	Document presence of coral re-growth in impacted areas	Instances of re-growth > 0
Tertiary Goal (1) Maintain potential as carbon		Visually assess the structural integrity of reefs and diversity of associated mega-fauna along monitoring	Structural integrity of reefs and associated mega-fauna

sink/reservoir		transects	above OSPAR EcoQO reference levels. Reference levels not established.
Primary Goal (2) Protect living populations of *Lophelia* pertusa and ensure contributions of local genetic diversity to *Lophelia* gene pool	Prevent all activities which cause unnatural mortality to *Lophelia* populations. Ensure contribution of local genetic diversity to *Lophelia* gene pool.	Calculate proportion of living to dead coral using video or photographic stills	Proportion of living to dead coral maintained at natural levels* for *Lophelia* as estimated** from multiple reference sites. *Natural levels defined in time and space to allow for natural shifts linked, for example, to climate change ** Reference limits not defined - methodology to be developed.

GOIS: Lessons learned

Here we list some lessons learnt while constructing the GOIS tables within PROTECT:

- It can be very difficult to devise goals and objectives that are clear and unambiguous. Most existing MPAs (in Europe and elsewhere) have been established without clearly articulated goals, making it virtually impossible to assess the utility of such MPAs in the long-term.

- It is often difficult to decide which is the primary goal of an MPA and which goals/objectives are secondary. This is particularly true for hypothetical examples, such as 'closures of the sandeel fishery in the North Sea' (***The North Sea case study***). In such cases, the primary goal can become very confused, - on the one hand- existing closures exist to ensure supply of sandeels for dependent predators (in the ***Firth of Forth***), however rebuilding of the sandeel stock in the central North Sea for commercial reasons has also been proposed as a possible goal for spatial closures, as well as closure of the main sandeel nursery/spawning areas for conservation of 'sandbank' habitat under the EU Habitats Directive. If an MPA has several goals, all of them must be incorporated.

- 'Indices of success' need to have clearly stated numerical thresholds or 'reference points' against which success can be judged (but see also bullet point 7 below). In the case of the deepwater coral case study, numerical thresholds were generally very clear because no level of fishing activity was deemed acceptable and 100% compliance was required. By contrast, it was much more difficult to set numerical thresholds in the ***sandeel and Baltic cod case studies*** because some level of exploitation was deemed necessary, and thus 'success criteria' had to be phrased relative to precautionary 'reference points' (e.g. B_{pa}) or population trends/trajectories (no decline in stocks, no decline in dependent predators) in relation to pre-exploitation or pre-closure levels.

- In some cases, indices of success are outputs of complex stock assessment models requiring substantial inputs of data; in other cases they are directly measurable in the environment.

- Non-stationary (environmental change over time) can make it very difficult to judge whether or not an MPA has been successful. This has been the case with the ***Firth of Forth sandeel fishery closure***. Following the closure there appears to have been an improvement in age one and older sandeel abundance until around 2003. However, environmental changes have during a number of years caused declines in sandeel size and seabird breeding productivity. This 'non-stationary' of natural ecosystems has been a confounding factor, influencing the apparent success or failure of other closure areas in the North Atlantic area, including the southern ***North Sea 'Plaice box'*** .

- It can be difficult to address the issue of fishery displacement within the GOIS tables. Avoiding the negative impacts of fishery displacement is an issue related to the implementation of the particular MPA and not usually a goal or objective in itself.

- Time-scale of effects is central: when implementing the MPA you may first have short-term economical losses, while benefits may come later. Is it sufficient to have 'progress towards…' or is it only possible to say that an MPA is succeeding once the threshold success-criterion has been passed/reached?

- MPAs are usually established primarily for conservation reasons (biophysical goals), with socio-economic goals as secondary (with some notable exceptions such as the Shetland box). Should socio-economic goals really be included in GOIS tables when they are a part of the implementation

process (to minimise socio-economic implications) and not usually a goal or objective in itself? It should be valuable to include goals that aim to minimise possible negative effects of the MPA. In a sense this is implicit also in many biophysical goals. Real socioeconomic goals of MPAs may be quite common, certainly in an international setting, but increasingly also in the European setting (if recreational/tourist development is included among socioeconomic goals).

- When devising the GOIS tables it often became difficult to separate the tools or mechanisms for achieving success (the management instruments), from the indicators of progress. It is preferable to formulate indicators that really measure a response in the environment (or in society), that is success indicators. Sometimes, however, it is very difficult or costly to measure such indicators, and as a second approach implementation indicators could be accepted (e.g. 15000 hectares of habitat x should have some form of legal protection by 2012...). This means that such management instrument indicators could be acceptable, if "real" indicators are too difficult to use.

