## VECTORS of Change in Oceans and Seas Marine Life, Impact on Economic Sectors

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VECTORS Overview

‘VECTORS seeks to develop integrated, multidisciplinary research-based understanding that will contribute the information and knowledge required for addressing forthcoming requirements, policies and regulations across multiple sectors.’

Marine life makes a substantial contribution to the economy and society of Europe. In reflection of this VECTORS is a substantial integrated EU funded project of 38 partner institutes and a budget of €16.33 million. It aims to elucidate the drivers, pressures and vectors that cause change in marine life, the mechanisms by which they do so, the impacts that they have on ecosystem structures and functioning, and on the economics of associated marine sectors and society. VECTORS will particularly focus on causes and consequences of invasive alien species, outbreak forming species, and changes in fish distribution and productivity. New and existing knowledge and insight will be synthesized and integrated to project changes in marine life, ecosystems and economies under future scenarios for adaptation and mitigation in the light of new technologies, fishing strategies and policy needs. VECTORS will evaluate current forms and mechanisms of marine governance in relation to the vectors of change. Based on its findings, VECTORS will provide solutions and tools for relevant stakeholders and policymakers, to be available for use during the lifetime of the project.

The project will address a complex array of interests comprising areas of concern for marine life, biodiversity, sectoral interests, regional seas, and academic disciplines and especially the interests of stakeholders. VECTORS will ensure that the links and interactions between all these areas of interest are explored, explained, modelled and communicated effectively to the relevant stakeholders. The VECTORS consortium is extremely experienced and genuinely multidisciplinary. It includes a mixture of natural scientists with knowledge of socio-economic aspects, and social scientists (environmental economists, policy and governance analysts and environmental law specialists) with interests in natural system functioning. VECTORS is therefore fully equipped to deliver the integrated interdisciplinary research required to achieve its objectives with maximal impact in the arenas of science, policy, management and society.

www.marine-vectors.eu
EXECUTIVE SUMMARY

Purpose

The marine environment is subject to many activities and pressures, each of which may be regarded as a vector of change which in turn may require to be managed or at least accommodated in order to achieve objectives set by society. Sustainable solutions to those marine vectors require a set of adopted policy objectives and tools to ensure those objectives are met. This policy synthesis aims to provide guidance in the achievement of governance solutions to ecological and economic issues identified by the wider VECTORS project (WP1-WP6) and to emphasise to marine managers from different sectors the need for tackling synergistic and antagonistic influences between different marine uses and users. In this context, governance is regarded as the policies, politics, administration and legislation required to inform and manage the marine environment. This report presents original VECTORS research which was discussed with marine stakeholders throughout the project. Feedback from marine stakeholders was considered in order to produce policy recommendations on governance controls, assessment tools and policy scenario analysis for the key vectors of change associated with fisheries, marine energy and shipping.

Aims & Objectives

This deliverable provides a policy and governance synthesis to benefit stakeholders and especially those responsible for managing the marine environment. In order to achieve this aim, a number of objectives were set:

1. Review current marine governance at the international, EU and national level, with a particular focus on three key VECTORS themes (renewable energy, fisheries and shipping);
2. Interview stakeholders to determine similarities and differences in governance regimes across Europe, identifying lessons learned and examples of best practice;
3. Use scenario analysis to investigate questions such as: Can the governance and legislation currently in place cope with future changes? What current and future instruments will be required and how will they be adapted?;
4. Explore the use of numerical models and their potential to produce outputs for use by policymakers and stakeholders;
5. Develop a method for undertaking risk assessments in the marine environment, with a focus on the three key VECTORS themes (renewable energy, fisheries and shipping);
6. Investigate the role of stakeholders in shaping the future of marine governance with the use of semi-structured interviews and a marine stakeholder workshop; and
7. Using best practice from stakeholder feedback, provide policy advice for future marine governance and risk assessment decisions based on scenarios analysis.

Stakeholder input has been obtained from a series of semi-structured interviews at a geographical case study level in the VECTORS regional seas and also at the EU-level. A marine stakeholder workshop was organised to obtain stakeholder feedback to improve our current understanding of and stakeholder wishes for marine governance and learn from examples of best practice in order to better advise on future policy and risk assessment decisions based on scenarios analysis. This direct feedback from stakeholders enables the VECTORS project to determine whether successful outcomes have been achieved from the production of interdisciplinary research-based outputs.

Outcomes

Governance Controls

Given the plethora of marine environmental legislation including international obligations, European Directives and national enabling legislation, the VECTORS project mapped for the first time the relevant international and European marine policies for all Member States and, as an example, showed the
national implementation in England (Boyes & Elliott, 2014). As a representative cross-section for Europe, VECTORS Member States provided a summary of how the key European Directives have been enacted at the national level and the administrations (Government Departments, Agencies, etc.) responsible for their implementation. The European marine environment has a complex system of management that has historically developed in a piecemeal fashion in order to deal with various political and sectoral issues (e.g. fishing, shipping, energy, pollution) which have arisen over many years. This has followed different directions in each Member State with sectoral approaches to both legislation and administration, for example different statutory bodies and laws dealing with conservation and pollution control.

Consequently, in response to the requirement to apply a more holistic, ecosystem approach to marine management, European policy has recently shifted towards the adoption of framework directives, for example: the Strategic Environmental Assessment Directive (SEA), the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) and the recently adopted Marine Spatial Planning Directive. When this research on Government Controls was presented to marine stakeholders, there was consensus between stakeholders that all key pieces of legislation were covered by the mapping exercise, and it was advocated as being necessary to illustrate how the legislation cascades down to the national and subnational level. This reinforces the need for vertical integration amongst the levels of governance as well as horizontal integration across the stakeholders (Elliott, 2014).

VECTORS investigated the role of stakeholders and policymakers in shaping future marine governance, and therefore it was essential to engage stakeholders throughout the duration of the project. Semi-structured interviews were undertaken within each VECTORS regional sea (North Sea, Baltic Sea, Western Mediterranean), at the EU-level, and through marine stakeholder workshops to disseminate results and obtain feedback to improve our current understanding of marine governance. Although the stakeholder case studies focused on four different parts of three different regional seas, there were several common themes which emerged. Firstly, there are conflicts between uses and users of the marine environment, which may require conflict resolution strategies. Conflicts were particularly intense between (would be) users and those stakeholders who want as high a level of protection as possible for the marine environment. Secondly, stakeholders had differing levels of knowledge both in relation to the functioning of marine ecosystems with regard to human activities, and also regarding the duties and responsibilities of different stakeholders. This not only prevented pressure and impacts being understood and placed in context but also led to entrenched views amongst the different stakeholders and in some areas, with few signs of these being overcome.

Uncertainties about the future efficacy and implementation of the MSFD and the Common Fisheries Policy (CFP) have contributed to the many concerns and potential difficulties in achieving an integrated management of the marine space. Similarly, those working in different sectors of marine management, do not appear to have a complete understanding of the legislation framework discussed above. It is notable that those with a statutory responsibility have a good knowledge of the legislation and agreements relating to their sphere of influence but less so for the other areas. It could be concluded that such regulators are too busy with their own fields that they have neither the time, resources, nor inclination to become familiar with all aspects of other sectors or with the implementation of the Ecosystem Approach per se.

Despite the above, there are elements of good practice, such as models of co-operation and collaboration at the national and transnational level both between Member States and stakeholders, as shown for The Dogger Bank, which can be transposed to other areas. The recent Concordat developed in the UK should prove worthwhile to ensure that one marine agency takes the lead in management issues in cases where several agencies occur with different statutory responsibilities.
VECTORS Policy Recommendations for Governance Controls

VECTORS recommends that it would be valuable to undertake a legislation and administration mapping exercise similar to that of England for each EU Member State to enable comparisons between Member States and to identify gaps and communicate these to regulators.

VECTORS recommends that future governance should focus on activities which are not currently regulated, for example sectors of the Blue Growth agenda (e.g. large scale offshore aquaculture, seabed mining, blue biotechnology) for which there is currently limited regulation and little is known about the ecosystems in which the activities take place.

VECTORS recommends that linking Marine Spatial Planning, Integrated Coastal Zone Management and Strategic Environmental Assessments is essential to integrate governance across sectors.

VECTORS further recommends that a harmonisation is required of the definition of the status assessments between the different directives (e.g. MSFD, WFD, HD) in relation to activities, pressures and impacts and their management.

VECTORS recommends that sufficient resources be allocated to fully integrate stakeholders in the management process, and that stakeholder input is managed more efficiently to avoid stakeholder fatigue.

VECTORS follows stakeholder demands and recommends that a ‘one-stop-shop’ be established within each Member State from which all marine data can be accessed and which acts as a focal point for decision-making.

Assessment Tools

The management of natural resources against a background of human uses and users is a complex process. It is driven by the dynamics of the natural system under the influence of decision-makers and other stakeholders, and therefore requires robust approaches that meet clear management objectives. In order to achieve such management objectives, Member States require tools to ensure that those objectives are met. VECTORS research has focussed on two particular types of tools which can be used by managers and stakeholders to achieve sustainable management of marine resources - modelling tools for management evaluations and methods of undertaking risk assessment of activities within the marine environment.

A wide range of models have been applied during the VECTORS project, with their strengths, weaknesses, value for specific management evaluation processes, the trade-offs and their status of application having been analysed for the purposes of this deliverable. For most models the level of implementation into management advice is limited due to a lack of precise objectives for using the model for management purposes, extensive data requirements of the model, the requirement for specialists to operate the model and the confusion and uncertainty amongst managers confronted with a plethora of models each with its own limitations. For example, biogeochemical lower trophic level models can provide estimates of projected changes at the base of the marine food web (phytoplankton, zooplankton) including key water quality parameters such as dissolved oxygen and nutrient dynamics. Those models lack realistic depictions of upper trophic levels and cannot provide advice on commercially-important living marine resources. A second example includes single and/or multi-species stock assessment models which are routinely used to provide advice on sustainable exploitation rates of fisheries resources. At the present time, these models do not explicitly take into account climate-driven changes in key abiotic factors such as water temperature and circulation patterns known to affect year-class success of many marine fishes. Finally, at the most complex end of the spectrum, ‘end-to-end models’ are being parameterized which include a management evaluation framework. Those models include interacting modules representing the physical environment, food web...
complexities, fishing activities and associated economic assessments to fishing fleets and associated sectors. Such models are ideal for strategic advice (what to do) but are too complex to provide tactical advice (how to do it).

A meta-analysis of the magnitude and direction of changes projected from both lower trophic level and upper tropic level models was undertaken by VECTORS modelling researchers. That analysis identified “hot spots” of change in the North Sea. Most of the parts of the North Sea that are expected to be most sensitive to climate-driven changes in ecosystem dynamics (and nutrient loading of coastal areas) are being overlooked. This finding has important implications for the management of the North Sea ecosystem and the sustainable use of its resources.

Risk Assessment is a well-established concept and indeed is implicitly or explicitly embedded within any impact assessment such as Environmental Impact Assessment, Appropriate Assessment, Strategic Environmental Assessment, etc. There are many methods of performing a Risk Assessment and, as an example, the Bow Tie analysis has been applied in the VECTORS project to both offshore wind energy and fisheries respectively for the real case-studies of the Dogger Bank and the Sardinian marine protected area (MPA). These were the first applications in Europe of the Bow Tie model in the risk assessment and management of marine ecological systems and these applications demonstrated it to be a successful proof-of-concept. This system allowed the causes and consequences of marine environmental change to be presented together with the prevention and mitigation strategies required by the management of the activities and pressures. The Bow Tie analysis will help managers to identify where there are particular hazards that are not effectively controlled, or where they perhaps may be being ‘over’ controlled and resources may be better allocated elsewhere. It allows management priorities to be decided and can be developed further into a quantitative model linked to scenario testing. In addition, VECTORS reviewed risk assessment tools and new decision support systems for European ports as required under the Ballast Water Management Convention. VECTORS developed a global Ballast Water Management (BWM) related risk assessment tool which provides administrations with a detailed step-by-step risk assessment model for exemptions from ballast water management. This model was applied to Intra-Baltic shipping, with the findings considered to be of value to other areas world-wide. VECTORS also produced a generic Ballast Water Management Decision Support System Model which was validated using a single year of real-world ballast water data from the Port of Koper, Slovenia.

**VECTORS Policy Recommendations for Assessment Tools**

VECTORS recommends that there is a need for the increased availability of highly spatially and temporally resolved information on human activities in the marine environment as this forms an important part of supporting decision making in marine spatial planning.

VECTORS recommends that there is the need for integrated, ecosystem-level analysis of spatially and temporally resolved data, in a transparent manner that is sufficiently user-friendly to be understood by managers and policy makers.

VECTORS recommends that the breadth of present and future risks which may significantly affect human societies, e.g. shipping, marine litter, invasive species, ocean acidification, climate change, oil and gas developments, noise and the blue growth sector, needs the causes of change to be addressed in combination.

VECTORS recommends that a clear set of priorities needs to be identified regarding future marine hazards and risks which would allow the regulatory framework to be structured to meet these needs.
VECTORS recommends that the Bow Tie methodology is an appropriate methodology to assess risks in the marine environment but it requires further development to account for combined pressures and cumulative impact assessments.

VECTORS recommends that to ensure data reliability in the ballast water management risk assessment model, port baseline surveys and regular monitoring programmes should be undertaken during the exemption period as new species found will influence the risk assessment.

**Vectors of Change**

Given an uncertain development of marine uses, users and the ecosystem response, VECTORS applied four contrasting future scenarios to test whether current marine policy actions are robust and sustainable. This research focussed on three of the VECTORS drivers of change (demand for food, energy and transport) and explored policy repercussions to 2050. Although the four scenarios can be regarded as extremes, they all contain recognisable events, for example society is globalising but at the same time becoming more aware of environmental issues. It is presumed unlikely that any of the four scenarios will evolve in an unconstrained way since future pathways are dependent upon existing legislation, obligations and conventions. Irrespective of that future trajectory, the continuing move from sectoral legislation and management to a more holistic approach is likely. The VECTORS marine stakeholders supported the use of future scenario analysis to test the relevance of current policy into the future. The stakeholders recognised that scenarios can be used to ‘test’ which policy actions are robust and sustainable and provide a valuable tool for conceptually modelling future societal changes. The importance of this approach to ensure that the scenarios used are not too conservative was raised by the VECTORS marine stakeholders. This VECTORS policy and governance research showed that the big challenge for using scenario analysis in this context is communicating the findings of the scenarios research effectively to stakeholders and policymakers. However, there may be some politically difficult elements of the scenarios and therefore these will need sensitive handling.

**VECTORS Policy Recommendations for Vectors of Change**

VECTORS recommends that scenarios analysis should be used to ‘test’ possible outcomes of policy decisions taken now and their future ramifications.

VECTORS recommends that given uncertainty in the future, all four scenarios should be applied but that a concerted attempt to also address the likely combined scenario will be needed.

**Linkages to Other Work Package Deliverables**

D60.6 provides a synthesis all of the work which has been undertaken within VECTORS WP6, which in turn has drawn upon information from other VECTORS work packages. In particular this deliverable synthesises the findings reported in:

- D60.1 Understanding stakeholder and policymaker needs for successful marine environmental management.
- D60.2 Database of alien species presence within and in the ‘vicinity’ of representative ports.
- D60.3 Review of ballast water discharge risk assessment tools and new decision support systems for EU ports.
- D60.4 Risk assessment for fisheries management.
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- D60.5 Risk assessment for renewable energy exploitation.

In addition, to findings reported in the Regional Seas Deliverables:

- D41.1 Synthesis report of the VECTORS findings that are relevant to the issues of the Western Mediterranean Regional Sea.
- D42.1 Synthesis report of the VECTORS findings that are relevant to the issues of the North Sea Regional Sea.
- D43.1 Synthesis report of the VECTORS findings that are relevant to the issues of the Baltic Sea Regional Sea.

Additional Publications

A number of peer-review publications have resulted from the research undertaken within WP6:

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1. INTRODUCTION

The VECTORS project aims to elucidate the drivers, pressures and vectors that cause change in marine life, the mechanisms by which they do so, the impacts that they have on ecosystem structures, functioning and services, and on the economics of associated marine sectors and society. The particular focus of the project is on causes and consequences of invasive alien species, outbreak forming species, and changes in fish distribution and productivity.

In order to understand the complexity of the issues being addressed within the VECTORS project, the DPSIR (Drivers-Pressures-State changes-Impacts-Responses) framework can be applied, which provides a useful problem structuring method (Atkins et al., 2011; Gregory et al., 2013). Marine management can be usefully defined within the DPSIR framework, recently expanded to the DAPSI(W)R framework, in which we consider the Drivers, the main demands from the system, the resulting Activities and the Pressures resulting from them, these in turn lead to State changes on the natural system which may be positive or negative, and then to Impacts on the human system, finally Responses may be applied to control the State changes and Impacts (Elliott, 2014; Smyth et al., 2015). Within the context of the VECTORS project, examples of vectors of change from Drivers through Impacts to policy Responses are highlighted in Table 1.1. In essence if integrated management is successful then following the implementation of the combined Responses, the Drivers and Pressures should not produce State changes and subsequent Impacts on societal welfare (Elliott, 2014).

Table 1.1: Examples of vectors of change – from drivers through impacts to policy responses (Elliott, 2014).

<table>
<thead>
<tr>
<th>Driver</th>
<th>Pressure</th>
<th>State Change</th>
<th>Impact (on human Welfare)</th>
<th>Response</th>
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<tr>
<td>Increasing urbanisation, agriculture and industrialisation</td>
<td>Changes in temperature regimes and weather patterns (storminess)</td>
<td>Climate change and related impacts (natural and anthropogenic; effects on structure and functioning and on Ecosystem Services (ES))</td>
<td>Local adaptation, compensation; policy, economic &amp; legal mechanisms</td>
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<tr>
<td>Increased CO2 and decreased pH</td>
<td>Ocean acidification</td>
<td>Reduced ecosystem services, ability for waste removal</td>
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<td>Diffuse and point source land-based pollution</td>
<td>Polluted components; Harmful Algal Bloom formation</td>
<td>Environmental and food quality reduction, reduced ES</td>
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<td></td>
</tr>
<tr>
<td>Space removal</td>
<td>Loss of carrying capacity</td>
<td>Loss (&amp; gain) of ecosystem services</td>
<td>Planning controls, Marine Spatial Planning</td>
<td></td>
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<tr>
<td>Demand for food</td>
<td>Capture fisheries</td>
<td>Changes to local populations, spawning sustainability, by-catch and habitat damage</td>
<td>Stock viability, ecosystem services reduction</td>
<td>Economic and legal instruments</td>
</tr>
<tr>
<td>Aquaculture</td>
<td>Changes to local ecology</td>
<td>Ecosystem services (+ and -)</td>
<td></td>
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<tr>
<td>Maritime transport (demand for movement of goods, etc)</td>
<td>NIS (non-indigenous species) introduction, infrastructure demands, pollution, dredging</td>
<td>Community change, habitat alteration Pest introduction, invasive and nuisance species; effects on ecosystem services</td>
<td>Introduction of new ballast water technologies and practices</td>
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<tr>
<td>Energy demands</td>
<td>Infrastructure demands</td>
<td>Habitat loss and gain, energy/hydrodynamic change</td>
<td>Effects on ecosystem services (+ and -)</td>
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<td>Tourism &amp; recreation demands</td>
<td>Loss of natural habitats, reduction in resilience</td>
<td></td>
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<td>Total societal demands</td>
<td>Interactions between multiple users &amp; sectors</td>
<td>Cumulative effects on natural structure and functioning</td>
<td>Effects on ecosystem services</td>
<td>Changes in policy</td>
</tr>
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</table>

Sustainable solutions to the vectors of change require a set of adopted policy objectives and tools to ensure those objectives are met. Thus the purpose of this policy synthesis is to provide guidance in achieving governance solutions to ecological and economic issues identified by the wider VECTORS project (WP1-WP6) and to emphasise to marine managers from different sectors the need for tackling synergistic and antagonistic influences between different marine uses and users. The pressures emanating from the activities of the uses and users of the marine system and the wider influences on the system create hazards and risks which need to be understood and where possible controlled, if not at least accommodated, mitigated or compensated for under a system of adaptive management (e.g. Elliott et al., 2014). Arguably three of the greatest Drivers in the marine environment relate to the
demand for food, maritime transport and energy (Table 1.1). As such WP6 has focussed on these three 
Drivers, and in particular on the Activities, Pressures, State changes, Impacts and Responses 
associated with the shipping, fishing and offshore renewable energy activities.

This deliverable (D60.6) aims to provide a policy and governance synthesis which can be used as a 
tool for stakeholders. In order to achieve this aim, a number of objectives were set:

1) Undertake a detailed review of current marine governance at the international, EU and national 
level, with a particular focus on renewable energy, fisheries and shipping;

2) Undertake a series of stakeholder interviews to determine similarities and differences in 
governance regimes across Europe, identifying lessons learned and examples of best practice;

3) Use scenarios analysis to investigate questions such as: How does the governance and 
legislation we have in place today cope with future changes? What instruments will still be 
around in the future and how will they be adapted?;

4) Explore the use of numerical models and their potential to produce outputs for use by 
policymakers and stakeholders;

5) Develop a method for undertaking risk assessments in the marine environment, with a focus on 
renewable energy, fisheries and shipping;

6) Investigate the role of stakeholders in shaping the future of marine governance with the use of 
both semi-structured interviews and a marine stakeholder workshop; and

7) Based on examples of best practice from stakeholder feedback, provide policy advice for future 
marine governance and risk assessment decisions based on scenarios analysis.

This deliverable provides a synthesis of all of the work which has been undertaken within WP6, which in 
turn has drawn upon the best available natural and social science from WP1-WP5. This is illustrated by 
Figure 1.1 below.

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Figure 1.1: Structure of WP6 synthesis for policymakers and stakeholders
In particular, this deliverable synthesises the findings reported in:

- D60.1 Understanding stakeholder and policymaker needs for successful marine environmental management.
- D60.2 Database of alien species presence within and in the ‘vicinity’ of representative ports.
- D60.3 Review of ballast water discharge risk assessment tools and new decision support systems for EU ports.
- D60.4 Risk assessment for fisheries management.
- D60.5 Risk assessment for renewable energy exploitation.

In addition, to findings reported in the Regional Seas Deliverables:

- D41.1 Synthesis report of the VECTORS findings that are relevant to the issues of the Western Mediterranean Regional Sea.
- D42.1 Synthesis report of the VECTORS findings that are relevant to the issues of the North Sea Regional Sea.
- D43.1 Synthesis report of the VECTORS findings that are relevant to the issues of the Baltic Sea Regional Sea.

The current forms and mechanisms of marine governance in relation to the vectors of change have been evaluated and this deliverable provides solutions and tools for relevant stakeholders and policymakers, to be available for use during the lifetime of the project. Given that the focus of this deliverable is on synthesising policy and governance as a tool for stakeholders, it was essential to involve stakeholders throughout the duration of the project. As illustrated by Figure 1.1, stakeholders and policymakers were directly involved in both Tasks 6.1 and 6.2, which were reported in D60.1 within the first 18 months of the project. This involved a series of semi-structured interviews (n=69) held within each VECTORS regional sea (North Sea, Baltic Sea, Western Mediterranean), and at the EU-level. A stakeholder workshop was also held in Month 37, at the start of the final year of the project, at which research findings from WP6 were presented and feedback was received from a wide range of marine stakeholders (see Annex 1 for further details). This feedback was incorporated into this synthesis report (D60.6) to improve our current understanding of marine governance and learn from examples of best practice in order to better advise on future policy and risk assessment decisions based on scenarios analysis. Specific feedback from the workshop has been highlighted throughout the document as a series of ‘Stakeholder-based Conclusions and Recommendations’ case study boxes (shaded in grey).
2. REVIEW OF CURRENT GOVERNANCE (INTERNATIONAL, EU AND NATIONAL)

2.1 Introduction

In Europe, the European Union (EU) is a pre-eminent player in the field of sustainable regional development and in recent decades, it has adopted more than 200 directives, regulations and many other forms of legislation and amendments in the area of environmental policy that have direct repercussions for regional development (Beunen et al., 2009). These have been adopted to deliver requirements of international law or in response to a European problem. This policy framework is aimed at the sustainable use of marine resources, but also the protection of marine biodiversity – indeed the main idea of marine management is to protect and enhance the natural structure, processes and functioning while at the same time delivering the ecosystem services from which society can take benefits (Elliott, 2011; 2013).