- Where MPAs have been introduced without clearly defined goals in the first place, there is a temptation to change the justification many years down the line. An example might be the NS Herring boxes: fisheries biologist could not demonstrate that they were useful in terms of stock recovery (because they were part of a package of measures), but the argument was put forward that they should be retained because they had resulted in inadvertent biodiversity benefits. When is it acceptable to remove non-successful MPAs? Their supposed utility often becomes a matter of faith. Goals should be updated and this should be a very transparent and conscious process. This highlights the value of a clear adaptive management process.

- For existing closures without clear objectives, a GOIS table should be carried out for each. This would ensure that the reasons for introduction are transparent and evaluations of success become easier.

Annex II: Further reading: PROTECT Scientific reports and publications

Publications and abstracts produced in relation to PROTECT

Armstrong, C.W. 2007. A note on the ecological–economic modelling of marine reserves in fisheries. Ecological Economics Volume 62, Issue 2, 20 April 2007, Pp. 242-250

Armstrong, C.W. & van den Hove, S. 2007. The formation of policy for the protection of cold-water coral off the coast of Norway. Marine Policy 32, 66-73.

Armstrong, C.W. & Falk-Petersen, J. 2008. Habitat Fisheries – a missing link. ICES Journal of Marine Science 65, 2008.

Bastardie, F., Nielsen, R. N., Kraus, G. Management Strategy Evaluation framework for the Eastern Baltic cod fishery including robustness against environmental conditions and fleet response scenarios. ICES J. Mar. Sci. (submitted).

Boulcott,P., Wright, P.J., Gibb, F.M., Jensen, H. , Gibb, I.M.(2007): Regional variation in maturation of sandeels in the North Sea. Ices Journal of Marine Science, 64: 369-376.

Christensen, A., Daevel, U., Jensen, H., Mosegaard, H., St John, M. and Schrum, C. (2007) Hydrodynamic backtracking of fish larvae by individual-based modelling. Marine Ecology Progress Series 347, 221-232.

Christensen, A., Jensen, H., Mosegaard, H., St John, M. and Schrum, C. 2008. Sandeel (*Ammodytes marinus*) larval transport patterns in the North Sea from an individual-based hydrodynamic egg and larval model. Can. J. Fish. Aquat. Sci. Vol. 65: 1498-1511.

Christensen, A. and Mosegaard, H.. Distance scaling analysis of larval transport - from climate to recruitment. Submitted to Journal of Marine Systems (2009).

Daunt, F., Wanless, S., Greenstreet, S.P.R., Jensen, H., Hamer, K.C. & Harris, M.P. (2008) The impact of the sandeel fishery closure in the northwestern North Sea on seabird food consumption, distribution and productivity. Canadian Journal of Fisheries and Aquatic Sciences 65: 362-38

Foley, N., van Rensburg, T. and Armstrong, C.W. The ecological and economic value of cold water coral ecosystems and their biodiversity. (revise and resubmit – Ecological Economics).

Fosså, J.H. and H.R. Skjoldal (in press). Conservation of cold-water coral reefs in Norway. In: R.Q. Grafton, R. Hilborn, D. Squires, M. Tait and M. Williams (eds). Handbook of Marine Fisheries Conservation and Management. Oxford University Press.

Frederiksen M., Jensen. H., Daunt F., Mavor R.A., and Wanless S. 2008. Differential effects of a local industrial sand lance fishery on seabird breeding performance. Ecological Applications, 18(3), 2008, pp. 701–710

Glenn, H. Wattage, P. Mardle, S. Van Rensburg, T. Grehan, A. and N. Foley (accepted). Marine Protected Areas – Substantiating their Worth. Marine Policy.

Gauger, M. (2008). Otoliths as indicators of good and poor conditions for sandeel 0-group recruitment in the North Sea. MSc Thesis, 118p. University of Hamburg, Institute for Hydrobiology and Fisheries Science.

Greenstreet, S., E. Armstrong, H. Mosegaard, H. Jensen, I. Gibb, H. Fraser, B. Scott, G. Holland and J. Sharples (2006). Variation in the abundance of sandeels *Ammodyes marinus* off southeast Scotland: an evaluation of area-closure fisheries management and stock abundance assessment methods. ICES J. Mar. Sci. vol. 63, 1530-1550.

Hinrichsen, H.H., Kraus, G., Voss, R., Stepputtis, D., and Baumann, H. (2005): General distribution pattern and mixing probability of Baltic sprat juvenile populations. ICES J. Mar. S. 58: 52-56.

Hinrichsen, H.-H., Voss, R., Wieland, K., Koester, F., Andersen, K. H., Margonski, P. (2007) Spatial and temporal heterogeneity of the cod spawning environment in the Bornholm Basin, Baltic Sea. Mar. Ecol. Prog. Ser., 345: 245-254.

Hoffmann, E. & Vestergaard, O. (2006): Advancing the development of new tools for monitoring, assessment and management of Marine Protected Area in the EU. Extended abstract in Proceedings of the First International Congress on Marine Protected Areas, Geelong, 25-28th Oct. 2005 (published early 2007). IMPAC 1 proceedings

Huwer B., Storr-Paulsen M., Riisgård H.U. and Haslob H. (2008) Horizontal and vertical distribution of the invasive ctenophore *Mnemiopsis leidyi* in the central Baltic Sea, November 2007. Aquatic Invasions, Volume 3, Issue 2, pages 113–124.

Kauppinen, Elsi (2008). Age estimation and growth of lesser sandeel (*Ammodytes marinus*) larvae. MSc Thesis, 27p. University of Joensuu, Faculty of Biosciences.

Köster, F.W., Möllmann, C., Hinrichsen, H.-H., Wieland, K., Tomkiewicz, J., Kraus, G., Voss, R., Makarchouk, A., MacKenzie, B.R., St. John, M.A., Schnack, D., Rohlf, N., Linkowski, T., and Beyer, J.E. 2005. Baltic cod recruitment – impact of climate variability on key processes. ICES J. Mar. Sci., 62: 1408-1225.

Kraus, G., Hinrichsen, H.H., Voss, R., Tomkiewicz, J., Teschner, E., and Köster, F.W. Egg production methods to estimate the stock size of Eastern Baltic cod (*Gadus morhua*). ICES J. Mar. Sci. (submitted).

Long, R. Marine Resource Law (London/Dublin/Toronto/Hong Kong, Thomson Round Hall, 2007) ISBN 1858004551, pp. 840. (pp.674-682 deals with marine SACs including the deep water coal sites); (pp. 180-254 deals with fishery management and the CFP).

Long, R. (2007), "Marine Scientific Research: Rights and Duties go hand-in-hand under the 1982 United Nations Convention on the Law of the Sea" in M. Nordquist, R. Long, T. Heidar, J. Norton Moore (Eds.), Law, Science and Ocean Management, (Boston/Leiden, Martinus Nijhoff, 2007), pp. 299-312.

Long, R. (2009) "Natura 2000 sites and fisheries management in Ireland: The deep-water coral sites" in China Ocean Law Review (forthcoming edition No. I (2009))

Nordquist, M., Long, R., Heidar, T., Norton Moore, J. (Eds.) 2007. Law, Science and Ocean Management (Leiden / Boston, Martinus Nijhoff, 2007), ISBN 9789004162556, pp. 850.

Pelletier, D. 2005. Designing operational quantitative tools and indicators for the assessment of Marine Protected Area Performance: A multidisciplinary project between scientists and managers. Extended abstract in Proceedings of the First International Congress on Marine Protected Areas, Geelong, 25-28th Oct. 2005 (published early 2007). IMPAC 1 proceedings

Pelletier, D., S. Mahévas, M. Jarraya, M. Capoulade, H. Drouineau, Y. Vermard, & F. Bastardie. 2005b. Investigating the consequences of Marine Protected Areas upon fish populations and fisheries through ISIS-Fish, a generic simulation tool. Extended Abstract in Proceedings of the First International Congress on Marine Protected Areas, Geelong, 25-28th Oct. 2005 (published early 2007). IMPAC 1 proceedings

Pelletier, D., J. Claudet, J. Ferraris, L. Benedetti-Cecchi, & J.A. García-Charton. 2008. Assessing ecological and fisheries-related effects of Marine Protected Areas: Current status and perspectives. Canadian Journal of Fisheries and Aquatic Sciences/ 65, 765-779.

Pelletier, D., S. Mahévas, H. Drouineau, Y. Vermard, O. Thébaud, O. Guyader, B. Poussin. (in press). Evaluation of the bioeconomic sustainability of complex fisheries under a wide range of policy options using ISIS-Fish. Ecological Modelling

Röckmann, C., St. John, M.A., Schneider, U.A. and Tol, R.S.J. (2007) Testing the implications of a permanent or seasonal marine reserve on the population dynamics of Eastern Baltic cod under varying environmental conditions. Fisheries Research 85 (1-2), 1-13.

Storr-Paulsen M and Huwer B (2008) Changes in distribution and lengths of *Mnemiopsis leidyi* in the central Baltic Sea between fall and spring. Aquatic Invasions, Volume 3, Issue 4, pages 441–446.

Sørensen, T.K. & Thomsen, L.N. (in press). A comparison of frameworks and objectives for implementation of marine protected areas in northern Europe and in Southeast Asia. Aquatic Ecosystem Health and Management Society.

Tomkiewicz, J., Kraus, G., Köster, F.W. & Parner, H. (2005) Timing of Baltic cod spawning and spawner demography. ICES CM 2005/Q:23

Tomkiewicz, J., Støttrup, J.G., Jacobsen, C. and Røjbek, M.C. Influence of lipid content and fatty acid composition on maturation and reproduction of Baltic cod (*Gadus morhua* L.) Marine Ecology Progress Series. (Submitted).