Few attempts have been made to collate and synthesise environmental policies to manage the marine environment (Boyes & Elliott, 2014), and therefore the VECTORS project provides an overview and discussion of the types of international law, European directives and the national implementation which specifically regulate or impact on three of the key VECTORS drivers: energy, fisheries and alien species. For each policy area the following information is presented:

1. A brief synopsis
2. Legal status (Contracting parties in relation to international law)
3. Key provisions
4. VECTORS Drivers (highlighting where alien species, energy (renewable and non-renewables) and fisheries are given specific mention in the text or impact on the ethos of the Convention/Directive)
5. Transboundary or domestic effect
6. Geographic scope
7. Institutional organisations
8. Subsidiary instruments

Each legal instrument is reviewed from its source text e.g. convention, directive or policy, using where appropriate the explanatory notes issued with the text. A detailed synopsis of these legislative measures is provided in D60.1, with national legislation and management organisations across Europe summarised in Annex 2 of this synthesis report.

2.2 International Law

D60.1 (section A2) reviews and summarises the international law including the fundamental marine law of the United Nations Convention on the Law of the Sea (UNCLOS) and the major international environmental instruments resulting from the 1992 Rio Earth Summit (UN Conference on Environment & Development (UNCED)) including the Convention on Biological Diversity (CBD) and the United Nations Framework Convention on Climate Control (UNFCCC). It reviews specific Conventions agreed to control pollution from ships (Convention for the Control and Management of Ships Ballast Water & Sediments (BWM) and MARPOL) and the dumping of other wastes (London Convention and Protocol). The Environmental Impact Assessment in a Transboundary Context (Espoo Convention) is reviewed together with the suite of Conventions, Strategies and Agreements designed to protect wildlife and habitats (Bern Convention, Ramsar, ASCOBANS, CITES and the European Strategy on Invasive Alien Species). Finally the Regional Seas Conventions (RSCs) of OSPAR, HELCOM and Barcelona are summarised and discussed in the context of the VECTORS drivers and how they address them.

The CBD emphasises the need for Marine Protected Areas (MPAs) to be designated both inside and outside national jurisdiction in accordance with international law including UNCLOS. These MPAs should be included in marine spatial planning and may influence the location of offshore renewable
activities and related grid infrastructure and the type of fishing activities which can occur. The CBD is the only globally applicable, legally binding instrument to generally address alien species introduction, control and eradication across all biological taxa and ecosystems, identifying them as a major cross-cutting theme (Shine et al., 2000).

Given that shipping is the major vector of species introductions to the marine environment through ballast water (including sediments) and biofouling, the International Maritime Organisation (IMO) started negotiations to consider the possibility of developing an internationally binding instrument to address the transfer of harmful aquatic organisms and pathogens in ship ballast water. In 2004, The International Convention for the Control and Management of Ships’ Ballast Water and Sediments (BWM) was adopted. Shortly thereafter biofouling as a species transport vector became an agenda item and was addressed by the relevant IMO working groups with the aim to reduce the risk of the introduction of species with biofouling. In particular the following instruments developed by the IMO were considered: (a) International Convention on the Control of Harmful Anti-Fouling Systems on Ships, and (b) the Guidelines for the Control and Management of Ships’ Biofouling to Minimise the Transfer of Invasive Aquatic Species and the Guidance for Minimising the Transfer of Invasive Aquatic Species as Biofouling (Hull Fouling) for Recreational Craft. These instruments are further discussed in Annex 3.

2.3 European Law

Chapter A3 of D60.1 details the relevant European legislation implemented to protect habitats and species (Habitats Directive, Wild Birds Directive, and the Common Fisheries Policy) and the health, quality and protection of marine and coastal waters through the Water Framework and Marine Strategy Framework Directives. Overall strategy documents to protect the marine environment and biodiversity are reviewed including the Integrated European Maritime Policy, the EU Biodiversity Strategy and the ICZM Protocol. Finally, the Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) Directives are summarised, all the above indicating the way in which they address the three VECTORS drivers of energy, fisheries and alien species.

Historically, the EU approach to the protection of the marine environment has been piecemeal (Boyes & Elliott, 2014). Since the 1970s, marine based activities have been regulated through various sectoral policies, where the sector including fishing, aquaculture, energy, navigation, infrastructure development, agriculture, etc. has been addressed through a specific piece of legislation, usually separate from other issues (Mee et al., 2008). Long (2011) considered that these policies were, and in some instances still remain ‘stand-alone policies’ with few common features giving holistic protection of the marine environment. Only recently has EU law changed to a whole system view (Apitz et al., 2006; Holt et al., 2011) with the development of a more holistic approach in terms of estuarine, coastal and marine management brought about by the evolution of EU directives. With framework directives now the principal means of regulatory intervention under the EU environmental policy, this large body of environmental legislation and policy has been developed in order to monitor, conserve and protect the marine environment. Where most sectoral directives are prescriptive in nature setting targets and giving detailed descriptions, in contrast, framework directives leave the details to the discretion of the Member States1 (MS). These newer instruments share a common objective of attaining sustainable development and through the implementation of the ecosystem approach, existing and new policy making and delivering institutions must be able to accommodate and adapt to a new multi-sectoral approach (Mee et al., 2008; Bainbridge et al., 2011; van Leeuwen et al., 2014). This in turn follows from

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1 Member States are countries within Europe who have joined to cooperate both economically and politically. The European Union (EU) is based on the rule of law: everything that it does is founded on treaties, voluntarily and democratically agreed by all member countries. These binding agreements set out the EU’s goals in its many areas of activity. The EU reached its current size of 28 member countries with the accession of Croatia on 1 July 2013.
the European Member States being signatories of the UN Convention on Biological Diversity which is based on the 12 principles of the ecosystem approach (e.g. Elliott, 2011). The recent directives formulate objectives which are not geographically bound to national jurisdiction, but apply to all uses and users of a designated marine area (Qui & Jones, 2013), ensuring regional sea management and protection. For example, the Strategic Environmental Assessment (SEA) Directive (2001/42/EC) focuses on larger areas and is an attempt to consider cumulative and in-combination effects thus expanding the control of EIA. Similarly, the so-called Natura 2000 Directives relating to Habitats and Species (92/43/EEC as amended) and Wild Birds (2009/147/EC - the codified version of Directive 79/409/EEC as amended) cover many features within designated areas (Special Areas of Conservation and Special Protected Areas respectively). Hence within those areas (and within adjacent areas), all activities, plans and projects have to be considered where they affect or potentially affect conservation objectives. The Water Framework Directive (WFD) (2000/60/EC) marked a change in emphasis in EU legislation, being part of the so called ‘third wave’ of EU legislation which adopts a holistic approach to water environmental protection and regulation (Moran & Dann, 2008). The WFD provides an integrated policy tool aimed at achieving Good Chemical and Good Ecological Status (GECs)\(^2\) of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater and also to prevent deterioration in the status of those water bodies by 2015 (Hering et al., 2010).

The EU vision for future management of its seas is set out in the 'Blue Book', the Integrated Maritime Policy (IMP) for the EU (EC, 2007). The EU IMP calls for the ‘integration of maritime governance’ to ensure stakeholder engagement, coherent agendas, removal of sectoral policy thinking and creation of cross sectoral management structures (EC, 2009). Implementation of an Ecosystem-Based Approach (EBA) through the Marine Strategy Framework Directive (MSFD) (2008/56/EC) thus forms the environmental pillar of the IMP. The MSFD seeks to establish an integrated framework for the management of marine spaces, and requires large ecoregions to achieve or maintain Good Environmental Status (GES) by 2020 (Borja et al., 2010, 2013; Hering et al., 2010). Whereas the WFD considers the ecological status according to a set of biological quality elements, the MSFD potentially focuses on the functioning and responses according to a set of 11 Descriptors. It enshrines in a legislative framework the EBA for the management of human activities having an impact on the marine environment, integrating the concepts of environmental protection and sustainable use (Ounanian et al., 2012). Hence, the MSFD is unique across European regional seas that requires assessing the range of issues that should encompass overall marine environmental sustainability (EC, 2008; Long, 2011; van Leeuwen et al., 2014).

The MSFD also addresses three of the VECTORS thematic topics. Member States are required to draw up a strategy aimed at achieving GES by 2020 in all of its marine waters, including the Renewable Energy Zone and those areas of the Continental Shelf over which it has jurisdiction. The Directive states that GES should ensure that anthropogenic inputs of substances and energy, including noise, into the marine environment do not cause adverse effects. Annex I qualitative descriptors for determining GES includes: 11) Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment. This is an important factor when considering the underwater noise created during the construction and operation of offshore renewables e.g. wind farms and tidal turbines. The Directive also specifies that Member States should enable the sustainable use of marine ecosystem goods and services and to ensure the marine environment is safeguarded for the use of future generations. In relation to fisheries, the MSFD significantly strengthens Member State competences and responsibilities to maintain or achieve GES for all exploited fish and shellfish stocks inside territorial waters and the exclusive economic zones (EEZs) with common goals (Hans-Joachim et al., 2010). The MSFD aims to foster and harmonise European fisheries management with ecosystem

\(^2\) Following Mee et al., 2006, and Borja et al., 2010, here we use GECs for Good Ecological Status rather than GES to differentiate it from Good Environmental Status in the MSFD.
approaches. In the text of the Directive, Annex I provides the qualitative descriptors, with Annex II giving information on pressures and impacts addressing fish populations and fishing activities in order to achieve GES. The MSFD is one of the first pieces of European legislation to address invasive alien species. Annex I qualitative descriptors specifically address alien species by requiring that: 2) Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems. In preparing marine strategies, Member States must provide an inventory of the temporal occurrence, abundance and spatial distribution of non-indigenous, exotic species or, where relevant, genetically distinct forms of native species, which are present in the marine region or subregion.

With the competition for maritime space and the need to reduce conflict between competing developments (Douvere, 2008), the EU has recently adopted a new directive addressing Maritime Spatial Planning (MSP) (2014/89/EU). This Directive will manage and give greater coherence to all activities and uses and users, aimed at reducing the existing over-regulation and administrative complexity within the marine environment (EC, 2014). The Directive should ensure a coordinated approach to MSP throughout Europe, to enable the efficient and smooth application of MSP in cross-border marine areas, to favour the development of maritime activities and the protection of the marine environment based on a common framework, all under the umbrella of similar legislative implications (EC, 2011). However, it has been argued that this new directive is essentially about promoting Blue Growth and neglects the framework nature and ultimate aims of achieving GES under the MSFD (Brennan et al., 2013), and favourable conservation status (FCS) under the Habitats Directives (Qui & Jones, 2013).

2.3.1 PROPOSED POLICY

As indicated above, the IMO initiated the BWM to prevent, minimise and ultimately eliminate the transfer of harmful aquatic organisms and pathogens through the control and management of ship ballast water and sediments. Although the European Commission has ‘strongly recommended’ that Member States should ratify the BWM Convention, very few EU countries have done so. In an effort to address the problem, the EU has developed interim measures through the four Regional Seas Conventions (HELCOM, OSPAR Commission, UNEP-MAP/Barcelona Convention and the Black Sea Commission) and introduced directives which address invasive alien species (IAS) (e.g. MSFD; Port Waste Reception Facilities Directive (2000/59/EC)). In 2013, the EC proposed new legislation which would require EU Member State to ascertain the routes of introduction and spread of IAS and set up surveillance systems and action plans (EC, 2013). The Regulation on the prevention and management of IAS will draw on the EU Resource Efficiency Roadmap and the EU Biodiversity Strategy to 2020. Guidelines have also been developed for Member States on how to apply the IMO guidelines, with further biofouling guidance developed for ships working within the European Union and for those entering the waters of the European Union States to promote harmonisation of the implementation of any biofouling related measures. Again these issues are discussed further in Annex 3.

2.4 Mapping Marine Legislation

As discussed above, all European Member States have to respond to a large suite of international, regional and national policies, laws and agreements controlling many sectors such as fisheries, energy and conservation. Consequently there are many organisations and administrative bodies responsible for these such that in all countries no single authority is responsible for addressing marine affairs (see Elliott et al., 2006; Boyes & Elliott, 2015). This has resulted in a patchwork of EU directives and policies and national legislation, managed through a large number of government bodies with overlapping duties. The international law, and European and national legislation currently in place (and proposed) to protect the marine environment has been mapped out in Figure 2.1 (Boyes & Elliott, 2014). This ‘horrendogram’ has been produced showing the complex nature of the different types of legislation from international law and European jurisdictions. Given that this then requires an enabling framework within each MS, we present as a case-example the national implementation in England used to protect the
marine environment. We take the view that although we focus on the European situation, the analysis is relevant to all maritime states and will give lessons for those states whose marine use and protection legislation is less well-developed than European and North American states.

At the centre are the international conventions, treaties and protocols (orange boxes for global law and agreements and blue boxes for International organisations) which many countries worldwide have signed and agreed to uphold. In a European context, for some Conventions such as the United Nations Framework Convention on Climate Change (UNFCCC), the signatory requirements have been given greater impetus through the implementation of a subsequent European Directive (Renewable Energy Directive). Shipping is also controlled on an international context, through IMO Regulations and MARPOL.

Moving out from the centre, the red boxes in Figure 2.1 show the EU Directives and policies which govern activities in the European seas, with blue ovals showing the primary target / status to be met. There is a wide range of legislation relevant to the exploitation of marine resources and the management of human impacts on the marine environment. Although this set of directives was previously dominated by sectoral policies such as the Dangerous Substances, Bathing Waters and Urban Waste Water Treatment Directives, the development of a more holistic approach in terms of coastal and marine management has been brought about by the recent creation of EU Framework Directives giving protection to the whole aquatic environment. Directives such as the WFD, MSFD, Birds and Habitats Directives and the SEA Directive formulate objectives which do not relate to administrative boundaries but to all uses and users and to large geographical areas. Several of these are Framework Directives which while giving the main thrust of the policy, ultimately leaves the detailed implementation to the MS. As such they have a built-in difficulty of ensuring that policies are consistent and coherent across both the Member State and the Directives even though there may be notable differences in implementation between Member States (e.g. Hering et al., 2010; Borja et al., 2013). A case in point was the original transposition of the Habitats Directive in England and Wales out to 12 nautical miles and the resulting legal action of Greenpeace. It is now settled in law that both the Habitats and Birds Directives apply to areas under the jurisdiction of coastal Member States including the EEZ and continental shelf and the waters above the seabed, up to a limit of 200 nautical miles from the baseline (R v. The Secretary of State for Trade and Industry ex parte Greenpeace Limited Case No: CO/1336/1999).

The figure also shows how this EU legislation has been implemented in England (including other primary enabling legislation) (green boxes) giving protection to the marine environment (purple ovals). Other Member States are likely to have a similarly complex national situation to England, especially those with a long history of enacting European and national environmental legislation. As a consequence, most existing UK environmental law is the product of legislative enactment, often in response to European Directives and is therefore related to sector specific activities. However, as the UK Government begins to take a more holistic approach to environmental management and by applying the Ecosystem-Based Approach to the management of human activities, environmental legislation now aims to enforce policies that focus on various policy goals. However not all English national legislation is in response to EU directives, for example, national acts such as the Marine and Coastal Access Act (2009) championed through government by environmental organisations (and the equivalent acts in Scotland (Marine (Scotland) Act 2010) and Northern Ireland (Marine Act (Northern Ireland) 2013)) pre-empt the MSFD and the proposed MSP Directive. Despite this, these UK Marine Acts were framed on the basis that they would allow these EU marine directives to be implemented.

2.5 National Implementation

VECTORS partners were asked to state how the International and European policy and law described in Deliverable 60.1 had been enacted in their national legislation through legislation and policy documents. Partners were also asked to indicate the main government ministry and agency with
responsibility for the implementation of the legislation. These summaries are provided in Annex 2. The tables illustrate that for the VECTORS themes addressed throughout the project, these are governed under a number of different government bodies and through their many agencies. Countries have to respond to a whole suite of international, regional (e.g. European) and national policies, laws and agreements controlling many of the sectors such as fisheries, energy and conservation by a plethora of organisations and administrative bodies (Fernandes et al., 1995; Ducrotoy & Elliott, 1997; Boyes et al., 2003a,b; Boyes & Elliott, 2003; Elliott et al, 2006; Elliott, 2014; Boyes & Elliott, 2014; 2015). No single authority is responsible for the management of the marine environment, with activities regulated on the national, international, supranational and transnational levels, each with its own rules and policies and often with a sectoral basis. Hence, and especially on a national basis, marine activities such as renewable and non-renewable energy, fisheries, shipping and conservation are regulated mainly through different government departments, sometimes with ineffective communication and lack of coordination. This can lead to a diverse range of conflicting marine activities being regulated by numerous pieces of legislation and policy (van Tatenhove, 2013).

There is now a complex management and governance framework (Elliott, 2014) in which local, national, regional and international initiatives have to be harmonised. In the case of Europe, at both the EU and Member State levels, progress towards managing and protecting the marine environment has been hindered and is very often insufficient (EC, 2006). The marine environment in many European countries has a complex system of management that has developed in order to deal with various political and sectoral issues which have arisen over many years (Defra, 2010).
Figure 2.1 International, European and English legislation giving protection to the marine environment (adapted from Boyes & Elliott, 2014)
2.6 Relevance for Policymakers and Stakeholders

The ‘horrendogram’ illustrates the complex nature of the legislation currently being used to manage and protect our transitional waters, coastal and marine environments (Boyes & Elliott, 2014) (Figure 2.1). As discussed above, whereas European policies until the 1990s were sectoral in nature, EU legislation has progressively become more holistic embracing the Ecosystem-Based Approach. Long (2011) suggests that one common feature of this new generation of EU legal instruments is that they establish a methodology for the management of natural resources that is ‘science-driven, adaptive and focused on enhanced Member State cooperation and coordination at regional levels’.

It is of note that although the new generation of EU law has been adopted, regulatory sectoral instruments such as the Nitrates Directive, the Bathing Water Directive and the Urban Waste-water Treatment Directive that are predominantly focused on preventing specific types of land-based pollution of the aquatic environment, are not replaced by the WFD and MSFD, but make an important contribution towards attaining their objectives. As these framework directives are not prescriptive in nature, Member States still rely on these older generation directives to achieve the new goals for the marine environment (Long, 2011). Therefore sectoral legislation is still in existence with the more holistic new generation law adding to the plethora of legislation which is required to manage the sea with its many uses and users.

The governance framework (‘horrendogram’ Figure 2.1) was presented and discussed at a series of scientific meetings and stakeholder workshops throughout the duration of the VECTORS project. Feedback was requested on the following issues:

1. Are there any tools/pieces of legislation missing for managing the marine environment which need to be included?
2. Have the links between the different articles been interpreted correctly?
3. Are there any areas of the marine environment where we still require a new piece of legislation at the International, European or national level to effectively manage the marine environment, or do we already have sufficient and all aspects are accommodated?
4. Given the diversity of legal requirements under different agreements, and that many overlap and conflict, for example, the different labelling of targets or objects under different regimes (EcoQO under OSPAR, GES under MFSD, GEcS under WFD etc.), are the different regimes coherent?

Feedback from stakeholders and the wider scientific community was used to improve the accuracy of representation of the figure. Stakeholders included EU Ministers, national government departments, nature conservation bodies, environmental agencies and non-governmental organisations. A summary of the feedback received from the VECTORS marine stakeholder workshop is presented below; further details regarding the workshop are presented in Annex 1.
Stakeholder-based Conclusions and Recommendations on the Governance Framework (‘horrendogram’)

- The governance framework illustrates the complex nature of current marine legislation but there was consensus amongst the stakeholders that most key pieces of legislation are covered by the diagram.

- It would be useful to have a similar diagram for all individual Member States to illustrate how the legislation is cascading down to the national and subnational level, to enable comparisons and to identify gaps.

- The importance of transnational cross-border co-ordination was raised by several stakeholders with the suggestion for marine/maritime ambassadors to co-ordinate such activities.

- The importance of assessing which activities are currently not protected was raised, as was the issue of weighting the legislation to show which are the most important.

- The Blue Growth Agenda (e.g. large-scale offshore aquaculture, seabed mining, blue biotechnology) was highlighted as a suite of rapidly developing sectors for which there is currently limited regulation and little is known about the ecosystems in which the activities take place.

- It was suggested that linking Marine Spatial Planning, Integrated Coastal Zone Management and Strategic Environmental Assessments would provide a powerful tool to integrate governance across sectors.
3. Stakeholder Case Studies

3.1 Stakeholder Case Studies

Four detailed case studies were undertaken for the VECTORS project (Dogger Bank, Catalonia, Puck Bay and Sinis MPA - Sardinia) in addition to a more general assessment of the main barriers to and drivers for successful European marine resource management. The case studies documented the views of stakeholders and policy makers on a wide range of marine governance issues in a number of regional sea case studies across Europe – full case studies are presented in D60.1 Part B. The case study approach was chosen to allow for both an in depth analysis of stakeholder requirements and a better understanding of the implementation of sub-national, national, European and regional marine governance in practice. A total of 69 interviews were carried out with the help of a semi-structured questionnaire which had been jointly developed by the case study researchers. By choosing four contrasting case studies, it has been possible to provide an in depth analysis in each of the three VECTORS regional sea areas (North Sea, Baltic Sea, and Western Mediterranean), and by using a bespoke semi-structured questionnaire all questions of relevance to all of the VECTORS thematic issues have been covered. As such the new empirical findings are relevant to all work packages within the wider VECTORS project. The key findings of each case study are presented below.

3.1.1 The Dogger Bank (North Sea)

Background

The Dogger Bank case study provided important new insights into a unique transnational decision-making process in which the main stakeholders (i.e. fishers and Environmental Non-Governmental Organisations (ENGOs)) were encouraged to use a bottom-up process to produce a compromise proposal for a fisheries management plan. Although the stakeholders failed to achieve consensus, the Dogger Bank case study nevertheless illustrated well how transnational implementation of EU environmental legislation (Natura 2000 and Habitats Directive) works in practice in an offshore sandbank which is shared by four different countries (Denmark, Germany, The Netherlands and UK).

Key Findings

The Dogger Bank case study provided a better understanding of the requirements of local stakeholders and self-regulatory conflict resolution attempts in an offshore marine area for which the usage for human activities is increasing. Since 2004, Germany and The Netherlands, which were followed by the UK, have started the designation procedure to establish marine protected areas (MPAs) in their respective parts of the Dogger Bank. Importantly, the Dogger Bank has become arguably a kind of test case for the EU for a new and, so far, unique process for cross-stakeholder involvement and transnational coordination of national management plans for a marine protected area of significant importance.