Papers in ICES Journal, Vol. 66, No. 1: European MPA Symposium.
(* papers directly connected to PROTECT)

* Erik Hoffmann and Angel Pérez-Ruzafa. Marine Protected Areas as a tool for fishery management and ecosystem conservation: An Introduction

Anthony Charles and Lisette Wilson. Human dimensions of Marine Protected Areas

* Simon Jennings The role of marine protected areas in environmental management

Ameer Abdulla, Marina Gomei, David Hyrenbach, Giuseppe Notarbartolo-di-Sciara, and Tundi Agardy. Challenges facing a network of representative marine protected areas in the Mediterranean: prioritizing the protection of underrepresented habitats

Patrícia Amorim, Miguel Figueiredo, Miguel Machete, Telmo Morato, Ana Martins, and Ricardo Serrão Santos. Spatial variability of seabird distribution associated with environmental factors: a case study of marine Important Bird Areas in the Azores.

Gwenaël Cadiou, Charles F. Boudouresque, Patrick Bonhomme, and Laurence Le Diréach . The management of artisanal fishing within the Marine Protected Area of the Port-Cros National Park (northwest Mediterranean Sea): a success story?

Olivier Chateau and Laurent Wantiez. Movement patterns of four coral reef fish species in a fragmented habitat in New Caledonia: implications for the design of marine protected area networks

* Asbjørn Christensen, Henrik Mosegaard, and Henrik Jensen. Spatially resolved fish population analysis for designing MPAs: influence on inside and neighbouring habitats

Sabrina Clemente, José Carlos Hernández, and Alberto Brito. Evidence of the top–down role of predators in structuring sublittoral rocky-reef communities in a Marine Protected Area and nearby areas of the Canary Islands

Charles T. T. Edwards, Rébecca A. Rademeyer, Doug S. Butterworth, and Éva E. Plagányi. Investigating the consequences of Marine Protected Areas for the South African deep-water hake (*Merluccius paradoxus*) resource.

Helen M. Fraser, S. P. R. Greenstreet, and Gerjan J. Piet. Selecting MPAs to conserve groundfish biodiversity: the consequences of failing to account for catchability in survey trawls

Simon P. R. Greenstreet, Helen M. Fraser, and Gerjan J. Piet. Using MPAs to address regional-scale ecological objectives in the North Sea: modelling the effects of fishing effort displacement

* Hans-Harald Hinrichsen, Gerd Kraus, Uwe Böttcher, and Fritz Köster,. Identifying eastern Baltic cod nursery grounds using hydrodynamic modelling: knowledge for the design of Marine Protected Areas

* Gerd Kraus, Dominique Pelletier, Julien Dubreuil, Christian Möllmann, Hans-Harald Hinrichsen, Francois Bastardie, Youen Vermard, and Stéphanie Mahévas. A model-based evaluation of Marine Protected Areas: the example of eastern Baltic cod (*Gadus morhua callarias* L.)

W. J. F. Le Quesne and Edward A. Codling. Mnaging mobile species with MPAs: the effects of mobility, larval dispersal, and fishing mortality on closure size.

Will J. F. Le Quesne. Are flawed MPAs any good or just a new way of making old mistakes?

Luigi Maiorano, Valerio Bartolino, Francesco Colloca, Alvaro Abella, Andrea Belluscio, Paolo Carpentieri, Alessandro Criscoli, Giovanna Jona Lasinio, Alessandro Mannini, Fabio Pranovi, Bruno Reale, Giulio Relini, Claudio Viva, and Gian Domenico Ardizzone. Systematic conservation planning in the Mediterranean: a flexible tool for the identification of no-take marine protected areas

Gorka Merino, Francesc Maynou, and Jean Boncoeur. Bioeconomic model for a three-zone Marine Protected Area: a case study of Medes Islands (northwest Mediterranean)

Søren Anker Pedersen, Heino Fock, Jochen Krause, Christian Pusch, Anne L. Sell, Uwe Böttcher, Stuart I. Rogers, Mattias Sköld, Henrik Skov, Magdalena Podolska, Gerjan J. Piet, and Jake C. Rice. Natura 2000 sites and fisheries in German offshore waters

Bastien Preuss, Dominique Pelletier, Laurent Wantiez, Yves Letourneur, Sébastien Sarramégna, Michel Kulbicki, René Galzin, and Jocelyne Ferraris. Considering multiple-species attributes to understand better the effects of successive changes in protection status on a coral reef fish assemblage

Catherine Seytre and Patrice Francour. The Cap Roux MPA (Saint-Raphaël, French Mediterranean): changes in fish assemblages within four years of protection.

Robert J. Smith, Paul D. Eastwood, Yoshitaka Ota, and Stuart I. Rogers. Developing best practice for using Marxan to locate Marine Protected Areas in European waters

Christopher J. Sweeting, Fabio Badalamenti, Giovanni D'Anna, Carlo Pipitone, and N. V. C. Polunin. Steeper biomass spectra of demersal fish communities after trawler exclusion in Sicily.

Prassede Vella, Robert E. Bowen, and Anamarija Frankic. An evolving protocol to identify key stakeholder-influenced indicators of coastal change: the case of Marine Protected Areas

Alan Williams, Nicholas J. Bax, Rudy J. Kloser, Franziska Althaus, Bruce Barker, and Gordon Keith. Australia's deep-water reserve network: implications of false homogeneity for classifying abiotic surrogates of biodiversity

Internal project documents and reports

- PROTECT newsletter, June 2005
- WP2: Review of Marine Protected Areas as a Tool for Ecosystem Conservation and Fisheries Management.
- WP3 Outline of 'Success criteria', working draft circulated prior to 1st Thematic workshop, Nantes, Nov 2005
- WP4: Introduction to meta-database, Dec 2005
- WP5: Outline of the economic approach to the PROTECT case studies, Dec 2005
- WP5: Outline of the PROTECT Overall Modelling Strategy, Feb 2006
- WP6 Outline of 'MPA Planning Scheme', working draft circulated prior to 1st Thematic workshop, Nantes, Nov 2005
- PROTECT Publishable Executive Summary, December 2006
- 12-Month Interim Activity Report, February 2006
- WP6: Report of 1st Thematic Workshop (Nantes, France), July 2006.
- WP6: Report of 2nd Thematic Workshop (Hamburg, Germany) , November 2006
- 24-Month periodic Activity Report, March 2007
- Final Report Case study 1
- Final Report Case study 2
- Final Report Case study 3
- Final WP3 Report
- Final WP4 Report
- Final WP5 Report
- Synthesis WP6 Final Report March 2009
- Final WP7 Report

Web-based publications

A detailed project introduction and news briefs have been posted at a number of international web portals and circulated in electronic newsletters dealing with marine science or conservation issues, including:

- EU FP6 Scientific Support to Policies portal – PROTECT description: http://europa.eu.int/comm/research/fp6/ssp/protect_en.htm
- EUCC Coastal News, No 3, March 2005: http://www.coastalguide.org/news/CN2005-03.pdf ; http://www.coastalguide.org/
- American Fisheries Society, April 2005 News: http://www.fisheries.org/html/April05diary.shtml
- PEW Ocean Institute for Ocean Science, April 2005: http://www.pewoceanscience.org/newsletter/newsletter.php http://listserv.miami.edu/scripts/wa.exe?A2=ind0504&L=seaspan&T=0&F=&S=&P=183
- One Ocean - Philippine's Coastal and Fisheries Management Information Center http://www.oneocean.org/overseas/200504/coastal_alert.html#26
- EurOcean Database of the Marine Science and Technology Projects Funded under FP6. http://www.eurocean.org/contents.php?id=346
- MPA News, Nov 2006: http://depts.washington.edu/mpanews/
- MPA News, Oct 2007 http://depts.washington.edu/mpanews/MPA90.pdf
- MPA News, Nov 2007 http://depts.washington.edu/mpanews/MPA91.pdf
- MPA News, Dec 2007 http://depts.washington.edu/mpanews/MPA92.pdf

Oral presentations to meetings and stakeholder fora

Armstrong, CW, van den Hove S. 2006. The formation of policy for protection of cold-water coral off the coast of Norway. Oral presentation given by CW Armstrong at ISRS 2006 European Meeting Bremen 19-22 September 2006.

Christensen, A. 2007. Toward area based management of sandeel in the North Sea. Oral presentation at the Nordic Workshop on Marine Spatial Planning.6-8 June 2007. Copenhagen, Denmark.

Foley, N.,Kahui, V. and Armstrong, C.W. 2007. 'The production function approach- estimating linkages between *Lophelia* and redfish on the Norwegian coast". Oral presentation at XVIII Annual Conference of the European Association of Fisheries Economists, Central Bank, Reykjavik, Iceland, 9 - 11 July 2007.

Fosså, J-H 2008. Effects of fishing on benthic habitats. Invited oral presentation to the Section for Environment and Fisheries of The Nordic Council of Ministers. Copenhagen, 17 January.

Fosså, J-H 2008. Research and management issues for Norwegian coral reefs. Talk at the Ecology Action Center in Halifax, 11 June, 2008.

Frederiksen, M. F. Daunt, M. Harris, M. Parsons, N. Ratcliffe & S. Wanless 2006. Effects of the North Sea sandeel closure on breeding seabirds. Presentation given at European Marine Biology Symposium, Cork, Ireland, September 4-8, 2006.