Barriers to Successful Management

A number of barriers to the successful management of the Dogger Bank were raised by the stakeholders. For example:

- different policy objectives set by Natura 2000 and the Common Fisheries Policy;
- different interests and strategies both between (and within) stakeholders (e.g. fishermen and ENGOs) and Member States (e.g. Germany, Netherlands, UK and Denmark) as well as different national policy styles (including different national regulatory traditions and guiding principles);
- different or even conflicting deadlines being set by each MS;
- vague terms of reference put forward by different stakeholders within the North Sea Regional Advisory Council (RAC) (e.g. 25-55% closures);
lack of sufficient resources (both staff and financial) and unrealistic deadlines set by the North Sea RAC;
uncertainties in relation to scientific evidence and legal and political processes;
the complexity of multi-level governance; and
venue shopping, i.e. the fact that some stakeholders lobby different decision-making levels (including the local, regional, national, EU and international levels) in order to achieve their objectives.

Policy Recommendations

Within the context of management of the Dogger Bank, a number of policy recommendations have been proposed:

- Unrealistically tight deadlines should be avoided as they exert excessive time pressure and/or lead to postponements of deadlines both of which can negatively impact on the outcome of the negotiation process.
- While it is important to set ambitious deadlines it is crucial to allow for sufficient negotiation time. It is unrealistic to expect quick results from a complex learning-by-doing negotiating process.
- Expectations need to be managed. Stakeholders need to be aware of the limits of their likely influence on the final outcome of the decision-making process.
- For stakeholder negotiation processes it is important to clarify how tasks and responsibilities are distributed.
- It is important to take into account that stakeholders only have limited time and staff resources. Therefore the objectives of stakeholder participation should be made clear while taking into account their time and staff constraints.
- Care needs to be taken about whether and when to ask a diverse stakeholder group to derive a consensus and/or compromise proposal and whether and when to allow for diverse opinions.
- In order to be able to fulfil its task properly the North Sea RAC ought to be given sufficient staff and financial resources.
- The NS RAC needs timely and clear terms of reference.
- There should be closer and better cooperation between the Dogger Bank Steering Group, North Seas RAC, ICES and the European Commission.
- There is a need for better scientific data, however, policy makers should make sure that claims of a lack of scientific proof cannot be used as a tactic to delay or even avoid the adoption of necessary environmental protection measures.
- Policy makers need to balance the interests of different stakeholders while avoiding both excessive environmental protection and serious environment damage.
- Policy makers need to take into consideration not only the views of the stakeholders represented within the North Sea RAC but also the views of others.
- Conflict resolution strategies need to take into account the different interests of the main stakeholders. However, they also ought to be sensitive to cultural differences and differences in environmental policy styles.

3.1.2 CATALONIA (WESTERN MEDITERRANEAN)

Background

The Catalonia case study assessed to what degree fisheries, aquaculture and all related recreational activities are compatible with the sustainable use of the marine environment. It also assessed policy makers and stakeholder demands and their interplay concerning marine management in the Catalonian region (Spain). Important themes which emerged from the interviews conducted for this case study
included the fragmentation of competences, and the lack of strategic planning and sparse knowledge about the marine environment together with a non-definition of the objectives to be achieved. Important stakeholders argued that common objectives should be defined and agreed by all actors involved in coastal management and that coordination and cooperation between the main stakeholders is important.

**Key Findings**

As expected on the multi-use Catalan coast, Integrated Coastal Zone Management (ICZM) emerged as an important theme. The interviewees also mentioned the following issues: fisheries, aquaculture, recreational fisheries, nautical activities, wind farms, society, tourism, gas and petroleum prospecting, maritime transport and ports, conservation and research. Importantly, the Catalonia case study showed that conflicts do not exist merely between users and ENGOs but also differences in opinion can be found within the same type of stakeholder group. For example, professional fishermen vs. recreational fishermen, professional fisheries vs. recreational activities and small-scale artisanal fisheries vs. other professional fisheries. Conflict resolution strategies therefore need to take into account that the underlying conflicts are complex because different types of fishermen have different interests.

**Barriers to Successful Management**

A number of barriers to the successful management of Catalonia were highlighted and include:

- fragmentation of competences among different public bodies (e.g. Spanish Government vs Catalan Government vs Local Authorities);
- existing conflicts between public administrations due to the fact that competences are not well defined;
- a lack of co-ordination and co-operation between public bodies, stakeholders and governance regimes;
- a lack of policies, planning and instruments such as integrated marine spatial planning;
- a lack of knowledge and scientific baseline data for the marine environment (as required by the MSFD) and the indirect ecological, economic and social benefits from the marine environment;
- a lack of a unified coastguard service with the necessary resources and competences;
- there are many different instruments for planning on land but there are no equivalent tools for the marine environment; and
- further research is needed on the indirect benefits of natural areas including their ecosystems and species.

**Policy Recommendations**

A number of policy recommendations have been highlighted with respect to the management of the Catalan coast:

- Certain European policies such as the Water Framework Directive have been successfully implemented but a benchmarking analysis should be undertaken in order to detect best practices and to identify the most successful strategies adopted for the implementation of the Directive.
- More research is needed concerning the indirect benefits of natural areas (including their ecosystems and species). New management, regulatory measures and investments should be based on the results of these research initiatives.
- It is necessary to increase societal awareness concerning the impacts of the marine and coastal activities while the users should be made more aware of their responsibility for their impacts.
The fishing sector needs to be better informed about financial instruments and existing initiatives such as *pescaturismo* (fishing tourism) in order to promote this economic activity. Public administrations need to become more involved in helping economic sectors in relation to these financial instruments.

An ICZM approach should be applied in order to improve coordination in Catalan coastal management activities and a body or organization is needed which would gather all public and private agents involved in the management of the Catalan coast.

Sustainable practices should be covered in different maritime-related training courses.

Management should be re-assessed in order to find feasible solutions for both fishing vessels that have reached their end-of-life and fishing vessels carrying out a non-feasible activity.

Local, regional and national management initiatives should be implemented to ensure that nautical boats are not abandoned but scrapping is managed in an environmentally sound manner.

Integrated marine spatial planning instruments should be developed.

More data are needed concerning marine parameter measuring and monitoring - increased monitoring and assessment is required (this should be done under the MSFD).

It is essential to give an economic value to natural capital for the benefit of natural resources.

More information should be made available to key stakeholders concerning the special dynamics of the Mediterranean.

### 3.1.3 Sinis MPA - Sardinia (Western Mediterranean)

**Background**

The Italian case study focused on the Marine Protected Area of the Penisola del Sinis – Isola di Mal di Ventre (hereafter Sinis MPA), Gulf of Oristano, in Sardinia. The main objective of the stakeholder interviews was to gain a better understanding of the implementation process of the MPA and its evolution as well as to gather information about the different views and interests of the main stakeholders. The key stakeholders identified within this case study included managers, politicians, recreational boat owners associations, diving schools, hotel owners and fishers.

**Key Findings**

The main constraints for successful marine management which were identified for this area included excessive fishing, cultural behaviour, a low level of tourism, bad management of funds, and a lack of dialogue between the main local stakeholders. The case study assessed the main reasons for the strong political influence of fishermen on the Cabras local municipality. It suggested a number of conflict resolution measures and strategies including the increase of controls (e.g. MPA rangers), the creation of a specific office within the MPA for communication and dialogue purposes and the raising of public awareness of the importance of the MPA through environmental education activities.

**Barriers to Successful Management**

The interviews identified four main barriers to the successful management of the Sinis MPA: (1) different perceptions of the management objectives of the MPA amongst different stakeholders; politicians appear to prioritise fishermen over all other stakeholders, there is a lack of sensitivity for and public awareness of environmental issues, a lack of interaction between stakeholders, fishermen are seen as the major beneficiaries of the MPA establishment and therefore all other stakeholders consider themselves as outsiders; (2) dialogue - stakeholders complained about the lack of an institution and a physical place where they could express their opinion and engage in a dialogue with the competent authorities; (3) lack of money - the low budget for the MPA is allocated by the Ministry of Environment which makes available little money for communication and surveillance; and (4) effectiveness of the MPA – little is known locally about the formal environmental recognition, very few conservation
objectives have been achieved, and there is a lack of proper use of resources (e.g. development of fishing as a tourist attraction or other types of tourism) limiting the economic development.

Policy Recommendations

Based on the findings from the stakeholder interviews, a number of policy recommendations have been proposed that could be used to improve the management of the Sinis MPA:

- Involve multiple municipalities other than Cabras to create a consortium of municipalities for the Sinis MPA. This may reduce the influence of fishermen from Cabras on the local municipality;
- Increase the surveillance on the MPA, including the presence of rangers;
- Create a specific office within the MPA for communication and dialogue; and
- Increase public awareness of the importance of the MPA through environmental education activities for both adults and young people.

3.1.4 PUCK BAY (BALTIC SEA)

Background

The Puck Bay case study identified the following six main groups of actors at the national level: (i) local, regional, or central authorities (including maritime administration), (ii) sectoral unions and associations, (iii) environmental and conservation organisations (predominantly ENGOs), (iv) the scientific community, (v) industry and (vi) the general public, particularly tourists. At the international level, a number of organisations and networks are active in the Baltic Sea Region, of which HELCOM and ICES are perhaps the most important, and it is arguable that there is greater and more long-standing cooperation between the Baltic States than in other regional seas. At the same time, the area fulfilled the aim of considering a multi-use/multi-user/multi-sectoral/multi-conflict marine system. In the Puck Bay case study, the main conflicts occurred in the areas of fishing, tourism and nature conservation.

Key Findings

Fisheries claim almost all of the Puck Bay area. Kuznica and Jastarnia are the main fishing ports in the region where small open boats primarily operate. Fixed gear fisheries are concentrated in the Outer Puck Bay, while recreational fishing focuses on specific areas, mostly around shipwrecks or large rocks. Tourism and recreation are dependent on the state of the marine and coastal environment. The “3s” (sun, sand, sea) holiday model is the most common in the area, but motor boating, windsurfing, diving and yachting are easily accessible and their popularity is increasing. The limited infrastructure for tourism is a problem for the most popular summer resorts in Puck Bay. As recreational facilities were often insufficient there is an increasing demand for the construction of new marinas, improving existing accommodation and transport infrastructure.

Barriers to Successful Management

The most important barriers to the successful management of Polish marine areas include:

- a failure to understand the characteristics of the sea;
- a lack of or short-term funding which limits the possibility of taking the necessary actions;
- poor legal and administrative frameworks, including poor consultation process;
- sectoral development perspective in MPA management; and
- a lack of natural and social science data.

Policy Recommendations

During the interviewing process, many respondents recommend improvement to the legal and administrative framework in order to better support management and protection of the marine areas.
However, sometimes these suggestions were contradictory. The most important recommendations include:

- establish a competent authority to create and manage MPAs;
- define and clarify the powers and responsibilities of institutions present in the management of coastal and marine areas, especially the maritime administration, the environmental agencies and local authorities (coastal municipalities);
- develop issue relevant bylaws, particularly those concerning marine spatial planning;
- prepare management plans for Natura 2000 sites and involve local communities in this process; and
- strengthen the public consultations and involve stakeholders in the early phases of planning and decision-making.

### 3.1.5 European Union

#### Background

The final case study was undertaken at the EU-level. The main objectives were to obtain stakeholder perceptions of the different VECTORS themes as well as their views about the governance and management of marine natural resources in the different European regions. A number of key institutions were identified and included EU institutions (European Commission (EC) and European Parliament (EP)), international conventions, international organisations, organisations for different economic sectors, and ENGOs all acting at the European level.

#### Key Findings

One of the main themes discussed was the difficulty of transnational cooperation among EU Member States given that there is no history of cooperation within the marine field. For most interviewees, such collaboration is difficult to achieve because of language differences (mainly at the local level), lack of knowledge about administrative systems of others countries, defence of national sectoral interests and a lack of money. The evidence presented in D60.1 demonstrates that cooperation can be both a barrier to and a driver for better marine governance. The case study concluded that cooperation, dialogue and more integrated policies (which apply an ecosystem approach) are important elements for the better management and governance of the EU’s regional seas.

#### Barriers to Successful Management

At the EU-level a number of drivers for change in governance were identified and include: the need to apply an ecosystem approach; regional conventions taking leading roles (HELCOM, OSPAR, UNEP-MAP) in different EU policies (long process to ratify a protocol, no sanctions); and ENGOs participating in the Conventions (as observers) and EU policies processes (lobbying of EP). With respect to the main barriers to achieve successful marine management, the following issues were identified: contradictions between goals of differing EU policies; contrasting positions between EP and EC (on CFP) constituent pressures; limited experience of Member States in transnational cooperation; and barriers to sectoral stakeholder participation in EU policy (limited finances for Member States and stakeholders, limited capacity, time, etc.).

#### Policy Recommendations

As a result of the EU-level interviews, a number of policy recommendations have been proposed:

- The presence of ENGOs within conventions and organizations widens the debate because they bring their own unique view to the table. Such a dialogue between environmental interests and sectoral interests should be viewed as beneficial for the management of the marine environment and resource conservation. The adoption of a compromise agreement, which combines the views of two antagonists (ENGOs and sectoral groups), could be seen as
proof for that diplomacy is working. It also shows successful cooperation between different types of stakeholders. Cooperation is based on good relations creating the feeling of being members of a community which share the same values and have the same objectives.

- Cooperation among Member States is difficult because there is no history of transnational cooperation; previously the EC controlled the implementation process of EU policies in its role as the guardian of the EU treaties and secondary laws but expects Member States to cooperate directly (transnational and/or multinational cooperation). Now the EU is asking Member States to establish good relations and to work together for the establishment of fisheries management plans, as well as ecosystem management in large marine and maritime areas, and to define the areas where different economic activity will be allowed. Cooperation could possibly be reached through the existing Regional Seas Conventions. However, it seems unlikely because the EU is not a member of all of these international organizations (for example the Bucharest Convention for the Black Sea). In other cases transnational cooperation is not possible because some EU policies are within the exclusive competences of the EU. The EU is reluctant to accept a change of its role and give up powers (e.g. in the RACs). There are other cases of non-cooperation which are due to Member States concerns about a loss of their national competencies.

- Cooperation among Member States and the EU could be easier to establish for sectoral issues and integration of ENGOs in the dialogue is of benefit for all the parties involved in marine governance. The different examples stated above show that cooperation can be both a barrier to and a driver for better marine governance. Cooperation, dialogue and more integrated policies (ecosystem approach) are important elements for the better management and governance of the EU’s regional seas.

### 3.1.6 Europeanisation Processes

A case study approach was chosen to allow for an in-depth analysis of stakeholder and policy maker views and requirements on European marine governance issues as well as a better understanding of the implementation of regional, EU, national and sub-national marine governance in practice. By selecting the Dogger Bank, Catalonia, Puck Bay and Sinis MPA as case studies it has been possible to provide an in-depth analysis (of particular areas) of three different seas, namely the Baltic Sea, North Sea and Western Mediterranean. Extensive qualitative research (i.e. semi-structured interviews and document analysis) was undertaken to provide a better understanding of the reasons behind the, at times, conflicting or even contradictory views of different types of stakeholders and policy makers at different levels of marine governance for the chosen case studies.

From these data it is possible to identify some common themes that have emerged from the four case studies which also help to explain the Europeanisation of marine governance in three different seas and thus also on similarities and differences in marine governance in Eastern, Northern and Southern Europe. Conflicts between different types of policy makers (e.g. national v. local officials) and stakeholders (e.g. fishers v. ENGOs) but also within the same type of policy makers (e.g. Agriculture Ministries v. Environment Ministries) and stakeholders (e.g. professional fishers v. recreational fishers) about the use of certain parts of the marine environment constitute arguably the most important common theme which emerged from the four case studies. Other important common themes include: scientific uncertainties and lack of knowledge about the marine environment; unclear or even conflicting (marine) governance objectives; fragmentation of competences; emergence of highly complex multi-use/multi-user/multi-sectoral/multi-conflict marine governance systems; attempts to facilitate self-regulatory conflict resolution amongst stakeholders; and, lack of financial, staff and knowledge resources especially on the local level.
Based on the empirical data (see above and D60.1) generated by the four case studies, the following general conclusions can be drawn about the Europeanisation of marine governance in different parts of Europe and on the different levels of governance:

- There has been a significant degree of Europeanisation of national and, although to a somewhat lesser degree, sub-national marine governance regimes across Europe.
- The emergence of the EU as a new marine governance decision-making arena has facilitated the introduction of novel innovative approaches (e.g. ecosystem approach and integrated European marine policy). However, it has also created additional veto points especially for well-resourced policy actors which often make use of ‘venue shopping’ (by lobbying different levels of governance) to achieve their objectives.
- Conflicts of interests occur between but often also within different types of stakeholders and policy makers about the use of (certain parts of) the marine environment are common across Eastern, Northern and Southern Europe.
- In the past the EU tried to resolve conflicts amongst core policy actors and stakeholders within the traditional EU decision-making processes and by adopting traditional (‘command-and-control’) regulatory instruments. However, more recently the EU has tried to encourage both direct transnational cooperation between member states and self-regulatory conflict resolution strategies between the core stakeholders on EU marine governance issues. The Dogger Bank constitutes a good example for the EU’s move towards new modes of (marine) governance.
- The lack of financial, staff and knowledge resources is a common problem across Europe as well as across different levels of governance. However it tends to be more severe in Eastern and Southern Europe (compared to Northern Europe) and more prominent on the sub-national level (compared to the national and EU level). This has led to a somewhat uneven Europeanisation of marine governance in different parts of Europe and on different levels of marine governance.
- Although local policy makers and stakeholders often lack financial and staff resources and in some cases also the necessary language skills to get involved in marine governance issues on the EU level, they usually possess vital knowledge about the local marine environment which is especially important for the successful implementation of EU marine governance.
- In particular, the environmental leader states amongst the Northern European Member States have tried to ‘upload’ to the EU level their preferred national marine governance priorities, instruments and regulatory principles. This can cause a ‘poor fit’ with the national marine governance priorities, instruments and regulatory principles of the Eastern and Southern European Member States and thus lead to the poor implementation of EU marine governance requirements in those Member States which, as was mentioned above, tend to suffer from a greater lack of (staff and financial) resources compared to the Northern European MS.
4. FUTURE SCENARIOS & POLICY IMPLICATIONS

4.1 Introduction

Scenarios are imagined alternative futures. They are not necessarily visions or plans, but they can help to guide strategy and can describe both optimistic and problematic futures. Scenarios can be used to ‘test’ whether policy actions are robust and sustainable and they can be a great tool to enable new ways of thinking and to model changes in society. For scenarios to be a useful tool, they must all be possible, plausible and credible.

Future scenarios are required to create a coherent framework within which to test climate versus economic versus political/legislation changes, and to minimise and constrain the number of possible permutations. To ensure a universal storyline is being used, four future scenarios have been developed based on work originally carried out by the Special Report on Emissions Scenarios (SRES) (IPCC, 2000), with complementary work carried out by the UK Climate Impacts Programme (UKCIP) (UKCIP, 2001), Hulme et al. (2002), European Lifestyles and Marine Ecosystems (ELME) study (Langmead et al., 2007) and most recently by the UK National Ecosystem Assessment Follow-on Phase for the marine environment (Turner et al., 2014). As recognised by the United Nations Environment Programme (UNEP), scenarios do not have to be developed from first principles but can be adopted and adapted from the literature. The benefit of using an existing framework is that some values can be used ‘off the shelf’.

The four contrasting future scenarios which are being applied by WP6 of the VECTORS project for the marine environment are listed and have been summarised in Figure 4.1 and Table 4.1 below:

A1 - World Market Scenario
A2 – National Enterprise
B1 – Global Community
B2 – Local Responsibility

Figure 4.1: VECTORS Scenarios (taken from ELME (Langmead et al., 2007))

The four-quadrant approach has become commonplace following its earlier adoption by the Intergovernmental Panel on Climate Change (IPCC, 2000) and its basis identifies the two driving forces with the greatest importance and the highest uncertainty. Many existing scenarios exercises seem to have also chosen similar criteria to define their ‘possibility-space’, with an axis representing ‘autonomic
to interdependent (local to global) and an axis representing ‘community to consumerism values’. In addition, the ‘Baseline’ scenario depicts future trends based upon what we know now and expectations from a variety of sources, described relative to the present.

Table 4.1: General characteristics of the VECTORS scenarios (shaded scenarios modelled in WP5)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Characteristics</th>
</tr>
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| A2 Protected Markets / National Enterprise (national / consumerist) | • Modest local environmental policy  
• Limited global environmental policy  
• Intermediate economic growth |
| B2 Local Communities/Responsibilities (National / Environmental) | • Ambitious local environmental policy  
• Modest global environmental policy  
• Low economic growth |
| A1 World Markets (global / consumerist) | • Modest local environmental policy  
• Modest global environmental policy  
• High economic growth |
| B1 Global Community (Global / Environmental) | • Ambitious local environmental policy  
• Ambitious global environmental policy  
• Intermediate economic growth |

4.2 Methodology

One of the stated scientific and technical objectives of the VECTORS programme is ‘to project the future changes and consequences of multi-sectoral human activity in the marine environment under possible scenarios of adaptation and mitigation’. Eight of the VECTORS project deliverables focus on scenarios in some form or another, and in addition to WP6 they are also integral to tasks of work packages 2, 3, 4, 5 and 7 (where they are explicitly mentioned in the Description of Work).

VECTORS WP5 has applied two of these scenarios (A2 – National Enterprise and B1 – Global Community) to the three Regional Sea areas of the North Sea, Baltic Sea and Western Mediterranean, projecting changes up to the year 2050 based on the SRES (IPCC, 2000) scenarios, which correspond to the ELME scenarios ‘National Enterprise’ and ‘Global Community’. WP6 has not only taken the two scenarios modelled and assessed by WP5, but has included the A1 (‘World Markets’) and B2 (‘Local Communities/Responsibilities’) future scenarios to explore the legislative, policy and governance repercussions, especially with respect to three of the key VECTORS drivers of change (demand for food, transport and energy) reviewed in WP1. The scenarios provide a framework for which to test and apply the possible future developments across the Baltic, Western Mediterranean and North Sea case study areas.

This section takes the view that the scenarios are not mutually exclusive and although each of the scenarios may be good for testing ideas, each one is extreme and unlikely and a more realistic future scenario is likely to include components of all four of them. Therefore to ensure the discussion is comprehensive and complete, all four scenarios were used.

This report aims to address the following questions:

- How does the current governance and legislation cope with these future changes?
- Based on the four scenarios, which instruments will remain and how will they be adapted and which will no longer be adhered to?

In February 2014, a workshop was held to disseminate WP6 work to stakeholders (see Annex 1). The four future scenarios and policy implications were presented to stakeholders, and their feedback and views have been incorporated into the discussion of this report.

4.3 Scenarios & Implications for Policy and Governance

This chapter gives a short précis of the four future scenarios as taken from the original IPCC descriptions (IPCC, 2000), with details on the socio-political conditions assumed under each scenario.
The impacts of the scenarios on future legislation, politics and governance for the marine environment are then addressed.

4.3.1 A2 – NATIONAL ENTERPRISE/Responsibility (WP5)

A very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines. Assumes that people want to achieve personal independence and material wealth but within a national cultural identity, with the balance of opinion favouring increased national isolation and independence in economic, foreign and defence policy. Long-term economic growth is limited by government policies, which limit international competition and protect important national industries. Conservation and environmentally friendly development are not a main priority. By 2100, marine ecosystems are under greater pressure than at present. Efforts to reduce the effects of human activity are abandoned where they conflict with issues of national self-sufficiency. Reductions in fish stocks affect local communities, and conflicts arise due to different priorities (for example, between different users of the marine environment) and poor relationships with other nation states. Large scale, environmentally damaging projects such as tidal barrages and wide-scale oil exploration develop under this scenario. Water quality deteriorates and this results in contaminated beaches and natural resources. Governments fail to deal with global problems (IPCC, 2000).

Although this scenario is depicted as being environmentally destructive through a lack of international cooperation and with the prioritisation of national economic activities, the latter in particular does not necessarily result in wanton environmental degradation, since the national interest still requires environmental goods and services. The focus will change from large marine ecosystem (LME) type systems to limited national or subnational scale systems. Although countries will opt out of the EU to gain national independence and the regional seas committees (RSC) will have less influence, existing national legislation will be still be binding until reformed. This will occur over many years when a transition period gradually moves the regionally-directed legislative (EU) framework to a more nationally-focused governance model. In essence, remove the lines of Figure 2.1 but the outer circles are still needed if a state wants to sustainably exploit its marine environment.

There will be limited global environmental policy – with countries adopting NIMBY\(^3\) attitudes, mainly in relation to pollution and the reduction of cross-border pollution problems. International environmental targets will be of secondary importance with the breaching of targets set by international conventions such as the Convention on Biological Diversity (CBD) and Kyoto Protocol in favour of national interests. The newly adopted Maritime Spatial Planning Directive (2014-89-EU) would give emphasis to national important non-renewable reserves e.g. oil. National policy changes will allow more marine developments to occur, especially non-renewables with reduced consideration of environmental concerns (without the strict EIA/SEA controls\(^4\)) with developments being approved as being of imperative reasons of overriding public interest (IROPI). However co-location and national Marine Spatial Planning (MSP) may still occur to maximise returns from spatially congruent activities. Although the marine environment will be under greater pressure from developments, this does not necessarily lead to degradation.

**Energy** – Priorities of the European Renewable Energy Directive and other international policy e.g. Kyoto Protocol and UNFCCC are abandoned. National policy changes will reflect new national energy targets.

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\(^3\) NIMBY – Not in my back yard

\(^4\) As it is still in a country’s interest not to ‘foul it’s nest’, it would still require planning laws to stop an internal free for all.
Fisheries – National governments will retain greater responsibility and control over their territorial waters under fisheries legislation, with the CFP focusing on resolving conflicts over straddling stocks. Fisheries policy may retain Maximum Sustainable Yields (MSY), since it theoretically ensures returns over a longer period. This scenario would not necessarily result in wanton disregard for the environment, however there may be less regard for the impacts of fishing on other States e.g. Spain and Portugal overfishing the Grand Banks type scenario.

Shipping/Ballast water/Alien Species – National policy would retain smaller ports discouraging larger international vessels. This in turn reduces the likelihood of AIS & IAS being introduced. BWM Convention standards still upheld but may not be actively enforced. If adopted the proposed IAS Regulation would again probably be upheld but not actively enforced.

4.3.2 B1 – GLOBAL COMMUNITY (WP5)

A convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource efficient technologies. This scenario assumes that people want high levels of welfare and a healthy environment. The best way to achieve these aims is through international cooperation. People see their personal interests as being connected to a strong and cooperative society. Sustainability is seen from a global viewpoint, including: maintaining biodiversity; protecting global commons (that is, the atmosphere, oceans, wilderness areas); providing fair access to environmental resources. Policies are co-ordinated at the European Union and international level. There is high taxation in this scenario. The health of the oceans improves across the world, international agreements become commonplace and aim to promote the long-term management of marine resources (IPCC, 2000).

All current international and European legislation is met, with possibly more legislation passed to achieve community goals. RSCs will continue to play an important role in achieving compliance with EU directives and international law. Strong international and European legislation to protect marine biodiversity (habitats and species) through the CBD, H&SD, MSFD etc. and the prohibition of dumping of waste at sea e.g. the London Convention and Protocol will be strictly adhered to and enforced. Strong international legislation to protect and also tighten international controls on safety at sea of ships, oil pipelines and dumping of waste. All planned Marine Protected Areas (MPAs) will be realised under existing EU Directives (including the newly adopted Maritime Spatial Planning Directive (2014-89-EU)) and the proposed Invasive Alien Species (IAS) Regulation will be adopted. However, marine waters will be seen as 'commons' with specific areas set-aside at the EU-level for electricity generation, fisheries and environmental protection purposes. There is importance given to co-location of marine activities but with the added protection of the marine environment. Environmental targets under the existing framework (e.g. WFD, MSFD) and sectoral directives (UWWTD, Bathing Waters) may be exceeded to achieve higher marine environmental protection, with Member States going even further than EU law requires.

Energy – Governments will have realised all their planned wind turbines in the marine environment by 2050, with greater promotion of cross border developments in renewable energy sources. Meeting targets of EU Renewable Energy Directive and associated national legislation. Environmental legislation will promote renewables (wind, tidal, wave, biofuels from algae) over oil and gas industries, with stricter environmental legislation to legislate the latter.

Fisheries – Legislation may ban trawl fisheries from MPAs in regional seas. There is an acceptance of limits of national fishing quotas. Fisheries continue to be managed through the CFP with increased regulation through fisheries quotas, gear use and landings in subsequent CFP reform to protect fish stocks. Sustainable aquaculture will be encouraged.
Shipping/Ballast water/Alien Species – International shipping legislation enforced e.g. UNCLOS, MARPOL and BWM with very strict rules to regulate the introduction of IAS through the proposed IAS Regulation (if adopted). Policy to increase port facilities to accept more international trade, with a Europe wide ports policy introduced.

4.3.3 A1 - WORLD MARKETS (ADDITIONAL TO WP5)

A future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. Assumes that people want to achieve personal independence, material wealth and greater mobility, all of which have a negative effect on wider societal and environmental goals. Pressure grows to reduce taxes, and more public services are privatised or privately managed. Social and environmental governance is achieved through international legal frameworks setting minimum standards, and by using market-based approaches. Marine ecosystems are damaged by human activity. Increased pressures on marine biological resources, either through using resources or through increasing levels of ‘stressors’ (for example loss of habitats and changes in water quality) (IPCC, 2000).

There is a continuation of international legislation but with more dependence on national legislation meeting minimum standards. International Conventions may see a greater reduction in participation, and a refusal by some countries to sign new agreements if they inhibit market forces (e.g. MARPOL). Member States no longer “gold-pla te” environmental directives but just carry out the bare minimum. There may be a greater pressure to commodify environmental resources, especially ecosystem goods and services since they would be a means to wealth generation. Maritime Spatial Planning will give priority allocation of space to the most important economic resources. European countries who implement aggregates levies will abandon these, with new legislation allowing increased aggregates removal (maybe in areas which were previously thought sensitive). There will be minimal EIA/SEA controls5. A lapse of UWWTD, WFD, MSFD, Bathing Water Directive quality standards and the Habitats Directive and Wild Birds Directive favourable conservation status will no longer be upheld. There will be a resumption of waste dumping at sea as countries no longer adhere to London Convention and Protocol, with no new legislation enacted to address plastic pollution. National policy will allow larger marinas and ports to be built to cope with larger tankers but these will be built without strict SEA/EIA/Habitats Directive procedures. Habitat loss will occur with no compensation. This scenario will lead to the large-scale transportation of oil and gas around the world, with larger tankers potentially leading to more accidents and spills. Renewable electricity generation is viable, but not widely adopted with the UNFCCC and EU Renewable Energy Directive targets given low priority and seen as secondary to economic growth.

Energy – Renewable electricity generation is viable, but is not widely adopted - United Nations Framework Convention on Climate Change (UNFCCC) and EU Renewable Energy Directive targets of lower priority. Policy changes will occur to promote the exploitation of non-renewable and nuclear sources (unless oil and gas prices rise due to diminishing returns and high extraction costs). If fewer planning and development controls exist, then frackings will increase both on land and offshore which will bring down fuel prices thus leading to greater exploitation.

Fisheries – Fisheries continue to be managed at a European scale but the CFP only plays a minor role. The key device in most international fisheries law is the maximum sustainable yield (MSY), which despite its shortcomings is a biological device. There have been calls to replace this with the Maximum Economic Yield (MEY) leading to economically low value species fished to collapse, and returns

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5 However as its still in a country’s interest not to ‘foul it’s nest’, planning laws are still required to stop an internal free for all.

6 Hydraulic fracturing, or fracking, is a technique designed to recover gas and oil from shale rock.
invested in high value species. Policy may change to encourage the export of fishing capacity into new markets (i.e. expansion of fisheries partnership agreements and distant waters fishing (DWF) in developing countries waters). Promotion of aquaculture/fish farming legislation and policies.

**Shipping/Ballast water/Alien Species** – Less strict controls on ballast waters (BWM Convention and proposed IAS Regs (if adopted)) allowing increase in numbers and occurrence of non-native, invasive, and alien species as shipping expands. To an extent, this already exists as regards flags of convenience. Larger marinas and ports built to cope with larger tankers but built without strict SEA/EIA procedures. Habitat loss will not be compensated. Few international agreements imposing penalties on vessels with lower safety standards therefore increasing the chances of pollution risk events. In the Mediterranean, action may be taken to control the spread of alien species by recreational craft, not to halt the environmental impact but to reduce economic impact-losses.

### 4.3.4 B2 – LOCAL RESPONSIBILITY (ADDITIONAL TO WP5)

A world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development. Public policies aim to promote economic activities that are small scale and regional. An important focus is on using technology and new ideas to make the best use of local and regional resources. Global and regional environmental problems receive less attention. Economic growth is slow, but considerable social and environmental improvements increase many aspects of the quality of life. Pressure continues to protect but also to use indigenous resources, and this results in a number of different effects - some marine areas become damaged, while others see great improvements. Local communities manage the marine environment (IPCC, 2000).

This scenario dictates that EU directives will be used even more than now as a basis for implementing stronger national legislation to protect the marine environment. The UNCLOS framework may remain, but the cooperative elements will become secondary. Although local action fails to address large-scale global environmental concerns, local scale marine ecosystems revert to what is perceived as a more ‘natural’ state and GES will be achieved. Global climate targets are viewed as being of only secondary importance (UNFCCC), however this will have a regional aspect (the north/south situation). Regional Sea Committees e.g. OSPAR, HELCOM, UNEP-MAP will have less importance and influence over national matters and are seen as secondary to the national interest. The fishing industry is heavily subsidised to protect local resources - the CFP may undergo further reforms which give greater protection to fisheries and may remove access to foreign fishing. Alternatively under a system of local governance, EU countries withdraw from the CFP, requiring a new EU directive to protect fish. The MSFD would also become more integral to the protection of fish. There is a strenuous effort to protect wildlife and habitats through existing EU directives but there may be potential problems in dealing with biodiversity beyond the local level, since there is a potential lack of cooperation in efforts to measure and regulate activities at large scales. Strong legal instruments would protect regionally important habitats and wildlife to mitigate against local environmental damage. River water quality improves greatly and targets are met and maintained, with stringent water quality standards, necessitating improved water treatment following the UWWTD / MSFD / WFD but with improved targets. Co-location becomes the big policy idea to accommodate all activities by a community which may result in a potential lack of development of national significant infrastructure projects since these would require decision and support at larger scales. The newly adopted Maritime Spatial Planning Directive (2014-89-EU) and will play an important role in setting aside marine areas at the national level for sustainable development. The ESPOO Convention may be neglected in favour of local goals and environmental protection.

**Energy** – Growth in offshore wind sector may be stifled whilst other local resources exist e.g. a wide range of small-scale renewable technologies exploited. Therefore countries still wanting to comply with
the EU Renewable Energy Directive but maybe not meeting targets by set deadlines. There may also be a potential decline in oil dependence in certain areas with an increase in renewable dependence.

Fisheries – The fishing industry will be heavily subsidised to protect local resources which may lead to a reform of the CFP which gives greater protection to fisheries and removes access to foreign fishing. Alternatively, under a system of local governance, EU countries could withdraw from the CFP, requiring a new EU directive to protect fish. A network of closed areas to protect stocks, habitats and species could be adopted under both national and EU fisheries legislation, MSFD, Habitats Directive and the adopted MSP directive. Greater stakeholder management - setting up No Take Zones for fisheries and self-policing possibly linked to the MPA designations. This will promote the sustainable and long-term local management/regulation of fisheries in all regional seas promoting greater fishing tourism activities in places like the Mediterranean.

Shipping/Ballast water/Alien species – Due to fewer international ships, there are fewer occurrences of introduced species, oil spills, ballast water problems and less damage due to port development. Increased monitoring and legal control of passing ships. In the Mediterranean Sea, local/national action would be taken to reduce the spread of exotic species by recreational craft.

4.4 Summary

With respect to three key VECTORS drivers of change (demand for food, transport and energy), Figure 4.2 shows how the governance of these sectors would change based on the four scenarios.

4.4.1 ENERGY SUPPLY (RENEWABLE)

Renewable energy supply in Figure 4.2 shows that in the National Enterprise scenario, a government’s main objective through its energy policy would be ensure a supply of cheap and secure energy. Natural resources would still be exploited offshore but offshore wind would only be promoted through policy if considered in the national interest. Other sources of marine renewables would be considered e.g. tidal barrages. In contrast, legislation under the Local Communities scenario would promote the exploitation of a wide range of small-scale renewable energy technologies, particularly wind. The main driver for renewables would be energy security. In the World Market scenario, the market continues to be
dominated by fossil fuels with natural gas exported from outside Europe. Policy will only promote offshore wind power if it becomes commercially viable. In contrast the governance in the Global Community scenario promotes major international action to reduce greenhouse gas emissions, and hence large-scale expansion of the offshore renewables industry beyond that currently proposed.

4.4.2 ENERGY SUPPLY (NON-RENEWABLE)

Non-renewable energy supply in Figure 4.2 shows that in the National Enterprise scenario, there is a reliance on supplies of fossil fuels, and consequently this scenario is perhaps the most environmentally damaging. Policy will promote the generation of national supplies with the possibly of nuclear production. Policy under the Local Communities scenario, would promote some exploitation of local coal and oil resources, but with high standards of environmental control. In the World Market scenario, countries would be more reliant on imports, but with a continued reliance on fossil fuels particularly natural gas. It is the Global Community scenario which would enact new legislation to reduce the consumption of natural resources and move policy to exploiting renewable energy.

4.4.3 FISHING PRESSURE

Fishing pressure in Figure 4.2 shows that in the National Enterprise scenario, governments would assume greater responsibility and control over their territorial waters, with the CFP focusing mainly on resolving conflicts over straddling stocks. In contrast, the Local Communities scenario indicates that Member States would adopt a system of local governance and withdraw from the CFP, with fisheries management transferring to regional committees. In the World Market scenario, fisheries policy becomes much less interventionist with fishing pressure continuing to be managed at a European scale although with greater emphasis on market forces, and fewer legal and technical restrictions. The CFP plays only a minor role and eventually there will be a collapse of stocks. In the Global Community scenario fisheries policy is enacted to balance high yields with low environmental impacts. The CFP is tightened up allowing no discards and other EU legislation is adhered to e.g. Marine Strategy Framework Directive.

4.4.4 BALLAST WATER, IAS AND POLLUTION RISK

Ballast water, IAS and pollution risk in Figure 4.2 shows that in the National Enterprise scenario, policy would dictate that fewer vessels would be entering national waters from far-afield, and therefore the non-native and invasive species could be less of a problem. The Local Communities scenario would also encourage a shorter supply chain which would result in fewer ballast water problems. With less strict controls on ballast waters regulations (e.g. BWM Convention and proposed IAS Regs (if adopted)) under the World Market scenario, the marine environment would see an increase in numbers and occurrence of non-native, invasive and alien species as shipping expands. It is the Global Community scenario where countries still adhere to international agreements which encourages safer ships and good practice, even with busier waterways and longer shipping routes.

4.5 Relevance for Policymakers and Stakeholders

Scenarios are valuable in providing insight about possible outcomes of decisions taken now and their future ramifications. Although the four future scenarios depict extreme events, they all contain recognisable events to which people can relate - for example society is globalising but at the same time is becoming more aware of environmental issues. When the scenarios were first developed in 2000 (IPCC, 2000), certain activities affecting the coast had not even been considered (e.g. fracking) or were off the political agenda (e.g. nuclear energy) and were therefore not written into the scenarios. However with government changes, the nuclear industry is once again being considered a solution to solving future energy needs for some countries. Future scenario testing has been used in many sectors of coastal management. Examples include scenario planning for storm surge flooding and loss of coastal wetlands in the UK (Nicholls, 2004) and the Mediterranean (Conte & Lionello, 2013); provision of
drinking water supplies in north east Spain (Marquès et al., 2013); climate change will mean that environmental targets are not met against moving baselines (Elliott et al., in revision); and climate change on European marine ecosystems (Philippart et al., 2011).

Stakeholders at the VECTORS workshop were asked to consider the following questions in relation to the future scenarios and their implications for policy and governance:

(1) the value of scenario raising and testing in determining the nature of marine changes and our ability to tackle the present and future hazards;
(2) the validity of the scenarios raised for marine policy and governance;
(3) the projected repercussions of the scenarios raised and the likelihood of the changes suggested; and
(4) of the four VECTORS scenarios presented, which parts from each scenario are more likely to give a true representation of the future marine environment?

A summary of the stakeholder views is presented below.

<table>
<thead>
<tr>
<th>Stakeholder-based Conclusions and Recommendations on the VECTORS Scenarios &amp; Policy Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The scenarios proposed in VECTORS are valid for marine policy, governance and management and given the future is uncertain there was support for using all four scenarios.</td>
</tr>
<tr>
<td>• Scenarios can be used to &quot;test&quot; which policy actions are robust and sustainable and may be a great tool to force you to think ahead and to model changes in society.</td>
</tr>
<tr>
<td>• The scenarios were felt to be a useful instruments to test the possible future outcomes.</td>
</tr>
<tr>
<td>• The stakeholders highlighted the importance of using 'extremes to think the unthinkable' and to ensure that the scenarios used are not 'too safe'.</td>
</tr>
<tr>
<td>• However the scenarios were questioned as to whether they are in fact extreme enough, for example at present, the scenarios only take into account growth of populations and the economy, and not declines in these factors.</td>
</tr>
<tr>
<td>• The big challenge is communicating the findings of the scenarios research effectively to stakeholders and policymakers. However there may be some politically difficult elements of the scenarios and therefore these will need sensitive handling.</td>
</tr>
</tbody>
</table>

Deliverable 60.1 lists a number of important international and European legislation/obligations which may affect activities in the marine environment, and to which many European countries are full signatories. The timelines including start date, longevity and reporting periods of these conventions and directives are shown in Figure 4.3. 2015 was used as the baseline date for current legislation, unless directives or Conventions give specific target dates in the future e.g. the Marine Strategy Framework Directive (MSFD) (2008/56/EC) requiring Good Environmental Status (GES) by 2020 or the EU Renewable Energy Directive (2009/28/EC) requiring 20% of all energy by renewable sources by 2020. This figure indicates the many instruments which currently govern the marine environment and which may still exist in 2050. The scenarios proposed in VECTORS are considered valid for marine policy, governance and management and given the future is uncertain, all four scenarios are needed in the analysis and provide a useful platform to test if policy actions are robust and sustainable.

It is acknowledged that these legal obligations have generally not been factored into the scenarios, but they do affect the likelihood of the scenarios unfolding. It is presumed unlikely that any of the four scenarios are free to evolve unconstrained since future pathways are dependent upon existing legislation, obligations and conventions. However, legislation in the future may change (be amended) or...
revoked (repealed) (e.g. The Water Framework Directive repealing four former directives) based on changes in policy. The enforcement of EU directives by the Commission or the enforcement of International law by the respective governing body may also change depending on the future scenarios. Countries may choose to step away from the obligations of the law or make it a secondary concern to other environmental or economic issues. Whatever the future scenario may be, what is becoming apparent is the move away from sectoral legislation to a more holistic approach (Boyes & Elliott, 2014).
**Figure 4.3:** Start date, longevity & reporting periods of international law and European directives and initiatives. 2015 was used as the baseline date for the purpose of this report.
5. RELIABILITY OF TOOLS FOR MANAGEMENT EVALUATIONS

The management of natural resources is a complex process driven by interactions between dynamics of the natural system, the decision-making and behaviour of stakeholders, and uncertainty at various levels of the management process and the natural system. Thus, there is a need to find robust approaches that meet management objectives under a range of potential resource situations and pressures on the resources (Mapstone et al., 2008). Recent advances in fisheries science and computational capabilities have provided new concepts for management of commercial fisheries and stocks by evaluating management scenarios in a virtual world by including stakeholders and by assessing its robustness to uncertainty. Simulation models within an adaptive framework enable the comparison of alternative strategies under multiple and often conflicting objectives. Moreover, they allow experimentation with a range of possible management procedures under a range of circumstances. In contrast, real-world experimentation is highly desirable to disentangle the drivers of the system, but is difficult to pursue for most natural resources. In this section we analyse the robustness of several models that are used for management evaluations including their strengths and weaknesses, their value for specific management evaluation processes, the trade-offs and their status of application.

5.1 Model evaluation matrices, model categorization, and use and trade-off summary tables of the use and development of integrated ecological and economic models in fisheries management

This study is part of the VECTORS project and compares selected integrated ecological-economic models with a focus on their coverage of the systems (ecosystems, fisheries systems, cross sector), use and implementation in scientific and advisory contexts (the full details of the study are provided in Annex 4). This comparative model evaluation and categorization according to a long row of criteria involved workshops with model developers and core model users and resulted in an identification and description of the main characteristics, forces and weaknesses of the different models given their purpose and context. It furthermore provides insight into necessary characteristics and coverage of the models in relation to which objectives they were addressing and given their coverage of different parts of the system. In particular, the evaluation elucidated some general gaps in coverage and usefulness for most existing models which need to be addressed in future model development. Major aspects of this are addressed in the following sections in relation to model characterisation of the models developed and applied in relation to the VECTORS project. The Ecosystem-based Approach to (Fisheries) Management (EAM) calls for an understanding and management of fisheries and other uses of the marine environment that explicitly take into account ecological, economic and social considerations. Although it is acknowledged that only human activities can be managed, their optimal management will depend on the ecosystem in which they take place and the ecosystem goods and services which are provided. Hence, the direct and indirect impact of fisheries on the marine ecosystem and vice versa must be assessed and predicted. This entails a move from single species to multispecies fisheries and stock assessment, as well as more broadly to ecosystem assessments. Also, successful marine management needs to include the economic and social sustainability of the activities. Therefore, explicit incorporation of economic and social components of fisheries and marine management needs be included in any management evaluation and model. Accordingly, tools need to be developed and implemented, which take the ecological-economic-social-governance interactions into account. The aim of this study was to describe and compare selected, relevant models in Europe, to discuss their development and level of implementation, and to develop a sound basis for evaluating and comparing these tools, including their robustness. It analyses the needed characteristics for the use in advisory context through a comparative and descriptive matrix and summary tables. Based on this analysis, the need for future research, development and advisory structures that can increase the level of use and implementation of the models is elucidated.
5.2 Supporting fisheries management by means of complex models: can we point out isles of robustness in a sea of uncertainty?

Ecosystems are usually complex, nonlinear and strongly influenced by poorly known environmental variables. Among these systems, marine ecosystems have high uncertainties; marine populations in general are known to exhibit large levels of natural variability and the intensity of fishing efforts can change rapidly. These uncertainties are a source of risks that threaten the sustainability of both fish populations and fishing fleets targeting them. Appropriate management measures have to be found in order to reduce these risks and decrease sensitivity to uncertainties. Methods have been developed within decision theory that aim to allow decision making under severe uncertainty. One of these methods is the information-gap decision theory. The information-gap method has started to permeate ecological modelling, with recent applications to conservation. However, these practical applications have so far been restricted to simple models with analytical solutions. A deterministic approach was implemented based on decision theory in a complex model of the Eastern English Channel. Using the ISIS-Fish modelling platform, populations of sole and plaice were modelled in this area. A wide range of values for ecosystem, fleet and management parameters were tested. From these simulations, management rules were identified which control fish harvesting that allow management goals recommended by ICES (International Council for the Exploration of the Sea) working groups to be reached while providing the highest robustness to uncertainties on ecosystem parameters. Further details of this study are provided in Annex 5.