Gallego, A. presented a talk on “Bio-physical models: an evolving tool in marine ecological research” at the 8th Larval Biology Symposium (Portugal)

Glen, H., Mardle, S., Wattage, P. Paper presented at a University of Portsmouth Business School hosted Conference entitled, “Measuring the Irish Publics Preferences and Willingness to Pay for the Protection of Newly Discovered Corals off their Coasts using Choice Experiments”.

Grehan, A.J., J-H. Fossa, J. Pinnegar, P. Nilsson, C. Armstrong, M. Mellett, D. Pelletier, P. Mortensen, S. Jennings: “Developing Success Criteria for the Management of Cold-Water Coral Protected Areas”, Presentation to the Third International Symposium on Deep Water Corals in Miami, USA, 1 December, 2005.

Grehan AJ, Pinnegar J, Fossa J-H, Nilsson P, Armstrong C, Pelletier D, Mortensen P. 2006. Developing success critieria to assess the usefulness of measures applied to manage cold-water coral protected areas. Presentation given by Anthony Grehan at ISRS 2006 European Meeting Bremen 19-22 September 2006.

Hoff, A., Andersen, J., Mosegaard, H. & Christensen, A. (talk based on paper in prep for submission in *Marine Resouce Economics*). Economic and biological effects of marine protected areas: The sandeel fishery in the North Sea expected to be presented at the conference for fisheries economists EAFE 2009 in July 2009 in Malta.

Jensen H., Mosegaard H. and Christensen A. 2007. December 2007. The sandeel fishery off the Scottish east coast. Presentation at FRS Marine Laboratory Aberdeen, workshop on Marine Top Predator Interactions.

Köester, F: Population dynamics, fisheries, management scenarios, including application of fishing closures in the Baltic Sea. Presentation to the Baltic Sea Fisheries Association, 21 June 2005, Copenhagen, Denmark.

Kraus, G. Ecological & Fisheries consequences of closed areas in the Baltic Sea, Future Ocean Symposium, 07.10.2008, Kiel, Germany.

Kraus, G. Modellierung von Schonzeiten und Schutzgebieten als Instrumente des Fischerei -managements. Institute of Baltic Fisheries, 08.12.2008, Rostock, Germany.

Kraus, G. et al. 2007: Egg production methods to estimate the stock size of Eastern Baltic cod (*Gadus morhua*). PICES/ICES/NAFO Symposium on Reproductive and Recruitment Processes in Exploited Marine Fish Stocks. Lisbon, Portugal, 03.10.2007.

Sørensen, T.K. MPAs as a tool for ecosystem conservation and fisheries management in a European context - scientific needs and approaches. Oral Presentation given at SAFMAMS: Workshop on Marine Environmental Management. Developing forms of scientific advice. Gothenburg, Sweden. 10-11 December 2007.

Sørensen, T.K. PROTECT: Area-based management of North Sea ecosystems and resources – concepts and tools. Oral presentation given at PROFET Policy North Sea Fisheries Workshop. Copenhagen. 23-24 June, 2008.

Sørensen, T.K. & Vestergaard, O. Application of pelagic habitat models – a spatial management approach. Oral presentation: BALANCE Project Final Conference, Copenhagen. 25-26 October 2007.

Vestergaard, O., Hoffmann, E. & Sørensen, T.K. 2006. MPAs for ecosystem conservation and

fisheries management. Oral presentation given at symposium Marine Nature Conservation in Europe, May 8-12, Stralsund, Germany.

Oral presentations during "European Symposium on Marine Protected Areas as a Tool for Fisheries Management and Ecosystem Conservation *Emerging science and interdisciplinary approaches".* 25-28 September 2007 Murcia, Spain

Oral presentations

Assessing the appropriateness of measures used to manage cold-water coral protected areas. Anthony J. Grehan, J. Pinnegar, J-H. Fossa, P. Nilsson, C. Armstrong, M. Mellett & D. Pelletier

Spatial and temporal distribution of spawning Baltic cod: Implication for fisheries closures. Gerd Kraus, Jonna Tomkiewicz, Friedrich Köster & Hjalte Parner

Spatially resolved fish population analysis for designing of MPAs. Asbjørn Christensen, Henrik Jensen & Henrik Mosegaard

An Individual Based Model of North Sea Plaice and Marine Protected Areas. Charlotte Deerenberg, Niels Daan, Willem Dekker, Frank Storbeck & Bert Brinkman

The production function approach – estimating linkages between *Lophelia* and redfish on the Norwegian coast. Naomi Foley, Viktoria Kahui & Claire W. Armstrong

Elaborating reliable quantitative diagnostics of the impact of Marine Protected Areas on fisheries using ISIS-Fish. Stéphanie Mahévas & Dominique Pelletier

Identification of Baltic cod nursery grounds as potential Marine Protected Areas using hydrodynamic modelling. Hans-Harald Hinrichsen & Gerd Kraus