5.3 The suitability of FishRent as a tool for management evaluations

When designing management plans that should sustain the resource, it is essential to understand how fishermen will response to these plans, but also to ecological and economic changes that might occur at the same time. VECTORS WP2.3 developed an integrative model system which includes the economics of multiple fleet sectors, the impact of fishing on stock development and their spatio-temporal interplay. The modelling approach is based on a bio-economic optimization and simulation model called “FishRent”. Compared with other existing models, the basic version of FishRent is an advanced model from the economic point of view, because it includes prices, costs, and fishermen behaviour, in terms of investment, disinvestment and fishing effort distributions between fleet sectors for a long period of time. In WP3.3 the basic version of FishRent was extended by replacing the Schaefer model, which was a simple deterministic stock growth production function, with a dynamic age-structured population model that accounts for stochasticity in the stock–recruitment relationship. Additionally seasonal migrations of species and dispersal of individuals to adjacent areas was included in the model. In the extended version of the model changes in fishing behaviour in terms of effort allocation patterns or entry and exit of vessels affect the catch, fishing mortality of species and ultimately the development of the fish stocks. To show the potential of the model it was applied to a case study, namely the North Sea saithe fishery, where the stock declines although a long-term management plan exists. In WP2.3 and WP3.3 the impacts of future climate scenarios on the North Sea saithe fishery were analysed and in WP6.4 two alternative management strategies were evaluated for that fishery. In this study, the suitability of the model for fisheries management evaluations is discussed considering the feedback of a German saithe fisherman. This feedback should represent an example of how fishermen’s knowledge can be helpful when evaluating the potential and limitations of fishery models. Indeed, this single interview already revealed insights of fishermen’s behaviour. The model showed good fits relative to the fishermen’s descriptions. The results confirm the notion that revenues from target species, species spatial distribution, fishermen’s knowledge/experience and fuel prices are essential factors in determining fishermen’s behaviour. However, this interview also showed that future work is needed to account for other factors, ranging from non-target fish and wider ecosystem impacts to the social implications of management measures and their impacts on fishermen. Further details of this study are provided in Annex 6.
5.4 Using macro-scale models to inform marine spatial planning – the North Sea case-study

Current marine spatial planning is required to employ management advice based on holistic analyses revealing how different anthropogenic pressures and economic sectors may affect marine ecosystems and not merely single components of the system (MEA, 2015; EC, 2008). The North Sea is one of the best studied systems in the world, for which a large amount of data have been collected, and a high number of macro-scale models exist, which can invaluably help to inform this task. These models are synthetic mathematical descriptions of ecosystem processes joined together, guided by a mechanistic understanding of their regulating environmental drivers and biota, which can be used to project changes in the bulk properties of an ecosystem and components of interest (e.g. biodiversity, target species, Cheung et al., 2009; Allen et al., 2010). In this way, such models provide a holistic view of ecosystems where the impacts of conservation, management, and global scenarios can be assessed (Barange, 2003; Levin et al., 2009). So while the information exists, the task focuses on the ability to convert this complex, detailed ecosystem-level research into a simple product that can be clearly communicated to management focusing on explicit questions with practical use: where is change happening, and how big is it? Such integrated data products are high in demand but are in short supply. Indeed, few products currently exist that provide estimates of the potential impacts of climate as well as other (manageable) human pressures on marine ecosystems, that can be easily communicated to, and used by, managers and policy makers, but such products could be used for strategic (what to do) as well as tactical (how to do it) advice. The meta-analysis of hot spots of ecosystem change in the North Sea (D4.2.1, Section 3.2) provides an illustration of a means to achieve this goal.

The primary aim of the analysis was to summarize and integrate the key patterns produced by model projections gathered from 64 datasets from 55 distinct models and to provide estimates at a spatial scale encompassing the entire North Sea ecosystem (WP2.2, WP4.2 & WP5.1), produced by 6 European modelling research groups. “Change” over the next 50 years was quantified for each dataset in a standardized manner, and then quantified at the ecosystem level, using random-effects meta-analysis modelling (D4.2.1, Section 3.2.) at a spatial scale that was compatible with an analysis of projected marine spatial planning actions. The distribution of hotspots of change – i.e. those areas for which the ecosystem-level change was quantified as being large and significant – was then plotted against projected marine spatial planning actions (MSPA) to gauge potential matches and mismatches in targets and efficiency, identifying areas where conflicts may arise within the next 50 years between ecological sensitivity of these marine systems and infra-structure or exploitation needs. Two types of MSPA were considered: the implementation of wind farms and the delimitation of conservation areas, estimated based on outputs of the FP7 Project Coexist for future human uses of the North Sea (http://www.coexistproject.eu/) and Delavenne (2012) for the Eastern English Channel. Because the ecosystem modelling datasets used were constrained primarily by environmental forcing (and our current understanding of biological responses to such forcing), the contrast between distributions of the considered MSPA and the distribution of hotspots of change were expected to highlight future challenges for marine spatial planning, providing a firm step toward the delivery of a simple product to management that considers both climate and human pressures on marine systems. A detailed description of the datasets, methods, findings, strengths and caveats of this analysis is currently in submission to a peer reviewed journal, but an extended summary can be found in VECTORS D4.2.1, Section 3.2.

The key finding of this analysis was that the vast majority of North Sea areas identified and those most likely to undergo ecosystem level change within the next 50 years are not currently aimed for protection as estimated in this project (as Natura 2000 areas). Overall, the proportion of the hotspots of change which are also aimed for protection varied between 0 and 33% (being lower than 10% in most of the analyses undertaken) and in half of the cases, between 15 and 31% of the area was also zoned for wind farm development. Some of these areas corresponded to the most severe hotspots of change identified. Possible negative impacts associated with the displacement and re-suspension of sediments during the wind farm construction phase have the potential to exacerbate the impacts identified here, which
incorporate current understanding of the biological responses to climate forcing. Conversely, protection from fisheries in the area within and surrounding wind farms may offer protection to fish species already hampered by climate driven effects. The full life-cycle analysis (construction, operation, and decommissioning) of the impacts of wind farms on marine ecosystem remains unquantified (Hooper & Austen, 2014). However, the patterns of change identified in this study suggest the need to consider long-term ecosystem dynamics (particularly as part of Environmental Impact Assessments) when decisions with long-term implementations such as these are made.

It is important to remember that the projected distribution of conservation areas used here considered ongoing discussions in the UK, Denmark, Germany, France and the Netherlands, but excluded potentially relevant initiatives from Norway. Thus, potential conflicts or mismatches can only be discussed for hotspots located within the Exclusive Economic Zones of the former 5 countries. The fact that, in many cases, hotspots of change were both areas projected for protection and wind farm development is a consequence of the scale at which the datasets were aggregated. This aggregation was however necessary to integrate the very diverse sources of information considered in these analyses. The potential conflict areas identified here can serve as indicators of areas where more finely resolved analysis should be conducted to more clearly identify specific challenges to effective planning.

5.5. Relevance for Policymakers and Stakeholders

The FISHRENT, F-CUBE, BALTIC FLR, ISIS-FISH, DISPLACE and ATLANTIS models applied in the VECTORS project have been evaluated. Their robustness, their strengths and weaknesses, their usefulness for specific management evaluation processes, the trade-offs and their status of application were analysed. Based on this analysis future research needs, development and advisory structures that can increase the level of use and implementation of the models was elucidated.

For most of the evaluated models the level of implementation into management advice is limited. There may be several reasons for this. The various types of models are well placed to inform management, but management is unclear how best to move beyond current practice - particularly with fisheries stock assessment. Part of the issue is that clients are not yet (really) asking for integrated, ecosystem-based advice that will require outputs from more holistic models. We are still stuck in a situation dominated by single-species stock assessments. More complex and integrated models such as FishRent, ISIS-FISH, DISPLACE, and ATLANTIS are relevant according to current management needs, however, management is not fully ready to adopt that information and integrated advice involving several stocks, several fisheries, and even more trophic levels. As such, the lack of implementation is likely related to the lack of clear formulation of use and needs for management and management questions to be addressed, lack of precise objectives for using the models (from the management side) and the essential information needed to use the model for this is not always precisely defined. Additionally, the models are generally complex and extensive data demanding models with a high number of parameters which may jeopardise robustness. Most models can be used to assess the feedback and possible trends, but not to precisely quantify the impact, often due to insufficient data availability. In general, specialists are needed to operate the models, i.e. the models are generally non-user friendly as they have been developed mainly for research purposes and most often not with a primary advice purpose. The models cover both short- to medium-term tactical management advice and broader long-term strategic management advice. Most models are multi-stock, multi-fleet, and multi-national i.e. mixed fisheries based. Also most models are flexible and generic, and not specific to a particular region. Some models are spatially explicit (e.g. FishRent, ATLANTIS) allowing for marine spatial planning evaluation in relation to fisheries as well as in relation to broader cross-sector marine management evaluation with respect to their impact on fisheries. Many of the tactical models do not have a sufficiently high resolution in space and time to obtain realistic prediction on variability in space and time of resources and fisheries. Only one type of model covers the full ecosystem (holistic models), but the lack of data and functional relationships for processes for the many parameters jeopardise precision and it can only be used for relatively long-term strategic purposes.
Among the models evaluated the following characteristics were observed:
- The models are multi-stock-and-multi-fleet-based considering mixed fisheries aspects;
- Only one of the models goes beyond multispecies into ecosystem considerations;
- Only two of the models tested have high implementation;
- Most of them are used in national advice frameworks;
- They have been published in peer-reviewed literature;
- Only one of the models was judged to be user-friendly;
- Most of them can only be operated by the developer, but most are flexible in use;
- They are all complex; and
- The models are relatively new.

The co-location of marine activities and co-use of areas to support the achievement of good environmental status by 2020 requires equal consideration of commercial and legal factors as well as biological and ecological attributions of each site (Christie et al., 2014). The information uncovered by Section 3.2 in WP4.2.1, highlighted here in Section 5.4, indicates that most of the North Sea which is expected to be most sensitive to climate-driven changes in ecosystem dynamics (and nutrient loading of coastal areas) is being overlooked. This finding has important implications for the management of the North Sea ecosystem and the sustainable use of its resources.

Increased availability of highly spatially and temporally resolved information on human activities taking place in the marine environment is an important part of supporting decision making in marine spatial planning. Equally important, is the need for integrated, ecosystem-level analysis of these data, in a transparent manner that is sufficiently user-friendly to be understood and used by managers and policy makers. High resolution empirical data associated with the impacts of human uses of the marine environment are not always available at the ecosystem scale, requiring large amounts of funding, cross border collaborations, and the coordination of monitoring programmes. Furthermore, our understanding of impacts of both pressures and conservation is, in many cases, still in its infancy. Macro-scale models similar to those used in Section 5.3 and D.4.2.1 - Section 3.2 have the potential to assist this task, by providing a holistic view of ecosystems where the impacts of conservation, management, and global scenarios can be assessed. Many of these models do not yet incorporate true information about the specific impacts of pressures such as renewable energy developments, awaiting the development of empirical evidence. However, large emphasis has been placed in model developments to help predict the ecosystem impacts of climate change. The integrated analysis of both types of information we have carried out in VECTORS (i.e. of non-manageable climate impacts, and of the impacts of manageable, direct human activities) is crucial to a robust, well-informed, ecosystem-based management of the marine environment. This meta-analysis is a significant step in this direction, bringing together a diverse range of information with regard to long-term ecosystem dynamics in the North Sea associated with climate change in the next 50 years, and its interpretation in the contexts of specific marine spatial planning actions. The explicit nature of the approach presented here provides a strong basis for future analyses that consider a wider base of evidence.
6. RISK ASSESSMENTS

6.1 Introduction

Risk Assessment (RA) is not a new concept and indeed is implicitly or explicitly embedded within any impact assessment such as Environmental Impact Assessment, Appropriate Assessment, Strategic Environmental Assessment, etc. Industries where there is potential for serious consequences of equipment or personal failure, for example, nuclear, aviation, space exploration, oil, rail and military industries have a long history of conducting risk assessment and mitigating for risks. For example, determining and minimizing the likelihood of a bird-strike which can cause engines to fail during aeroplane take-off by considering local bird populations. Similarly, where errors have the possibility of affecting human health, such as in the medical, hospital, and food industries, risks are controlled and risk assessments performed on a continual basis. In order to understand and perform a RA, certain basic concepts must be defined.

*Hazard*: the potential that there will be damage to a human asset/activity, or to the environment.

*Risk*: the amount of asset/activity/environment etc. that may be affected.

The UK Department for Environment, Food and Rural Affairs 2001 risk assessment guidelines note the following definitions for hazard and risk (Defra, 2011):

*Hazard*: A situation or biological, chemical or physical agent that may lead to harm or cause adverse effects.

*Risk*: The potential consequence(s) of a hazard combined with their likelihoods/probabilities.

*Hazard* is therefore the cause and *Risk* is therefore the probability of effect (likely consequences) leading to adverse or unwanted effects especially on human and valued assets.

Recently, a typology of hazards has been created to try to summarise the nature and number of marine hazards (Elliott *et al.*, 2014, Table 6.1). As potential consequences (the risk) of a hazard (the cause) can occur for different types of asset, methods for assessment of risk may differ between industries and whether the RA refers to financial decisions, environmental concerns, human health concerns, or damage to a physical structure. There are increasing frameworks adopted whereby RA is incorporated into marine management (e.g. Cormier *et al.*, 2013). For example, most people would understand Scenario A, in Table 6.2, as a simple risk assessment due to a high visual impact and much media coverage over events such as this. However, a risk assessment for Scenario B is also applicable. In each case the numerical probability of each scenario occurring would be assessed and appropriate measures put in place to ensure the likelihood was minimised.
Table 6.1 Typology of Hazards in Coastal and Coastal Wetland Area (from Elliott et al., 2014)

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) Surface hydrological hazards</td>
<td>Natural but exacerbated by human activities</td>
<td>High tide flooding, spring tide and equinoctial flooding; flash flooding, ENSO/NAO patterns</td>
</tr>
<tr>
<td>B) Surface physiographic removal by natural processes - chronic/long-term</td>
<td>Natural but exacerbated by human activities</td>
<td>Erosion of soft cliffs by slumping</td>
</tr>
<tr>
<td>C) Surface physiographic removal by human actions - chronic/long-term</td>
<td>Anthropogenic</td>
<td>Land claim, removal of wetlands for urban and agricultural area</td>
</tr>
<tr>
<td>D) Surface physiographic removal - acute/short-term</td>
<td>Natural</td>
<td>Cliff failure, undercutting of hard cliffs</td>
</tr>
<tr>
<td>E) Climatological hazards - acute/short-term</td>
<td>Natural but exacerbated by human activities</td>
<td>Storm surges, cyclones, tropical storms, hurricanes, offshore surges, fluvial and pluvial flooding</td>
</tr>
<tr>
<td>F) Climatological hazards - chronic/long-term</td>
<td>Natural but exacerbated by human activities</td>
<td>Ocean acidification, sea level rise, storminess, ingress of seawater/saline intrusion</td>
</tr>
<tr>
<td>G) Tectonic hazards - acute/short-term</td>
<td>Natural</td>
<td>Tsunamis, seismic slippages</td>
</tr>
<tr>
<td>H) Tectonic hazards - chronic/long-term</td>
<td>Natural</td>
<td>Isostatic rebound</td>
</tr>
<tr>
<td>I) Anthropogenic microbial biohazards</td>
<td>Anthropogenic</td>
<td>Sewage pathogens</td>
</tr>
<tr>
<td>J) Anthropogenic macrobial biohazards</td>
<td>Anthropogenic</td>
<td>Alien, introduced and invasive species, GMOs, bloom-forming species</td>
</tr>
<tr>
<td>K) Anthropogenic introduced technological hazards</td>
<td>Anthropogenic</td>
<td>Infrastructure, coastal defences</td>
</tr>
<tr>
<td>L) Anthropogenic extractive technological hazards</td>
<td>Anthropogenic</td>
<td>Removal of space, removal of biological populations (fish, shellfish, etc.); seabed extraction and oil/gas/coal extraction leading to subsidence</td>
</tr>
<tr>
<td>M) Anthropogenic acute chemical hazards</td>
<td>Anthropogenic</td>
<td>Pollution from one-off spillages, oil spills</td>
</tr>
<tr>
<td>N) Anthropogenic chronic chemical hazards</td>
<td>Anthropogenic</td>
<td>Diffuse pollution, litter/garbage, nutrients from land run-off, constant land-based discharges, aerial inputs</td>
</tr>
</tbody>
</table>

Table 6.2 Simple hazard—consequence—control combinations.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Hazard (cause)</th>
<th>Risk (Consequence)</th>
<th>Possible control measure</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Oil spill from tanker ship</td>
<td>Rare seabird population nesting on nearby beach killed by oil</td>
<td>Tanker to take a different route to destination during breeding season</td>
<td>In this scenario, the manmade asset (the oil in the tanker) is a potential hazard to the nesting bird population</td>
</tr>
<tr>
<td>B</td>
<td>Encrusting marine fauna</td>
<td>Corrosion and weakening of ship hull resulting in spillage of oil</td>
<td>Use of antifouling paint to discourage growth of marine life</td>
<td>In this scenario, the environment is the potential hazard to the manmade asset.</td>
</tr>
</tbody>
</table>

The hazard can be categorised as biological, chemical, radiation and/or physical (Calewaert, 2013; Defra, 2011) and can occur at the cell, individual, population, community or ecosystem level (Calewaert,
2013; Fairman et al., 1999). The asset that is affected (sometimes referred to as the risk receptor) can vary in size and scale, e.g. cellular changes, human beings (individuals or population), fauna and flora (single species or whole ecosystems), and materials (e.g. impacts on buildings by acid rain, loss or damage of property by a storm surge).

It is important to define a measurable end point for each asset affected. Different scenarios will have different end points which may be health related (e.g. mortality), ecology/environmental related (e.g. habitat or species loss), financial related (e.g. revenue loss) or physical in nature (e.g. properly loss/damage). For example, in the oil spill example above (Scenario A in 2), the end point could be the complete destruction of the breeding colony or it could be the loss of 50% of breeding adult birds. The methods used to perform the RA will be dependent on which risks, assets and end-points need to be investigated. Each RA will be unique, there is no “one size fits all” RA that can be used.

There are many methods of performing a RA and, as an example, the Bow Tie analysis has been used in the VECTORS project to assess offshore energy and fisheries. A Bow Tie is a diagram that visualises the scenario to be dealt with in one clear and easy to read picture. Shaped like a bowtie, the diagram creates a clear differentiation between preventative and mitigation measures – effectively ways to prevent an event from happening, and if it does, ways to mitigate any effects (Figure 6.1). The power of a Bow Tie diagram is that it summarises numerous risk scenarios that can be understood by all levels of an organisation. It provides a simple, visual explanation of a risk that would be much more difficult to explain otherwise. Originally designed for the risks associated with health and safety practices, the wide scope and capabilities of Bow Tie analysis mean that it can be adapted for a number of purposes including reviews of legislation and ecological assessments and investigations, and it can be expanded to include quantitative information as well as incorporating factors that may affect the adequacy of any control measures.

A six stage process was developed by the VECTORS project for assessing the risks associated with offshore energy, fisheries and aquatic invasive species (Table 6.3).
Table 6.3: Six steps in performing an Environmental Risk Assessment to be included to make the assessment more quantitative (expanded and adapted from basic procedures described in Fairman et al 1999; Brandsaeter, 2002; Calewaert, 2013).

<table>
<thead>
<tr>
<th>Six steps of an ERA and associated key-questions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Problem Formulation</td>
<td>What needs to be assessed?</td>
</tr>
<tr>
<td>2. Hazard Identification</td>
<td>What can go wrong? (What are the hazards?)</td>
</tr>
<tr>
<td>3. Cause Identification</td>
<td>What can lead to the hazard occurring? (What causes the hazard?) Quantitative: How often or how likely is it that these causes will occur?</td>
</tr>
<tr>
<td>4. Exposure Assessment</td>
<td>Quantitative: How does the hazard reach the receptor? At what intensity? How long for and/or how frequently does the hazard reach or affect the receptor? Quantitative: How likely is it that the receptors will be exposed to the hazard?</td>
</tr>
<tr>
<td>5. Consequence or Effect Identification</td>
<td>What are the consequences of the hazard if it occurs?</td>
</tr>
<tr>
<td>6. Risk Characterisation and Estimation for Consequences</td>
<td>What are the risks (quantitative or qualitative measure)? Quantitative: What is the probability of the consequence happening? This can be estimated for both before and after preventative and mitigation measures are put in place.</td>
</tr>
</tbody>
</table>

6.2 Energy

6.2.1 OFFSHORE WIND POWER ON THE DOGGER BANK, NORTH SEA

Risk analysis that considers everything concerning offshore energy is a complex task, hence the case study of offshore wind power on the Dogger Bank in the North Sea was chosen as an example of an area primed for large scale wind development in the near future, and was reported in full in D60.5. It is proposed that lessons learned from this case study are relevant to all other European marine areas. Hence, the Bow Tie method for the analysis for risk assessment and management was chosen to help determine whether this form of analysis would work for such an intricate case, in order to assess the efficacy of marine planning in managing risk and determine risk minimisation procedures. Under the umbrella of future climate change, the top-level ways in which the environment could affect the successful operation of the wind farm and the use of the wind resource were examined, as were the ways that the wind farm may affect the environment in the context of the Marine Strategy Framework Directive (MSFD) descriptors of Good Environmental Status (GES).

Use of the Bow Tie approach has been successful in being able to map out all aspects that are related to a particular event that we do not want to happen, including ways of preventing and mitigating risk. In this case these two events have been:

1) the loss of renewable energy resources; the context of this Bow Tie was: ways that climate change can cause the environment to affect the wind farm; and

2) changes to the environment in terms of the MSFD GES indicators; the context of this Bow Tie was: ways that the wind farm can affect the environment.

A strength of the Bow Tie program is that complex information can be included in clickable boxes, as can links to relevant documentation. The resulting diagram can be extended for quantitative analysis if probability information exists for the hazard under study as well as to incorporate the principles of
DPSIR (see Section 1) by creating chained and nested Bow Tie diagrams to give a full overview of a system, at various ecological scales. Different depths of understanding will be needed by different levels of an organisation, therefore the Bow Tie program serves many purposes whereby the diagrams are sufficient to be disseminated to those who may only need to know the top-level outcome, this may be the public or the media. Those members of the organisation implementing changes and working on the logistics of the wind farm development can access all of the deeper information to help make more informed decisions and improve and edit the risk assessment as more information becomes available.

A potential drawback is the apparent linear nature of the diagram. Sometimes not all mitigation or prevention measures are needed, or sometimes more than one may be applied simultaneously. This is not evident from the diagrammatic format of the Bow Tie Risk Assessment and may be misleading for those not familiar with the Bow Tie scheme.

The current deliverable is a top-level risk assessment that attempts to encompass the entire system. For a complete risk management method then more precise Bow Ties could be constructed that allow different aspects of the system to be analysed in a greater level of detail. As our knowledge and understanding of the impacts caused by and to wind farms progresses, the contents and prominence of risk assessments will change and the Bow Tie can be quickly adapted to accommodate these. Furthermore, the Bow Tie value and use is increased by adding quantitative elements should such information become readily available.

The aim of this work was not to specifically find a way to effectively manage the hazards created by the competing uses and users of the Dogger Bank, but rather an assessment into whether the Bow Tie technique would be a suitable method for risk assessment and risk management (RARM). Hence this exercise has been considered to be successful as a proof of concept and has shown that the Bow Tie scheme is appropriate for mapping out causes, consequences, hazards and risks caused by and to wind energy in the North Sea and will allow for further development of the model for RARM in future studies.

6.3 Fisheries

6.3.1 Sea Urchin Fishery, Sinis MPA, Sardinia

This section provides a summary of D60.4 of the VECTORS project, which builds on information provided by WP1 on resource exploitation - fisheries (D1.1 and D1.2), WP4.1 which focuses on Western Mediterranean research, and WP6 on policy and stakeholders (D60.1). The aim of D60.4 is to assess the efficacy of marine planning in minimising risk in the context of fishery management in an MPA in the Western Mediterranean Sea.

This fisheries case study covers the risk assessment and management of an important fishery resource, the sea urchin Paracentrotus lividus, in the MPA of “Penisola del Sinis - Isola di Mal di Ventre” (Sinis MPA, Sardinia). This was identified as a major social and economic issue following the VECTORS stakeholder interviews and the analysis of regional and national legislation, as reported in D60.1. The Bow Tie analysis tool was used to determine how risks of over-exploitation of the biological resource can be prevented or, if not prevented, how they can be mitigated (Smyth & Elliott, 2014, Cormier et al., 2013).

Following the identification of potential impacts, the Bow Tie XP/XL software was used to create a diagram of the factors influencing the management of the sea urchin fishery in the Sinis MPA in order to visualize the hazard and associated causes/effects and to propose preventative and mitigation measures. As described in Section 6.2 above, the Bow Tie methodology is used for risk assessment, risk management and risk communication. The method is designed to give a better overview of the situation in which certain risks are present. Many risk assessments are currently done using quantitative instruments. These may be sufficient for certain types of cases but are less valuable for organizational risk assessment. Human actions as well as biological resources trends are less easy to predict than technological or other simple closed systems. The combination of pressures associated with
environmental systems, within the sustainable fisheries challenge, means that the results of certain consequences cannot be left unmanaged. Hence all possible scenarios need to be assessed for solutions. This is exactly what the Bow Tie method has helped us to accomplish for the management of the sea urchin resource in the Sinis MPA. Risk in the Bow Tie methodology is elaborated by the relationship between hazards, top events, threats and consequences. Barriers are used to display what measures an organization has in place to prevent and/or mitigate risk. This was the first application of the Bow Tie approach for the risk assessment and management of a marine biological resource. There are two key benefits of the use of the Bow Tie approach for the fishery (sea urchin) case study:

1) it allowed a quick analysis of what has been done in term of management of the biological resource throughout the years, and

2) it will support the Sinis MPA managers in the drafting and the adoption of proper management plans that take into account possible repercussions if some of the factors involved in the sustainable use of the biological resources are overlooked.

This exercise is considered to be successful as a proof of concept in its application to fishery (sea urchin) over-exploitation and has shown that if proper management actions are not taken, the natural equilibrium can be disturbed by the loss of components of the food web induced by overfishing or variation of environmental conditions as a result of climate change. Adaptive policies are needed to address the complex interaction between human activity and MPAs safeguarding both ecosystem services and ecological functions supplied by natural resources, as well as the impressive environmental and socio-economic value of MPAs.

6.3.2 SAITHE FISHERY, NORTH SEA

Modelling fishermen response to alternative area closures and bycatch prevention strategies: Bio-economic implications for the North Sea saithe fishery

Designing an effective management system requires understanding human behaviour under the management system. Fishermen change their behaviour in response to economic and management incentives, which lead to different fishery outcomes. This study presents a management strategy evaluation tool that was applied for the North Sea saithe fishery (further details are provided in Annex 7). FishRent, a bio-economic simulation and optimisation model, was used to explore how various area closures in combination with a quota-system affect levels of bycatches, net profits of individual fleet segments from different ports, and the stock development. Tested area closures differed in duration, size and location relative to major ports and to species seasonal movement patterns. This investigation was done in the light of a high level of natural variation in recruitment. Additionally, a discard ban and an inter-species quota flexibility system where quota of saithe could be used to cover the over-quota catch of cod at a ratio 1:5 were tested. Area closures that were parallel to the seasonal migrations of saithe tended to lead to greater increases in the spawning stock than closures that were perpendicular to the migration route. Even the area closure with the worst condition in terms of stock protection resulted in an increased spawning stock. Simulations demonstrated that the benefits of the various area closures were distributed heterogeneously among the individual fleet segments. Increases of saithe stock size were offset by increases in cod bycatches. The location of an area closure relative to the home port of fleet segments determined whether steaming costs increased and catches decreased. Quota flexibility showed that it can be beneficial both biologically for the stocks and economically for the fleet segments in that fishery in the long-term. A discard ban may not achieve the Common Fisheries Policy reform objective of reduced unwanted catches. Instead a discard ban involves high costs in terms of 11% to 29% lower net profits for individual fleet segments generating little economic incentive to avoid discards.
6.4 Ballast Water

6.4.1 REVIEW OF BALLAST WATER DISCHARGE RISK ASSESSMENT TOOLS AND NEW DECISION SUPPORT SYSTEMS FOR EU PORTS

D60.3 integrates and interrogates four complex topics: (1) vessels and ballast water, and ballast water discharge assessment (BWDA), (2) international ballast water management (BWM) requirements and the situation in the EU seas, (3) ballast water risk assessment (RA) under the BWM Convention, and (4) BWM decision support system (DSS).

Where a vessel is not fully laden, ballast water ensures the vessel seaworthiness; vessels depend fundamentally on ballast water for safe navigation and operations as a result of their design and construction. Fully or partially laden vessels may need ballast water because of (a) a non-equal distribution of cargo on the vessel, (b) adverse weather and sea conditions, (c) an approach to shallower waters, and (d) the fuel consumption during the voyage. VECTORS D60.3 describes ballast water systems of vessels, ballast tank designs, ballasting and deballasting processes and also safety and legislative aspects of ballast water operations.

In species invasion ecology, it is important to understand and evaluate the dimensions and processes of the transfer of aquatic organisms with vessels ballast water. The assessment of the quantity of discharged ballast water as the transfer medium of species is one of the basic elements in ballast water risk assessment and management. To assess the ballast water intended for discharge in advance of the vessel arrival in a port enhances the management process and enables port State authorities to make a timely response with adequate measures. A generic ballast water discharge assessment (BWDA) model was prepared and is based on vessel cargo operations and dimensions. This model was tested considering real shipping traffic and ballast water discharge data for the Port of Koper, Slovenia. The results show high confidence that the model predicts correctly whether or not a vessel will discharge ballast water, and also assesses the quantity of ballast water to be discharged. Through a case study approach it was planned that the model would be used to estimate ballast water discharges in different EU ports. Many EU ports were contacted to request that they make data available to run the model. However, the complete data which are needed to apply the BWDA model were only available for the Port of Hamburg, Germany, and Port of Tallin, Muuga Harbour, Estonia. Nevertheless, BWDA principles were applied to obtain an overall ballast water discharge assessment for 2012. These case studies are presented. In addition, by using the BWDA model principles, the global ballast water discharge from vessels engaged in the international seaborne trade was estimated as 3.1 billion tonnes in 2013.

Ballast water as a transport vector of aquatic species was initially addressed in a 1973 International Maritime Organization (IMO) resolution. As a consequence, IMO worked towards the finalization of the International Convention for the Control and Management of Ships’ Ballast Water and Sediments (BWM Convention). This convention was adopted at a diplomatic conference in London in February 2004. The main aim of the BWM Convention is to prevent, minimize and ultimately eliminate the risks to the environment, human health, property and resources which may arise from the transfer of harmful aquatic organisms and pathogens (HAOP) via ship ballast waters also considering related sediments. HAOP in this context are not limited to non-indigenous species, but HAOP include all aquatic species irrespective of whether they are native so that cryptogenic and native species are also covered. IMO defines BWM as “mechanical, physical, chemical, and biological processes, either singularly or in combination, to remove, render harmless, or avoid the uptake or discharge of Harmful Aquatic Organisms and Pathogens within Ballast Water and Sediments.” The BWM Convention (and its supporting guidelines) are described in D60.3 which addresses the ballast water exchange and performance standards, warnings concerning ballast water uptake in certain areas, ballast water reception facilities, sediment management as well as exemptions and exceptions from BWM requirements. D60.3 also includes a description of implementation options of the BWM Convention.
A number of countries world-wide have chosen to implement BWM requirements in a national approach. Most national requirements are based on the IMO Ballast Water Exchange Standard (IMO BWM Convention, Regulation D-1), but some countries also refer to the Ballast Water Performance Standard (IMO BWM Convention, Regulation D-2) and a few countries in addition refer to land-based ballast water reception facilities.

In the EU, different BWM approaches have been developed at regional levels and are voluntary (HELCOM/OSPAR/REMPEC BWM approaches). However, a common and mandatory EU wide BWM approach has not yet emerged. Voluntary BWM approaches in Europe are explained in D60.3, and the EU response on BWM is described. In addition we provide recommendations which may be considered when developing further BWM measures in the EU which has linkages to the EU Maritime Policy and EU Marine Strategy.

The risk assessment (RA) developed in VECTORS strictly follows the BWM Convention and is the most recently prepared global BWM related RA. It enables a selective BWM approach according to the BWM Convention and the G7 Guidelines so that only those vessels carrying critical ballast water are required to conduct BWM. Three different BWM RA methods are described, "environmental matching", "species' biogeographical" and "species-specific" RA. Firstly, in the environmental matching RA non-biological parameters are considered as surrogates for the species survival potential between the areas of ballast water origin and discharge considers. Secondly, the species' biogeographical RA identifies species which show overlapping distributions in the ballast water donor and recipient ports and biogeographic regions. An overlap is taken as an indication of direct similarity of the environmental conditions and hence it indicates the species survival in the new environment. Thirdly the species-specific RA is explained. It is focused on life history information and physiological tolerances of species to identify their physiological limits with the aim of estimating their potential to survive or complete their life cycles in the new environment. This approach considers target species.

There are two different RA approaches under the BWM Convention, the selective and the blanket approach. In a blanket approach all ships intending to discharge ballast water in a port would be required to conduct BWM measures. The selective approach means that different BWM measures are required depending on different risk levels posed by the ballast water intended for discharge. The logic here is that ships may be exempt from BWM requirements provided the risk level of a ballast water intended for discharge is acceptable. On the other hand, if the risk for ballast water intended for discharge is identified as (very) high or extreme, these ships may be required to take additional measures based on the IMO G13 Guidelines. The risk level is a case-by-case RA result and the reliability of RA input data is of key importance. A detailed step-by-step RA model for exemptions from BWM requirements and for selective BWM measures, ready to be used by administrations, is provided. RA can also be used to exempt vessels from BWM requirements.

As the BWM Convention nears its entry into force, the interest in exemptions increases. As a case study, the RA model for exemptions was applied to intra-Baltic shipping considering different RA methods, i.e., environmental matching, species-specific method including target species and species biogeographical aspects. As reliable species data in the ports considered are unavailable and following the precautionary principle, no exemptions should be granted. To ensure data reliability, port baseline surveys and regular monitoring programs should be undertaken during the exemption period as new species found will influence the RA result and the exemption given may have to be revoked. The RA model prepared in VECTORS is considered to be of value to other areas world-wide.

Decision Support Systems (DSS) are supporting tools enhancing a (complex) decision-making process. Decision-makers are faced with the problem to take decisions especially on very complex issues. This usually requires an input of large data sets and a timely decision making process. DSSs are multi-faceted tools to provide decision makers with an instrument to (a) reduce uncertainties, (b) simplify and speed-up the decision process, (c) avoid subjectivism induced by the decision-maker and (d) guarantee transparency of the entire decision-making process. The DSS approach was introduced in BWM
because of the selective BWM approach. More precisely, it was soon recognised that a supporting tool is needed to provide transparency and consistency on BWM requirement decisions with the aim of improving environmental protection and lessening the BWM burden on vessels. The complex DSS process has several steps and starts with communication and data input, continues with RA, BWM decisions, vessel’s action(s) and ends with a monitoring and review process. During the complete decision process information needs to be exchanged with sources from the outside (e.g., vessels, other ports) and inner sources (e.g., vessel particulars, compliance history). Therefore adequate communication processes and data management are essential. When the required BWM measures are not conducted to the satisfaction of the port of call the BWM DSS endpoints range from discharging unmanaged ballast water to cases where vessels may be turned away. The report gives a detailed step-by-step DSS model ready to be used by administrations and other authorities involved in BWM related decision making processes.

The generic BWM DSS model developed during VECTORS was validated by using one year of real ballast water discharge information of the Port of Koper, Slovenia including comprehensive data on vessel voyages (collected or assessed), vessel movements, their main routes, navigational constraints and ballast water patterns. Ballast water patterns include the amount of ballast water to be managed per vessel and vessel type, ballast water exchange (BWE) capacity rates per vessel type and further the source ports relevant for RA. The data were analysed to assess (a) the number of vessels which would have been able to conduct BWE on their intended routes according to the BWM Convention, and (b) the quantity of ballast water intended for discharge (managed versus unmanaged). In the case of the Port of Koper, it is most likely that only vessels from outside the Adriatic Sea are enabled to conduct BWE before they call for the port. The designation of a ballast water exchange area in the Adriatic Sea would open more options to conduct BWE. However, this may be difficult to agree with all Adriatic Sea countries. The RA results from the ballast water source ports were related to each vessel in order to assign a risk level to each vessel intending to discharge ballast water. A critical situation arises in cases when ballast water is assessed to pose an extreme risk because the BWM DSS would conclude that these vessels would not be allowed to discharge unmanaged ballast water. This end point would hinder shipping in cases where a vessel needs to discharge ballast water (it could not continue cargo operations whilst keeping ballast water onboard, including the tank-to-tank transfer of ballast), but may only be avoided by using ballast water reception facilities or by applying “emergency” ballast water treatment, which could involve the addition of chemicals. However, in the latter case it needs to be shown that the discharge of this chemically treated ballast is environmentally acceptable.

6.4.2 ALIEN SPECIES DATABASE

Knowledge on alien, cryptogenic and other (potentially) harmful species in ports is needed to alert the shipping industry to harmful species occurring in ballast water uptake zones in order to fulfil the obligations of the IMO Ballast Water Management Convention and to enable ballast water management related risk assessments. With strong links to WP2 (Mechanisms of change) and WP3 (Impacts and implications of change), D60.2 of the VECTORS work documents the development of a database of alien species presence within and in the vicinity of representative EU ports. These work packages have therefore jointly developed a structure for an alien and cryptogenic species database for ports and for the seas in VECTORS’ focus. The database contains presence/absence, abundance and other data (if available) and will eventually be used to provide data needed for development of ballast water management related risk assessment procedures. No “critical” alien or cryptogenic species which can be transported by ballast water are currently known from the ports selected so no ballast water uptake warning needs to be issued at this stage.

6.5 Combined Pressures and Cumulative Impact Assessment

Wind energy projects being planned for and developed in the North Sea basin should not be considered singularly. Areas such as the Dogger Bank have plans for numerous developments and there is a patchwork of planned and existing installations from the Scottish waters in the north, to the German
waters in the south. This patchwork of wind farms has the potential to become a network and the potential effects of pressures in this region may therefore become combined/cumulative in their interactions. With the addition of the pressure of future climate change, such combined pressures mean that any predicted effects need also to be considered cumulatively at the EIA stage.

In general, there is a poor understanding of the cumulative effects with regard to wind farms (either terrestrial or offshore). This may be largely due to there being relatively few large scale wind farms operating and none are what may be considered as multiple large scale wind farms in the same area. Most available studies consider impacts that may occur to shipping and navigation, migration routes of birds, as well as effects from sound on marine mammals. There are also reports that large scale wind farms may affect weather patterns (see report D60.5 for more details).

Where one Bow Tie diagram may be sufficient for a small case study, for instance the effects of laying a cable route over a specific sandy beach, it would not be sufficient for tracing the effects of that cable route from a remote offshore wind farm to the landfall point a few km inland, across all the various habitats and taking into account all the users and uses of the sea bed in between. In this case, a nested and chained Bow Tie approach can be used and several Bow Ties linked together to form one overall diagrammatic model of the system in which users can click and be shown only the links that are relevant to the cause, consequence or even the control measure of question. This way of linking Bow Tie diagrams together allows for the incorporation of the DPSIR (DPSWR) principles and would enable users to see in a simple way how one Pressure may lead to many State changes (on the natural system), and that each individual State change could lead to a range of potential Impacts (on the human system), across different environmental scales. The Responses are then incorporated into the model as the various prevention and mitigation measures.

Furthermore, by using linked Bow Ties in the future it should be possible to create links between projects that have the potential to affect the same area, for instance renewable energy, aggregate extraction, commercial fisheries etc. Linking the causes and effects of such activities together should enable predictions to be made on where activities may have more (or less) of an impact based on other users or uses of the area in question.

6.6 Relevance for Policymakers and Stakeholders

Ballast Water Management (BWM) is a specialist service to support the shipping industry. The associated risk assessment has been developed in VECTORS to enable a selective BWM approach according to the International BWM Convention and its G7 Guidelines and bearing in mind the needs and practices of the shipping industry. It has been developed and tested in association with key stakeholders and is thus already highly relevant to the requirements of the international shipping industry and to ports.

Risk assessment needs to be highly relevant to both policy makers and stakeholders and this is strength of the Bow Tie method for risk assessment and analysis and the software chosen to facilitate it. The diagrams are only the first stage. Complex information can be included in clickable boxes, as can links to relevant documentation such as permits, EU Directives, EIA reports etc. It is possible to make the diagram quantitative if probability information exists for the hazard under study. Different levels of depth will be needed by different levels of an organisation, therefore the Bow Tie program serves a multifaceted purpose whereby the diagrams alone are sufficient to be used to disseminate to those who may only need to know the top-level outcome, this may be the public or the media for example. Those members of an organisation implementing changes and working on the logistics and policy implications a development can access all of the deeper information to help make more informed decisions and improve and edit the risk assessment as more information becomes available. The Bow Tie therefore allows information to be communicated various levels, from simple diagrams to complex data sets.

The VECTORS marine stakeholders were asked to consider two key questions in relation to the marine hazards and risk assessments being undertaken within the VECTORS project: what are the priorities for
tackling marine hazards and risk both now and in the future; and what is the value of the available risk assessment methodologies in addressing and communicating the hazard and risk analysis. A summary of the stakeholder views obtained from the VECTORS marine stakeholder workshop is presented below.
Stakeholder-based Conclusions and Recommendations on the VECTORS Hazards and Risk Assessments

- The breadth of present and future risks, e.g. shipping, marine litter, invasive species, ocean acidification, climate change, oil and gas developments, noise and the blue growth sector, may significantly affect human societies and so need to be addressed in combination.

- It was recognised that it is possible to control causes and manage for effects of endogenic (within the system) pressures such as oil exploration, however, exogenic pressures (those emanating from outside of the system, such as climate change), are more difficult as you can only manage for the consequences rather than the causes at the management scale (e.g. regional seas).

- Risk assessment allows us to accommodate the precautionary principle and to take account of unintended consequences, for example species where data are limited.

- The lack of clear and agreed realistic objectives for managing regional seas across sectors, agencies, countries, etc.

- The lack of a clear set of priorities about future marine hazards and risks – if priorities were identified then the regulatory framework could be structured to meet these. For example, in the UK the draft marine plans for the east coast have been released, and although they discuss all of the sectors, they do not attempt to prioritise them - such marine plans are seen as an opportunity to develop such a list of priorities.

- It is difficult to assign a list of priority marine hazards and risks for a number of reasons. For example, more affluent societies focus on long-term problems however it is more difficult to make decisions on risk when the focus is on the long-term.
7. KEY FINDINGS AND POLICY RECOMMENDATIONS

7.1 Key Findings

Review of current governance

- International conventions and laws provide harmonisation of regulations and protection to the marine environment across the world, but only when ratified and given additional emphasis/compliance through regional law.
- Historically, the EU approach to the protection of the marine environment has been piecemeal, tackling problems on a sectoral basis (e.g. fishing, shipping, energy, pollution). Only recently has European law changed to a more holistic view, embracing the Ecosystem Approach through the introduction of framework directives.
- Anticipating future impacts of VECTORS of change and mitigation measures is a prerequisite to informing current and future policy. The MSFD (2008/56/EC) addresses many of these impacts, and if implemented correctly, can help Member States to achieve Good Environmental Status (GES) in marine waters by 2020.
- Mapping marine legislation highlights the numerous pieces of international law, European and national legislation used to manage and protect our transitional waters, coastal and marine environments (Boyes & Elliott, 2014). The resulting ‘horrendogram’ illustrates the complexity.

Stakeholder case studies

- Although the stakeholder case studies focused on four different parts of three different seas, there were a number of common themes which emerged as well as the general assessment of the main barriers to and drivers for successful European marine resource management. Conflicts between different stakeholders about the use of certain parts of the marine environment, and possible conflict resolution strategies, constitute one important common theme. Conflicts were particularly intense between (would be) users and those stakeholders who would want as high a level of protection as possible for the marine environment.
- It was notable that there were differing levels of knowledge amongst respondents both in relation to the functioning of marine ecosystems with regard to human activities, and also regarding the duties and responsibilities of different stakeholders. There are entrenched views amongst the different stakeholders and in some areas, little signs of these being overcome. Hence, these have perpetuated conflicts amongst stakeholders. However, there are elements of good practice and future deliverables and publications from VECTORS will indicate and discuss these. In particular, there are models of co-operation and collaboration which can be transposed to other areas.
- Uncertainties about the future efficacy and implementation of the Marine Strategy Framework Directive and the Common Fisheries Policy have contributed to the many concerns and potential difficulties in achieving an integrated management of the marine space. Similarly it is of note that few players in the management of sectors have a complete understanding of the legislation framework identified and explained in Section 2 of this report. It is notable that those with a statutory responsibility have a good knowledge of the legislation and agreements relating to their sphere of influence but less so for the other areas. It could be concluded that such players are too busy with their own fields that they have neither the time, resources, nor inclination to become familiar with all aspects or with the implementation of the Ecosystem Approach per se.

Future scenarios and policy implications

- Given the future is uncertain, VECTORS research applied four contrasting future scenarios to test whether current marine policy actions are robust and sustainable. This research focussed
on three of the VECTORS drivers of change (demand for food, energy and transport) and explored policy repercussions to 2050.

- Although the four scenarios depict extreme events, they all contain recognisable events which people can relate to, for example society is globalising but at the same time becoming more aware of environmental issues.
- It is presumed unlikely that any of the four scenarios are free to evolve unconstrained since future pathways are dependent upon existing legislation, obligations and conventions.
- Whatever the future scenario may be, what is becoming apparent is the move away from sectoral legislation to a more holistic approach.
- There was support from the VECTORS marine stakeholders for the use of future scenario analysis to test the relevance of current policy into the future.

Reliability of tools for management evaluations

- The management of natural resources is a complex process, which is driven by the dynamics of the natural system and anthropogenic influence in the form of decision-making and stakeholders, and therefore requires robust approaches that meet management objectives.
- A wide range of models have been applied during the VECTORS project, with their strengths, weaknesses, usefulness for specific management evaluation processes, the trade-offs and their status of application having been analysed for the purposes of this deliverable.
- For most models the level of implementation into management advice is limited as a result of a lack of precise objectives for using the model for management purposes, extensive data requirements of the model, and the requirement for specialists to operate the model.
- A meta-analysis undertaken by VECTORS modelling researchers indicates, for example, that the majority of the North Sea which is expected to be most sensitive to climate-driven changes in ecosystem dynamics (and nutrient loading of coastal areas) is being overlooked. This finding has important implications for the management of the North Sea ecosystem and the sustainable use of its resources.
- Increased availability of highly spatially and temporally resolved information on human activities in the marine environment is an important part of supporting decision making in marine spatial planning.
- Equally important is the need for integrated, ecosystem-level analysis of these data, in a transparent manner that is sufficiently user-friendly to be understood by managers and policy makers.