Using Marine Protected Areas within an Ecosystem Based Governance regime as a paradigm for the development of an Oceans Policy. Mark Mellett

A bioeconomic model of habitat-fisheries linkages. Viktoria Kahui & Claire Armstrong

A model-based evaluation of the performance of Marine Protected Areas as a fishery management measure for a stock facing strong environmental variability - the example of Eastern Baltic cod (*Gadus morhua callarias*). Gerd Kraus, Dominique Pelletier, Julien Dubreuil, Christian Moellmann, Hans-Harald Hinrichsen & Youen Vermad

Effects of the North Sea sandeel closure on breeding seabirds. Francis Daunt, Morten Frederiksen, Simon Greenstreet, Matt Parsons, Henrik Jensen, Keith C. Hamer & Sarah Wanless

An individual-based, multispecies model as a tool for exploring spatial management options. Ewen D. Bell, Julia L. Blanchard, Steve Mackinson & John K. Pinnegar

Evaluation frame for MPA and closed seasons applied to Baltic cod. Rasmus Nielsen, Bo Sølvgaard Andersen & Per Sparre

Poster Presentations

Glen, H., Mardle, S., Wattage, P. Poster presentation “Marine protected Areas – Irish Deep-Sea Corals – Environmental Valuation” at an EU Committee of the Regions Conference on MPAs “Meeting the targets of Marine Protected Area Networks” Brussels 16 May 2008.

Hoffmann, E., Vestergaard, O. & Sørensen, T.K. 2005. MPAs as a tool for ecosystem conservation and fisheries management. Poster presented at IMPAC1, 23-27 Oct 2005, Geelong, Australia.

Hoffmann, E., Vestergaard, O. & Sørensen, T.K. (2006). MPAs as a tool for ecosystem conservation and fisheries management. Poster presented at European Marine Biology Symposium, Cork, Ireland, September 4-8, 2006.

Pelletier, D. 2005. Designing operational quantitative tools and indicators for the assessment of Marine Protected Area Performance: A multidisciplinary project between scientists and managers. Poster presented at the First International Congress on Marine Protected Areas, Geelong, 25-28th Oct. 2005.

Presentations at national and regional meetings and stakeholder fora

Bergström, U. 2006. MPA discussion in November 2006 in Blekinge, Sweden with 20 commercial fishermen and 20 other stakeholders.

FGFRI organized fisher consultations that were arranged in Sweden, Denmark and Poland. The fisher consultation meetings were held by subcontractor Iconex Ltd. The fisher consultation plan is found in *Fishermen consultation plan final.* The plan was designed and accepted by all partners that took part in the Baltic CS. The fisher consultation summary (output) is found in *Fisher consultations*. The resulting information increases the understanding past conflicts around MPA impositions and identifies likely sources of agreement and disagreement in the future

Fosså, JH 2007. Member of ICES *Ad hoc* Group on Western Irish Natura Sites (AGWINS). Dublin, 21 June 2007.

Fosså, JH 2007. Participation in FAO Deep-Sea Fisheries Expert Consultation. Bangkok, 11-14 September.

Fosså, JH 2008. Input by correspondence to ICES Workshop on dealing with Natura 2000 and Related Requests (WKN2K). Copenhagen 5 June 2008.

Fosså, JH 2008. Member of the Norwegian delegation to FAO Technical consultation on International guidelines for deep-sea fisheries in the high seas. FAO, 4-8 February, Rome.

Fosså, JH 2008. Member of the Norwegian delegation to the CBD Ad hoc open-ended working group on protected areas. FAO, Rome, 11-15 February.

Fosså, JH and Mortensen, PB 2007. Organizers of a Nordic Workshop on cold-water corals. Status, methods and management. Thorshavn, 10-11 May 2007.

Grehan, A. March 2008. Participated in a FEUFAR (Future of European Fisheries and Aquaculture) stakeholder consultation workshop in Brussels.

Grehan, A. September, 2007. “PROTECT - How effective are Marine Protected Areas? (http://www.kfo.ie/downloads.html).Oral presentation at the Sixth Framework Programme PROFET Policy Workshop, Dublin, Ireland.

Hoffmann, E. 2006. The PROTECT Project. Presentation given during ICES Workshop (BFN): *Fisheries management in marine protected areas*. April 2006, Copenhagen. Present were European fisheries representatives, managers and scientists.

Hoffmann, E., Vestergaard, O. & Horsten, M. (2005). MPAs as a tool for ecosystem conservation and fisheries management. Oral presentation and Poster presented at the Conference of the North Sea Commission, Ringkøbing, Denmark, April 2005.

Hoffmann, E., Vestergaard, O. & Sørensen, T.K. (2005). PROTECT project poster displayed during Miljøuge (Thematic Environment Week), Bornholm, Denmark. (In Danish).

Hoffmann, Erik (2007): Marint vern og fiskeri (*Marine protection and fishery)* Bergen, Conference arranged by the Norwegian Fishermen's Organization.

Köster, FW. 2005. Presentation of the PROTECT project before the Baltic Sea Fisherman's Association. 21 June, 2005.

Kraus, G.: "Marine Protected Areas as a Tool for Ecosystem Conservation and Fisheries Management – The Baltic Sea case study". Seminar on Marine Protected Areas, DG Fisheries & Maritime Affairs of the European Commission, Brussels, Belgium, 17.01.2007.

Long, R. & Foley, N. 2008. Oral presentation "Natura 2000 sites and fisheries management in Ireland: The deep water coral sites" at the conference "Marine Natura 2000 sites and fisheries management:
The results of the EMPAS project" in Stralsund, Germany. 3-5 November 2008.

Long, R. Sept 2007. "Some issues generated by EU policies which impact on technical conservation measures". Oral presentation at the Sixth Framework Programme PROFET Policy Workshop, Dublin, Ireland.

Möllmann, C. 2007. "Marine Protected Areas (MPA) as a tool for fisheries management: The Baltic Case Study". Oral presentation at PROFET Policy –EUROFISH "Baltic Sea Fisheries Research Workshop". 19-20 April 2007. Vilnius, Lithuania.

Mortensen, P.B. 2007. Member of the Working Group on Deep Water Ecology (WGDEC) at ICES Headquarters Copenhagen, 25-28 February 2007.

Mortensen, P.B. 2008. Contribution on corals for the Development of a nature index for Norway. Lead by the Norwegian Pollution Control, Oslo, 22 May 2008.

Mortensen, P.B. 2008. Contribution on corals to OSPAR on Development of Ecological Quality Objectives for Threatened and Declining habitats in the OSPAR maritime area. August 2008.

Mortensen, P.B. 2008. Member of the ICES-NAFO Joint Working Group on Deep Water Ecology (WGDEC), Copenhagen 10-14 March 2008.

Mosegaard, H. 2005. North Sea RAC meeting, 11 May 2005, London, UK. Preliminary result from the closures at Firth of Forth.

NUI Galway (Partner 11) has established an Irish Steering Committee under the chairmanship of Cmd. Mark Mellett of the Irish Naval Service to streamline identification and access to appropriate data-sets held by national agencies.

Sørensen, T.K. 2006. Monitoring of fisheries in the Skagerrak- incl. new tendencies in European fisheries management (in Danish). Forum Skagerrak, Hirtshals, 19-20 April 2006.

Sørensen, T.K., Hoffmann, E., Vestergaard, O. 2006. Present and past MPAs used in fisheries management. Presentation given during ICES Workshop (BfN): *Fisheries management in marine protected areas*. April 2006, Copenhagen. Present were European fisheries representatives, managers and scientists.

Sørensen, T.K.. January 2007. Discussion meeting with fisheries stakeholder group on island of Bornholm, DK. PROTECT work among issues described and discussed.

Sørensen, T.K. Thematic meeting on marine protected areas. Consultation meeting with the Danish Ministry of Agriculture and Fisheries. Charlottenlund, Denmark. 14 May, 2008.

Sørensen, T.K. (together with A. Grehan and Gerd Kraus) presented the project during STECF/SGMOS-07-03 Working group and cited project results in the report on evaluation of closed area schemes (March 2007, Brussels & October 2007, Ispra)

Sørensen, T.K. PROTECT: Area-based management of North Sea ecosystems and resources – concepts and tools. Oral presentation given at PROFET Policy North Sea Fisheries Workshop. Copenhagen. 23-24 June, 2008.

Vestergaard, O. 2005. “Overview of PROTECT and potential linkages to MARBEF”. Presented at Marine Biodiversity and Ecosystem Functioning (MARBEF, FP6), project meeting, 5-6 Sept. 2005, Copenhagen.

Vestergaard, O. 2005. Baltic Sea RAC meeting, 22 June 2005, Copenhagen, Denmark, general introduction to PROTECT.

Vestergaard, O. 2006. “Introduction to an ongoing MPA research project in Northern Europe ("PROTECT") and to a new Nordic MPA Expert Forum”. Presentation at the 3rd North Atlantic Conference on Marine Protected Areas June 6 - 7, 2006, Tromsø

Vestergaard, O. 2006. Meeting and introduction to PROTECT with broad group of Norwegian fisheries and environmental managers. Oslo, Dec. 14, 2006.

Vestergaard, O. and Sørensen, T.K. 2005. Workshop on the European Marine Strategy, 3-4 Nov. 2005, Copenhagen, organised by Nordic Council of Ministers. Presentation “Linking fisheries and ecosystem management in the context of the European Marine Strategy”.

Partner 1, 11, 15. January 2007. DG Fish Conference and round table discussions on "Marine Protected Areas" Review of knowledge - evaluation of its EFFECTS”