Risk assessments

- Risk Assessment is not a new concept and indeed is implicitly or explicitly embedded within any impact assessment such as Environmental Impact Assessment, Appropriate Assessment, Strategic Environmental Assessment, etc.
- There are many methods of performing a Risk Assessment and, as an example, the Bow Tie analysis has been applied in the VECTORS project to both offshore energy and fisheries.
- These were the first applications in Europe of the Bow Tie model in the risk assessment and management of ecological systems and these applications demonstrated it to be a successful proof-of-concept.
- The findings of the Bow Tie analysis will help managers to identify where there are particular hazards that are not effectively controlled, or where they perhaps may be being “over” controlled and resources may be better allocated elsewhere.
- VECTORS reviewed risk assessment tools and new decision support systems for European ports as required under the Ballast Water Management Convention.
- VECTORS developed a global Ballast Water Management (BWM) related risk assessment tool which provides administrations with a detailed step-by-step risk assessment model for
exemptions from ballast water management. This model was applied to Intra-Baltic shipping, with the findings considered to be of value to other areas world-wide.

- VECTORS produced a generic Ballast Water Management Decision Support System Model which was validated using a single year of real-world ballast water data from the Port of Koper, Slovenia.
- VECTORS developed an online information system on aquatic non-indigenous and cryptogenic species (AquaNIS) designed to assemble, store and disseminate comprehensive data on organisms introduced to marine, brackish and coastal freshwater environments of Europe and neighbouring regions, and assist the evaluation of the progress made towards achieving biological invasion management goals.
- The decision process by managers and researchers measuring progress towards the implementation of the EU (e.g. Water Framework Directive, Marine Strategy Framework Directive) and international legislative acts (e.g. IMO Ballast Water Management Convention) should be based on scientifically validated, continuously updated and reliable source of information, such as AquaNIS, providing also data on spread, biological traits, ecology and impacts of invasive species.

7.2 Policy Recommendations

Review of current governance

- VECTORS recommends that it would be valuable to undertake a similar legislation and administration mapping exercise for each EU Member State to enable comparisons between Member States and to identify gaps and communicate these to regulators.
- VECTORS recommends that future governance should focus on activities which are not currently regulated, for example sectors of the Blue Growth agenda (e.g. large scale offshore aquaculture, seabed mining, blue biotechnology) for which there is currently limited regulation and little is known about the ecosystems in which the activities take place.
- VECTORS recommends that linking Marine Spatial Planning, Integrated Coastal Zone Management and Strategic Environmental Assessments is essential to integrate governance across sectors.
- VECTORS further recommends that a harmonisation is required of the definition of the status assessments between the different directives (e.g. MSFD, WFD, HD) in relation to activities, pressures and impacts and their management.

Stakeholder case studies

- VECTORS recommends that sufficient resources be allocated to fully integrate stakeholders in the management process, and that stakeholder input is managed more efficiently to avoid stakeholder fatigue.
- VECTORS follows stakeholder demands and recommends that a ‘one-stop-shop’ be established within each Member State from which all marine data can be accessed and which acts as a focal point for decision-making.

Future scenarios and policy implications

- VECTORS recommends that scenarios analysis should be used to ‘test’ possible outcomes of policy decisions taken now and their future ramifications.
- VECTORS recommends that given uncertainty in the future, all four scenarios should be applied but that a concerted attempt to also address the likely combined scenario will be needed.

Reliability of tools for management evaluations
VECTORS recommends that there is a need for the increased availability of highly spatially and temporally resolved information on human activities in the marine environment as this forms an important part of supporting decision making in marine spatial planning.

VECTORS also recommends that there is the need for integrated, ecosystem-level analysis of spatially and temporally resolved data, in a transparent manner that is sufficiently user-friendly to be understood by managers and policy makers.

Risk assessments

VECTORS recommends that the breadth of present and future risks which may significantly affect human societies, e.g. shipping, marine litter, invasive species, ocean acidification, climate change, oil and gas developments, noise and the blue growth sector, needs the causes of change to be addressed in combination.

VECTORS recommends that a clear set of priorities needs to be identified regarding future marine hazards and risks which would allow the regulatory framework to be structured to meet these needs.

VECTORS recommends that the Bow Tie methodology is an appropriate methodology to assess risks in the marine environment but it requires further development to account for combined pressures and cumulative impact assessments.

VECTORS recommends that to ensure data reliability in the BWM risk assessment model, port baseline surveys and regular monitoring programmes should be undertaken during the exemption period as new species found influence the risk assessment.
REFERENCES


Defra, 2010. Charting Progress 2


EC, 2006. Supra note 34 pp. 2–3.


EC, 2014. Commission welcomes Council's agreement to improve how seas and coastal areas are used.


Elliott, M., Borja, A., McQuatters-Gollop, A., Mazik, K., Birchenough, S., Andersen, J.H., Painting, S. & Peck, M., in revision. Climate change will affect our ability to achieve Good Environmental Status for marine biodiversity. *Aquatic Conservation: Marine & Freshwater Ecosystems* (in revision).


Policy and governance synthesis as a tool for stakeholders


Shine, C., Williams, N & Gündling, L. 2000. A Guide to Designing Legal and Institutional Frameworks on Alien Invasive Species. IUCN


ANNEX 1 – VECTORS MARINE STAKEHOLDER WORKSHOP SUMMARY

Author: Daryl Burdon (UHULL)

A VECTORS Marine Stakeholders Workshop took place on Wednesday 5 February 2014 at Europe House, London, UK. The workshop was attended by a wide range of stakeholders from the North Sea, Baltic Sea and Western Mediterranean, representing 26 organisations from over 13 EU member states. As well as introductory presentations from key members of the VECTORS project, the event was structured primarily to facilitate interactive discussion with the stakeholders in order to better understand their concerns and hear about their experience of how policy and governance can help us to manage the marine environment. This feedback is being used in VECTORS to improve our current understanding of marine governance and learn from examples of best practice in order to better advise on future policy and risk assessment decisions based on scenario analysis. Attendees were provided with a briefing document, including a list of proposed points for discussion, two weeks prior to the workshop. The workshop was divided into two sessions, the key feedback from each of these sessions is provided here and the plenary presentations are available online (www.marine-vectors.eu).

SESSION 1: CURRENT GOVERNANCE FRAMEWORKS & BEST PRACTICE

The morning session was divided into two parts. The first part provided an overview of current governance frameworks (as ‘horrendograms’) and got feedback on whether there are any tools/pieces of legislation missing, whether the links between articles have been interpreted correctly, whether further pieces of legislation are missing, and are the different regimes coherent. Key issues raised by the stakeholders include:

- The ‘horrendogram’ illustrates the complex nature of current marine legislation but there was consensus amongst the stakeholders that most key pieces of legislation are covered by the diagram7.
- It would be useful to have a similar diagram for all individual member states to illustrate how the legislation is distilling down to the national and subnational level, to enable comparisons and to identify gaps.
- The importance of transnational cross-border co-ordination was raised by several stakeholders with the suggestion for marine/maritime ambassadors to co-ordinate such activities.
- The importance of assessing which activities are currently not protected was raised, as was the issue of weighting the legislation to show which are the most important.

7 The ‘Marine Legislation: International Law, European Directives & National Implementation. Case Study: England’ diagram was circulated to all attendees before the workshop.
The Blue Growth Agenda (e.g. large-scale offshore aquaculture, seabed mining, blue biotechnology) was highlighted as a rapidly developing sector for which there is currently limited regulation and little is known about the ecosystems in which the activities take place.

It was suggested that linking Marine Spatial Planning, Integrated Coastal Zone Management and Strategic Environmental Assessments would provide a powerful tool to integrate governance across sectors.

The aim of the morning’s second part was to discuss the main impediments to integrated marine management, to identify the roles of stakeholders, and to explore whether there are elements of good practice. Key issues raised include:

- Despite a move to an ecosystem approach to marine management, data are still collected sectorally and there is no ‘one-stop-shop' to obtain data on the marine environment.
- While there are many agencies, players and administrations involved in marine management, each is very familiar with their own sphere but often do not have the time or capacity to consider all the spheres and sectors.
- The potential for stakeholder fatigue suggests that care needs to be taken with regards to when, where and how stakeholders are included in the marine management process.
- There is a lack of resources to fully integrate stakeholders in the management process - in general the only people who are paid to attend stakeholder meetings are the meeting conveners.
- Stakeholders provide a sense check for management with the point at which stakeholders are brought into the process being key however this is often dictated by political tradition.
- The form of stakeholder communication was also an issue of concern – some stakeholders like round-table discussions whereas others prefer to communicate in different ways.
- The scale of the issue is important. For example, it is easier to involve stakeholders in relation to wind farm developments on the Dogger Bank than in management of the North Sea as a whole.
- Cross-border co-operation was deemed important although the timeframe available for such transnational co-ordination was deemed to be often prohibitively short.
- The MSFD and MSP Directive are seen as a way forward for cross-border co-operation as it is obligatory for member states to work at the regional seas level, hence requiring more emphasis on cross-border co-operation.
- Establishing actual and perceived risks is one of the biggest barriers – there is often a misunderstanding of what are the actual (as opposed to the perceived) conflicts.
- It is important to understand the framing and implementation of the legal framework. For example, in the Netherlands it is easy for sectors to challenge the government, whereas in other member states this is not the case.
- There are always opportunities to learn from others and a number of examples of best practice were highlighted, including local eco-management of artisanal fisheries in Catalonia, management of marine litter in the Netherlands, and the bottom-up process used for the Dogger Bank management plan.

SESSION 2: FUTURE GOVERNANCE, RISK ASSESSMENTS & SCENARIOS

The afternoon session considered the priorities for tackling present and future marine hazards and risk, the value of risk assessment and scenario methodologies, and the validity and projected repercussions of the scenarios presented. Key issues raised and discussed by the stakeholders include:

- The breadth of present and future risks, e.g. shipping, marine litter, invasive species, ocean acidification, climate change, oil and gas developments, noise and the blue growth sector, which may significantly affect human societies.
• It was recognised that we can control causes and manage for effects of endogenic (within the system) pressures such as oil exploration, however, exogenic pressures (those emanating from outside of the system, such as climate change), are more difficult as you can only manage for the consequences rather than the causes at the management scale (e.g. regional seas).

• Risk assessment allows us to accommodate the precautionary principle and to take account of unintended consequences, for example species where data are limited.

• The lack of clear and agreed realistic objectives for managing regional seas across sectors, agencies, countries, etc.

• The lack of a clear set of priorities about future marine hazards and risks – if priorities were identified then the regulatory framework could be structured to meet these. For example, in the UK the draft marine plans for the east coast have been released, and although they discuss all of the sectors, they do not attempt to prioritise them - such marine plans are seen as an opportunity to develop such a list of priorities.

• It is difficult to assign a list of priority marine hazards and risks for a number of reasons. For example, more affluent societies focus on long-term problems, less affluent societies focus on short-term issues, and in the long-term it is more difficult to make decisions on risk.

• Scenarios can be used to “test” if policy actions are robust and sustainable and may be a great tool to force you to think ahead and to model changes in society – you need the extremes to think the unthinkable – if not it is too safe.

• The scenarios proposed in VECTORS are valid for marine policy, governance and management and given the future is uncertain, all four scenarios are needed in the analysis. However, at present, the scenarios only take into account growth of populations and the economy, and not declines in these factors.

• The big challenge is communicating the findings of the scenarios research effectively to stakeholders and policymakers. However there may be some politically difficult elements of the scenarios and therefore these will need sensitive handling.

This workshop summary can be downloaded as a 2-page factsheet from the VECTORS website (www.marine-vectors.eu). The factsheet is available for download in English, French, Italian and Spanish.
ANNEX 2 – NATIONAL LEGISLATION AND MANAGEMENT ORGANISATIONS ACROSS EUROPE

Each VECTORS representative country was asked to provide details on how both the International and European legislation had been enacted in the national context. The following tables show this information for the following countries.

Table A2.1 Marine and coastal regulatory framework for Denmark

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>EUROPEAN REGULATORY FRAMEWORK</th>
<th>DANISH REGULATORY FRAMEWORK</th>
<th>DANISH AUTHORITY RESPONSIBLE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>II. The revised Bathing Water Directive (76/160/EEC) is an updated version of the current Bathing Water Directive (76/160/EEC).</td>
<td>Various ministerial orders on bathing water and bathing areas:</td>
<td></td>
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<td></td>
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<td>• Order on quality assurance for environmental assessments (Bekendtgørelse om kvalitetskrav til miljømålinger, no 332 of 25/03/2010)</td>
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<td></td>
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<td>• Order on amendments to the order on wastewater permissions according to the Environmental Protection Law, chapter 3 an 4 Order no 1448 of 11/12/2007 (Spildevandsbekendtgørelsen)</td>
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<td></td>
<td></td>
<td>Target program for the Natura 2000 plans for the period of 2010-2015</td>
<td></td>
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<tr>
<td>Ballast Water</td>
<td>Ballast Waters Management</td>
<td>Act on the Protection of the Marine Environment (Havmiljøloven) and the Environmental Protection Act (Miljøbeskyttelsesloven)</td>
<td>Ministry of Environment Administering authority: Nature Agency</td>
</tr>
<tr>
<td></td>
<td>- IMO International Convention for the Control and Management of Ships Ballast Water and Sediments, London</td>
<td>- Implement of parts of the ballast water convention and set the regulation on environmental impact assessments (EIAs) for aquaculture placed more than 1 nm from the coast</td>
<td></td>
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<td></td>
<td>- 2004 (BWM Convention):</td>
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<tr>
<td>Invasive Alien Species</td>
<td>- Global Invasive Species Programme (GISP);</td>
<td>- Environmental Protection Act § 31, part 1 (order no 85/2002), determines that animals that do not naturally occur in Denmark should not be set out in nature without permission from the Ministry of Environment</td>
<td></td>
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<tr>
<td></td>
<td>- Invasive Alien Species (IAS) – International obligations under the Convention on Biological Diversity (CBD); Management tools used to monitor IAS.</td>
<td>The Fisheries Law (marine aquaculture requires permission, order no. 281/1999).</td>
<td></td>
</tr>
<tr>
<td>Fisheries</td>
<td>Common Fisheries Policy</td>
<td>The Fisheries Law</td>
<td>Ministry of Food, Agriculture and Fisheries (Fødevareministeriet)</td>
</tr>
</tbody>
</table>
### Policy and governance synthesis as a tool for stakeholders

#### Danish Regulatory Framework

<table>
<thead>
<tr>
<th>Topic</th>
<th>European Regulatory Framework</th>
<th>Danish Regulatory Framework</th>
<th>Danish Authority Responsible</th>
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</table>

#### Estonian Regulatory Framework

<table>
<thead>
<tr>
<th>Topic</th>
<th>European Regulatory Framework</th>
<th>Estonian Regulatory Framework</th>
<th>Estonian Authority Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated Coastal Zone Management</td>
<td>ICZM Protocol to the Barcelona Convention.</td>
<td>none</td>
<td>County-level thematic planning in place in a few counties.</td>
</tr>
<tr>
<td></td>
<td>repealing by 2014 the &quot;old&quot; Bathing Water Directive (76/160/EEC)</td>
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<tr>
<td>Ballast Water</td>
<td>Ballast Waters Management</td>
<td>None.</td>
<td>Ministry of Environment</td>
</tr>
<tr>
<td></td>
<td>- IMO International Convention for the Control and Management of Ships Ballast Water and Sediments, London</td>
<td>Ratification of the BWMC is planned to 2013.</td>
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<td></td>
<td>- 2004 (BWM Convention);</td>
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</table>
## Table A2.3 Marine and coastal regulatory framework for France

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>EUROPEAN REGULATORY FRAMEWORK</th>
<th>FRENCH REGULATORY FRAMEWORK</th>
<th>FRENCH AUTHORITY RESPONSIBLE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>- de se donner les outils en vue d’atteindre en 2015 l’objectif de «bon état» des eaux fixé par la Directive Cadre sur l’Eau (DCE)</td>
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<td></td>
<td></td>
<td>- d’améliorer le service public de l’eau et de l’assainissement :</td>
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<tr>
<td></td>
<td></td>
<td>- accès à l’eau pour tous avec une gestion plus transparente</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- de moderniser l’organisation de la pêche en eau douce</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Enfin, la LEMA tente de prendre en compte l’adaptation au changement climatique dans la gestion des ressources en eau.</td>
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<td></td>
<td></td>
<td>Code de l'environnement Livre 2</td>
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<td></td>
<td></td>
<td>Code de la santé publique</td>
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<td></td>
<td></td>
<td>Code général des collectivités territoriales</td>
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<td></td>
<td></td>
<td>Code de l'urbanisme</td>
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<tr>
<td></td>
<td></td>
<td>Code rural</td>
<td></td>
</tr>
<tr>
<td>Marine Protected</td>
<td>EU biodiversity strategy to</td>
<td>Biodiversité, Espèces Et Milieux : Articles 123 A 150 De La</td>
<td>Ministère de l'Ecologie, du Développement</td>
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<td></td>
<td>Protection</td>
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<tr>
<td>TOPIC</td>
<td>EUROPEAN REGULATORY FRAMEWORK</td>
<td>FRENCH REGULATORY FRAMEWORK</td>
<td>FRENCH AUTHORITY RESPONSIBLE</td>
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<td></td>
<td>&quot;La stratégie nationale pour la création d'aires marines protégées : Note de doctrine pour les eaux métropolitaines&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Code de l'environnement Livre 3 : espaces naturels</td>
<td></td>
</tr>
<tr>
<td>Ballast Water</td>
<td>Ballast Waters Management</td>
<td>Loi Grenelle 1, Loi n° 2009-967 du 3 août 2009 de programmation relative à la mise en œuvre du Grenelle de l'environnement Articles 23 et 35</td>
<td>Ministère de l’Écologie, du Développement durable, des Transports et du logement (MEDDTL)</td>
</tr>
<tr>
<td></td>
<td>- IMO International Convention for the Control and Management of Ships Ballast Water and Sediments, London</td>
<td></td>
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<tr>
<td></td>
<td>- 2004 (BWM Convention)</td>
<td>L’article L.411-3 du Code de l’environnement prévoit la possibilité d’interdire l’introduction dans le milieu naturel des espèces exotiques envahissantes et que dès que la présence dans le milieu naturel d’une des espèces visées est constatée, l’autorité administrative peut procéder ou faire procéder à la capture, au prélèvement, à la garde ou à la destruction des spécimens de l’espèce introduite et aux sanctions.</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>L’arrêté interministériel en date du 30 juillet 2010 fixe la liste des espèces d’animaux vertébrés dont l’introduction dans le milieu naturel, sur le territoire métropolitain, est interdite.</td>
<td></td>
</tr>
<tr>
<td>Invasive Alien Species</td>
<td>- Global Invasive Species Programme (GISP); - Invasive Alien Species (IAS) – International obligations under the Convention on Biological Diversity (CBD); Management tools used to monitor IAS.</td>
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<td></td>
</tr>
<tr>
<td>Energy and Climate change</td>
<td></td>
<td>Code rural et de la pêche maritime (Livre 9)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Loi Grenelle 2, loi n° 2010-788 du 12 juillet 2010 portant engagement national pour l’environnement (Titre III, articles 67 à 93 de la loi Grenelle II)</td>
<td>Ministère de l’Écologie, du Développement durable, des Transports et du logement (MEDDTL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Code l’environnement article L. 229-25 (émissions de gaz à effet de serre)</td>
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</table>

Table A2.4 Marine and coastal regulatory framework for Germany

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>EUROPEAN REGULATORY FRAMEWORK</th>
<th>GERMAN REGULATORY FRAMEWORK</th>
<th>GERMAN AUTHORITY RESPONSIBLE</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Prospectively through the Federal Water Act (Wasserhaushaltsgesetz (BGBI. I S. 2585)) from 31 July 2009, last amendment December 2011.</td>
<td>Regional ministries in the Federal States</td>
</tr>
<tr>
<td>TOPIC</td>
<td>EUROPEAN REGULATORY FRAMEWORK</td>
<td>GERMAN REGULATORY FRAMEWORK</td>
<td>GERMAN AUTHORITY RESPONSIBLE</td>
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<tr>
<td>Water quality</td>
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<tr>
<td>Marine Protected Areas</td>
<td>EU biodiversity strategy to 2020 National Strategy on Biological Diversity</td>
<td>Ministry for Environment, Nature Protection and Nuclear Safety</td>
<td></td>
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<tr>
<td>Wild Birds Directive 2009/147/EC (this is the codified version of Directive 79/409/EEC as amended)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fisheries</td>
<td>Common Fisheries Policy Sea Fisheries Law (See Fisch G.) (2011)</td>
<td>Federal Ministry for Nutrition, Agriculture and</td>
<td></td>
</tr>
<tr>
<td>TOPIC</td>
<td>EUROPEAN REGULATORY FRAMEWORK</td>
<td>GERMAN REGULATORY FRAMEWORK</td>
<td>GERMAN AUTHORITY RESPONSIBLE</td>
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</tr>
<tr>
<td>Energy and Climate change</td>
<td>EU Climate Change Policy</td>
<td>Regional legislation in the Federal States</td>
<td>Consumer Protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Renewable Energy and Thermal law (2009)</td>
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</tbody>
</table>

Table A2.5 Marine and coastal regulatory framework for Greece

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>EUROPEAN REGULATORY FRAMEWORK</th>
<th>GREEK REGULATORY FRAMEWORK</th>
<th>GREEK AUTHORITY RESPONSIBLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated Coastal Zone Management</td>
<td>ICZM Protocol to the Barcelona Convention.</td>
<td>Ongoing; a new spatial Framework for ICZM is under preparation by the Ministry of Environment</td>
<td>Ministry of Environment, Energy and Climate Change</td>
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<tr>
<td></td>
<td></td>
<td>Information on the current status of its implementation can be found in:</td>
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<td></td>
<td></td>
<td>Energy and Climate Change</td>
<td>Energy and Climate Change;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>also: Presidential Decree 51 (Government Gazette 54/18.03.2007)</td>
<td><a href="http://www.ypeka.gr/LinkClick.aspx?tid=347&amp;locale=en-US&amp;language=el-GR">http://www.ypeka.gr/LinkClick.aspx?tid=347&amp;locale=en-US&amp;language=el-GR</a></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Still in its infancy; information on its current implementation status in:</td>
<td>- Department of Natural Environment Management</td>
</tr>
<tr>
<td>Marine Protected Areas</td>
<td>EU biodiversity strategy to 2020</td>
<td>The Natura 2000 Network in Greece includes 202 Special Protection Areas (SPA) and 241 Sites of Community Importance (SCI)</td>
<td>- Ministry of Environment Energy and Climate Change;</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="http://www.ypeka.gr">http://www.ypeka.gr</a></td>
<td>- Department of Natural Environment Management</td>
</tr>
<tr>
<td>Natura 2000 Network</td>
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<tr>
<td>TOPIC</td>
<td>EUROPEAN REGULATORY FRAMEWORK</td>
<td>GREEK REGULATORY FRAMEWORK</td>
<td>GREEK AUTHORITY RESPONSIBLE</td>
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<tr>
<td>Ballast Water</td>
<td>Ballast Waters Management - IMO International Convention for the Control and Management of Ships Ballast Water and Sediments, London 2004 (BWM Convention);</td>
<td>Accepted and directly implemented in practice; not yet been ratified by national legislation Information (in Greek) can be found in: a) <a href="http://dspace.lib.ntua.gr/bitstream/123456789/3415/3/kapetanead_wbm.pdf">http://dspace.lib.ntua.gr/bitstream/123456789/3415/3/kapetanead_wbm.pdf</a></td>
<td>Ministry of Development, Competitiveness, and Shipping; No specific Secretariat or Directorate is yet authorised</td>
</tr>
<tr>
<td>TOPIC</td>
<td>EUROPEAN REGULATORY FRAMEWORK</td>
<td>IRISH NATIONAL REGULATORY FRAMEWORK</td>
<td>IRISH AUTHORITY RESPONSIBLE</td>
</tr>
<tr>
<td>-------------------------------------------</td>
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<td>------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Integrated Coastal Zone Management</td>
<td>ICZM Protocol to the Barcelona Convention.</td>
<td></td>
<td>Department of Environment Community and Local Government</td>
</tr>
<tr>
<td></td>
<td>repealing by 2014 the &quot;old&quot; Bathing Water Directive (76/160/EEC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine Protected Areas</td>
<td>EU biodiversity strategy to 2020</td>
<td>National Biodiversity Plan (2002)</td>
<td>Department of Arts Heritage and Gaeltacht (National Parks and Wildlife Service)</td>
</tr>
<tr>
<td></td>
<td>Natura 2000 Network</td>
<td>European Communities (Birds and Natural Habitats) Regulations 2011 - SI 477/2011</td>
<td>DAHG (NPWS)</td>
</tr>
<tr>
<td></td>
<td>Wild Birds Directive 2009/147/EC (this is the codified version of Directive 79/49/EEC as amended)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- IMO International Convention for the Control and Management of Ships Ballast Water and Sediments, London</td>
<td></td>
<td>Department of Transport</td>
</tr>
<tr>
<td></td>
<td>- 2004 (BWM Convention);</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Invasive Alien Species</td>
<td>Invasive Alien Species (IAS)</td>
<td>European Communities (Birds and Natural Habitats) Regulations 2011 - SI 477/2011</td>
<td>DAHG (NPWS)</td>
</tr>
<tr>
<td></td>
<td>- Global Invasive Species Programme (GISP);</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- IAS – International obligations under the Convention on Biological Diversity (CBD); Management tools used to monitor IAS.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• EU Strategy on Invasive Alien Species</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fisheries</td>
<td>Common Fisheries Policy</td>
<td>Fisheries Acts ( SI 17/1939 To SI 21/2003) and subsequent amendments</td>
<td>Department of Agriculture, Food and the Marine</td>
</tr>
<tr>
<td>TOPIC</td>
<td>EUROPEAN REGULATORY FRAMEWORK</td>
<td>IRISH NATIONAL REGULATORY FRAMEWORK</td>
<td>IRISH AUTHORITY RESPONSIBLE</td>
</tr>
<tr>
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</tr>
<tr>
<td>Energy and Climate change</td>
<td>EU Climate Change Policy European Renewable Energy Directive 2009/28/EC which amends and subsequently repeals Directives 2001/77/EC and 2003/30/EC</td>
<td>DECLG</td>
<td></td>
</tr>
</tbody>
</table>

**Table A2.7 Marine and coastal regulatory framework for Israel**

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>EUROPEAN REGULATORY FRAMEWORK</th>
<th>ISRAELI REGULATORY FRAMEWORK</th>
<th>ISRAELI AUTHORITY RESPONSIBLE</th>
</tr>
</thead>
</table>
| Integrated Coastal Zone Management | ICZM Protocol to the Barcelona Convention. | Israel signed the Barcelona Convention’s ICZM Protocol in 2008 Legislation:  
- Protection of the Coastal Environment Law, 2004 – which integrates ICZM policy  
- Planning and Building Law (1965) – through which ICZM principles are implemented  
Policy documents, national project:  
- Coastal Area Management Programme (CAMP) for Israel (1996-2000)  
- Territorial Waters Policy Document (1999)-which founded on ICZM principles | Ministry of the Environmental Protection |

national project with relevance:  
National monitoring plan (2001-onwards): a plan for monitoring Environmental quality of Israel’s Mediterranean coastal waters  
[Comment: IOLR submitted proposals to expand the scope of the national plan to include elements from the Directive] | Ministry of the Environmental Protection through Israel Oceanographic & Limnological Research Ltd. |

- The Prevention of Sea Pollution from Land-Based Sources Law, 1989  
- Prevention of Sea Pollution (Dumping of Waste) Regulations, 1984  
- Protection of the Coastal Environment Law, 2004  
- Prevention of Sea Pollution from Land-Based Sources Regulations (Prevention of Sea Pollution Levy), 2011  
national project:  
National monitoring plan (2001-onwards): a plan for monitoring Environmental quality of Israel’s Mediterranean coastal waters | Ministry of Environment Protection  

The Law for the Protection of the Coastal Environment, 2004: aims to, among others, to preserve the coastal environment | Ministry of Environmental Protection |

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<table>
<thead>
<tr>
<th>TOPIC</th>
<th>EUROPEAN REGULATORY FRAMEWORK</th>
<th>ISRAELI REGULATORY FRAMEWORK</th>
<th>ISRAELI AUTHORITY RESPONSIBLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine Protected Areas</td>
<td>EU biodiversity strategy to 2020</td>
<td>strategy document: Israel's National Biodiversity Plan (2010)</td>
<td>Ministry of Environmental Protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>and the coastal sand for the benefit and enjoyment of the public in present and future generations.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>repealing by 2014 the &quot;old&quot; Bathing Water Directive (76/160/EEC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natura 2000 Network</td>
<td>Wild Birds Directive 2009/147/EC (this is the codified version of Directive 79/409/EEC as amended)</td>
<td>None</td>
<td>Ministry of Environmental Protection through Israel Nature and parks Authority</td>
</tr>
<tr>
<td>Fisheries</td>
<td>Common Fisheries Policy</td>
<td>the Fisheries Ordinance, 1937 the fisheries regulations, 1937 (as amended)</td>
<td>Ministry of Agriculture and Rural development</td>
</tr>
</tbody>
</table>
### Table A2.8 Marine and coastal regulatory framework for Italy

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>EUROPEAN REGULATORY FRAMEWORK</th>
<th>ITALIAN REGULATORY FRAMEWORK</th>
<th>ITALIAN AUTHORITY RESPONSIBLE</th>
</tr>
</thead>
</table>
| Integrated Coastal Zone Management | ICZM Protocol to the Barcelona Convention. | Towards the activation and implementation of the National Strategy for ICZM according to:  
- Recommendation relating to the activation of ICZM in Europe (2002/413/CE) of 30 May 2002;  
- MSFD 2008/56/CE;  
- Barcelona Convention and related Resolution (c.d. interim arrangements);  
- Chart of Siracusa on Biodiversity, signed 24 April 2009 (G8 Environment). | Ministry for Environment, Territory and Sea and coastal Regions (including Sardinia)  
http://www.sardegnaambiente.it/inde\index.php?xsl=611&s=23&v=9&c=5121&na=1&n=10&nodesc=2 | |
http://www.camera.it/parlam/legge/deleghe/testi/10190dl.htm  
http://www.salute.gov.it/balneazione/archivioNormativaBalneazione.jsp?lingua=italiano&menu=normativa | |
http://www.minambiente.it/home_int/menu.html?mp=/menu/menu_attivita/&m=argomenti.html|biodiversita|strategia_Nazionale_per_la_biodiversita.html | |
Definizione dei criteri per determinare il divieto di balneazione, nonché’ modalità e specifiche tecniche per l’attuazione del decreto legislativo 30 maggio 2008, n. 116, di recepimento della direttiva 2006/7/CE, relativa alla gestione della qualità delle acque di balneazione, (10A06405)  
D.Lgs n. 116 - 30 May 2008  
Attuazione della direttiva 2006/7/CE relativa alla gestione della qualità delle acque di balneazione e abrogazione della direttiva 76/180/CEE  
D.Lgs n. 94 - 11 July 2007 | Ministry of Health  
http://www.salute.gov.it/balneazione/archivioNormativaBalneazione.jsp?lingua=italiano&menu=normativa | |
| Marine Protected Areas | EU biodiversity strategy to 2020 | Digs n. 979/1982 Sea Protection Act, December 31st, 1982 (GURI nº 16, January 18th, 1983)  
Digs n.394/1991 (GURI nº 292, December 13th, 1991) (for Protected Areas and National Parks].  
Law n° 426-98 promoting new interventions in the environmental field, December 9th, 1998 (GURI nº 291, December 14th, 1998) [for Protected Areas and National Parks].  
Testo della Strategia Nazionale per la Biodiversità  
Decreto di istituzione del Comitato paritetico per la Biodiversità, dell’Osservatorio nazionale per la Biodiversità e del Tavolo di consultazione  
Conferenza Nazionale per la Biodiversità e Workshop preparatori | Ministry for Environment, Territory and Sea  
http://www.minambiente.it/home_Intmenu.html?mp=/menu/menu_attivita&m=argomenti.html|biodiversita|fa.html|strategia_Nazionale_per_la_biodiversita.html | |
<table>
<thead>
<tr>
<th>TOPIC</th>
<th>EUROPEAN REGULATORY FRAMEWORK</th>
<th>ITALIAN REGULATORY FRAMEWORK</th>
<th>ITALIAN AUTHORITY RESPONSIBLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation of natural habitats and of wild fauna and flora (Habitats Directive) 92/43/EEC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ballast Water</td>
<td>Ballast Waters Management - IMO International Convention for the Control and Management of Ships Ballast Water and Sediments, London - 2004 (BWM Convention);</td>
<td>Decree of the General Director of the Ministry of the Environment on the management of BW. However, there is not yet the decree for the implementation of the BWM convention.</td>
<td>Ministry for Environment, Territory and Sea</td>
</tr>
<tr>
<td>Invasive Alien Species</td>
<td>Invasive Alien Species (IAS) - Global Invasive Species Programme (GISP); - IAS – International obligations under the Convention on Biological Diversity (CBD); Management tools used to monitor IAS. - EU Strategy on Invasive Alien Species</td>
<td>D.Lgs. 190 13 Oct 2010 Invasive Alien Species (IAS); National strategy for the biodiversity: Chart of Siracusa (not a law).</td>
<td>Ministry for Environment, Territory and Sea</td>
</tr>
</tbody>
</table>
Policy and governance synthesis as a tool for stakeholders

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>EUROPEAN REGULATORY FRAMEWORK</th>
<th>ITALIAN REGULATORY FRAMEWORK</th>
<th>ITALIAN AUTHORITY RESPONSIBLE</th>
</tr>
</thead>
</table>

Table A2.9 Marine and coastal regulatory framework for Lithuania

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>EUROPEAN REGULATORY FRAMEWORK</th>
<th>LITHUANIAN REGULATORY FRAMEWORK</th>
<th>LITHUANIAN AUTHORITY RESPONSIBLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine Protected Areas</td>
<td>EU biodiversity strategy to 2020</td>
<td>National Environmental Strategy of Lithuania Biodiversity Conservation Strategy and Action Plan</td>
<td>Ministry of Environment</td>
</tr>
<tr>
<td>Ballast Water</td>
<td>Ballast Waters Management - IMO International Convention for the Control and Management of Ships Ballast Water and Sediments, London - 2004 (BWM Convention);</td>
<td>Law on changes to law on protection of the marine environment (Nr. XI-1205)</td>
<td>Ministry of Environment</td>
</tr>
</tbody>
</table>
### Invasive Alien Species

- Global Invasive Species Programme (GISP);
- IAS – International obligations under the Convention on Biological Diversity (CBD);
  - EU Strategy on Invasive Alien Species

Order by the Minister of Environment (Nr. 352, 2002 July 1) on the “Introduction, reintroduction and relocation of non-indigenous organisms, invasive species control and management programme confirmation”

Ministry of Environment

### Fisheries

Common Fisheries Policy

Common Fisheries Policy

Ministry of agriculture

### Energy and Climate change

EU Climate Change Policy


National Renewable Energy Resource Development Strategy (LR Government resolution Nr. 789)

Ministry of energy

### Table A2.10 Marine and coastal regulatory framework for Poland

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>EUROPEAN REGULATORY FRAMEWORK</th>
<th>POLISH REGULATORY FRAMEWORK</th>
<th>POLISH AUTHORITY RESPONSIBLE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICM Protocol to the Barcelona Convention.</td>
<td>An amendment to the Water Law bill (2001; Prawo wodne) and other legal acts is in progress;</td>
<td>Ministry of the Environment</td>
</tr>
<tr>
<td></td>
<td>Environmental Law (2001; Prawo ochrony środowiska)</td>
<td>Legal act on water supply and sewage disposal (2001; ustawa o zbiorowym zaopatrzeniu w wodę i zbiorowym odprowadzaniu ścieków)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Legal act on water supply and sewage disposal (2001; ustawa o zbiorowym zaopatrzeniu w wodę i zbiorowym odprowadzaniu ścieków)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Note: several bylaws and implementing acts/regulations exist;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Note: most important bylaws and implementing acts/regulations are as follow:</td>
<td>National Water Management Authority</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Legal act on bathing water profile (2011; Ministry of the Environment);</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- Legal act on registration and labeling bathing places (2011; Ministry of Health);</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- Legal act on the supervision over the quality of bathing water and places used for bathing (2011; Ministry of</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chief Sanitary Inspectorate</td>
<td></td>
</tr>
<tr>
<td>TOPIC</td>
<td>EUROPEAN REGULATORY FRAMEWORK</td>
<td>POLISH REGULATORY FRAMEWORK</td>
<td>POLISH AUTHORITY RESPONSIBLE</td>
</tr>
<tr>
<td>-------</td>
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</tr>
<tr>
<td>Marine Protected Areas</td>
<td>EU biodiversity strategy to 2020</td>
<td>The National Strategy for the protection and sustainable use of biodiversity and the Action Programme for 2007-2013 (Krajowa strategia ochrony i zrównoważonego użytkowania różnorodności biologicznej oraz Program działań na lata 2007-2013)</td>
<td>Most relevant institutions include: Ministry of the Environment, Ministry of Agriculture and Rural Development, Governors of the provinces &amp; local authorities, Maritime Offices; Other institutions are also involved depending on the operational objectives;</td>
</tr>
<tr>
<td>Conservation of natural habitats and of wild fauna and flora (Habitats Directive 92/43/EEC)</td>
<td></td>
<td>Legal act on public access to information about the environment and its protection, public participation in environmental protection and environmental impact assessment (2008; ustawa udostępnianiu informacji o środowisku i jego ochronie, udziale społeczeństwa w ochronie środowiska oraz o ocenach oddziaływania na środowisko)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Note: several bylaws and implementing acts/regulations exist;</td>
<td></td>
</tr>
<tr>
<td>Ballast Water</td>
<td></td>
<td>BWM Convention: is not ratified. The process is likely to finish in 2013, preliminary implementation analysis was prepared;</td>
<td></td>
</tr>
</tbody>
</table>
### Topic: Invasive Alien Species

<table>
<thead>
<tr>
<th>European Regulatory Framework</th>
<th>Polish Regulatory Framework</th>
<th>Polish Authority Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Global Invasive Species Programme (GiSP);</td>
<td>Nature Conservation Act (2004; Ustawa o ochronie przyrody);</td>
<td>The General Directorate for Environmental Protection</td>
</tr>
<tr>
<td>- IAS – International obligations under the Convention on Biological Diversity (CBD); Management tools used to monitor IAS. EU Strategy on Invasive Alien Species</td>
<td>Legal act on alien species of plants and animals, which, if released to the environment, may threaten native species and habitats (2011; rozporządzenie w sprawie listy roślin i zwierząt gatunków obcych, które w przypadku uwalnienia do środowiska przyrodniczego mogą zagrozić gatunkom rodzimym lub siedliskom przyrodniczym)</td>
<td></td>
</tr>
</tbody>
</table>

### Topic: Fisheries

<table>
<thead>
<tr>
<th>European Regulatory Framework</th>
<th>Polish Regulatory Framework</th>
<th>Polish Authority Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Fisheries Policy</td>
<td>Fisheries Act (2004; Ustawa o rybactwie);</td>
<td>Ministry of Agriculture and Rural Development;</td>
</tr>
<tr>
<td>Inland Fisheries Act (1985; Ustawa o rybach swojemu);</td>
<td>Legal act on the organisation of fisheries market (2008; Ustaw o organizacji rynku rybnego);</td>
<td>The Department of Fisheries;</td>
</tr>
<tr>
<td>Legal act on supporting the sustainable development of the fisheries sector through the European Fisheries Fund (2009; Ustaw o wspieraniu zrównoważonego rozwoju sektora rybackiego z udziałem Europejskiego Funduszu Rybackiego);</td>
<td>Note: several bylaws and implementing acts/regulations exist;</td>
<td>Please note: number of actions are carried out in cooperation / through the government agencies, e.g., regional sea fisheries inspectorates or regional branches of Agency for Restructuring and Modernisation of Agriculture;</td>
</tr>
</tbody>
</table>

### Topic: Energy and Climate change

<table>
<thead>
<tr>
<th>European Regulatory Framework</th>
<th>Polish Regulatory Framework</th>
<th>Polish Authority Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>European Renewable Energy Directive 2009/28/EC which amends and subsequently repeals Directives 2001/77/EC and 2003/30/EC</td>
<td>Renewable energy development strategy (2001; Strategia rozwoju energetyki odnawialnej);</td>
<td>Ministry of Economic Affairs</td>
</tr>
<tr>
<td>Please note: these are a soft instrument but is indirectly implemented by several legal acts;</td>
<td>Energy Law (1997; Prawo energetyczne)</td>
<td></td>
</tr>
<tr>
<td>Note: several bylaws and implementing acts/regulations exist;</td>
<td>Draft legal act on renewable energy sources (Projekt ustawy o odnawialnych źródłach energii) is currently under the approval process (by the government);</td>
<td></td>
</tr>
</tbody>
</table>

### Table A2.11 Marine and coastal regulatory framework for Slovenia

<table>
<thead>
<tr>
<th>Topic</th>
<th>European Regulatory Framework</th>
<th>Slovenian Regulatory Framework</th>
<th>Slovenian Authority Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional strategy documents:</td>
<td>Regional development plan of South Primorska</td>
<td>Regional development Centre of South Primorska <a href="http://www.rk-op-sq.si/regionalni-razvoj-program.html">http://www.rk-op-sq.si/regionalni-razvoj-program.html</a></td>
<td></td>
</tr>
<tr>
<td>• Regional development plan of South Primorska</td>
<td>Coastal management programme Slovenia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOPIC</td>
<td>EUROPEAN REGULATORY FRAMEWORK</td>
<td>SLOVENIAN REGULATORY FRAMEWORK</td>
<td>SLOVENIAN AUTHORITY RESPONSIBLE</td>
</tr>
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<td>-------------------------------------------</td>
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</tr>
</tbody>
</table>
Policy and governance synthesis as a tool for stakeholders

### Policy and Governance Synthesis

#### TOPIC: Energy and Climate change

**EUROPEAN REGULATORY FRAMEWORK**

- EU Climate Change Policy

**SLOVENIAN REGULATORY FRAMEWORK**

- Decree of Parliament of the Republic of Slovenia regarding climate changes (2009) and Climate change act (in preparation)

**SLOVENIAN AUTHORITY RESPONSIBLE**

- Ministry of agriculture and environment

---

#### Table A2.12 Marine and coastal regulatory framework for Spain

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>EUROPEAN REGULATORY FRAMEWORK</th>
<th>SPANISH REGULATORY FRAMEWORK</th>
<th>SPANISH AUTHORITY RESPONSIBLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invasive Alien Species</td>
<td>Global Invasive Species Programme (GIISP); - Invasive Alien Species (IAS) – International obligations under the Convention on Biological Diversity (CBD); Management tools used to monitor IAS.</td>
<td>Royal Decree 1628/2011, of November 14th, for the regulation of the Spanish list and catalogue of invasive species: (Real Decreto 1628/2011, de 14 de noviembre, por el que se regula el listado y catálogo español de especies exóticas invasoras.)</td>
<td><a href="http://www.boe.es/dias/2011/12/13/pdfs/BOE-A-2011-10986.pdf">http://www.boe.es/dias/2011/12/13/pdfs/BOE-A-2011-10986.pdf</a></td>
</tr>
</tbody>
</table>

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Policy and governance synthesis as a tool for stakeholders

<table>
<thead>
<tr>
<th>Topic</th>
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<th>Dutch Regulatory Framework</th>
<th>Dutch Authority Responsible</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>IBN (Integraal Beheersplan Noordzee) 2011</td>
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<tr>
<td></td>
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<td>Nationaal Waterplan (2009)</td>
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<td>Nationaal Waterplan (2009)</td>
<td></td>
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<td></td>
<td></td>
<td>Nationaal Waterplan (2009)</td>
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<td></td>
<td></td>
<td>Wet hygiëne en veiligheid bad- en zwemgelegenheden (Whvzb) +Besluit hygiëne en veiligheid badinrichtingen en zwemgelegenheden (Bhvz).</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Beleidsprogramma biodiversiteit 2008-2011</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nationaal Waterplan (2009)</td>
<td></td>
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<td></td>
<td></td>
<td>Nationaal Waterplan (2009)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Nationaal Waterplan (2009)</td>
<td></td>
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</tbody>
</table>

**Table A2.13 Marine and coastal regulatory framework for The Netherlands**
### TOPIC

#### EUROPEAN REGULATORY FRAMEWORK

| Ballast Water | Ballast Waters Management - IMO International Convention for the Control and Management of Ships Ballast Water and Sediments, London - 2004 (BWM Convention); | Ratification of the BWMC in 2010, and implemented when international regulation is operative. National guidelines are laid down in “BVVS Besluit Voorkoming Verontreiniging door Schepen”.
| Invasive Alien Species | Invasive Alien Species (IAS) - Global Invasive Species Programme (GISP); - IAS – International obligations under the Convention on Biological Diversity (CBD); Management tools used to monitor IAS. - EU Strategy on Invasive Alien Species | Beleidsnota Invasieve Exoten (2007) Beleidlijn Verplaatsing Schelpdieren (2011) (transfer bivalves policy) Other indirect frameworks such as Flora en fauna Act.
| Fisheries | Common Fisheries Policy | Fisheries Act (1963)

### Table A2.14 Marine and coastal regulatory framework for UK (specifically England and Scotland)

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>EUROPEAN REGULATORY FRAMEWORK</th>
<th>ENGLISH &amp; SCOTTISH REGULATORY FRAMEWORK</th>
<th>REGULATORY AUTHORITIES</th>
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<td>Defra through the Joint Nature Conservancy Council (JNCC). Also MMO.</td>
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<td>- Biodiversity 2020: A strategy for England’s wildlife and ecosystem services (Defra, 2011)</td>
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<td>- Working with the grain of nature: a biodiversity strategy for England (Defra, 2002)</td>
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<td>- UK Marine Policy Statement (HM Government 2011)</td>
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<td>- Scotland’s Biodiversity - It’s In Your Hands 2004</td>
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<td>- The 2020 Challenge for Scotland’s Biodiversity (draft) 2012</td>
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<td>Natura 2000 Network</td>
<td>Wild Birds Directive 2009/147/EC (this is the codified version of Directive 79/409/EEC as amended)</td>
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<td>Defra through a number of agencies namely Natural England, but with the MMO, EA, Inshore Fisheries Conservation Authorities (IFCAs) and other competent authorities.</td>
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<td>Wildlife and Countryside Act 1981 as amended by the Countryside and Rights of Way Act 2000, which in turn was amended by The Natural Environment and Rural Communities Act 2006</td>
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<td>Marine Guidance Notes (MGNs):</td>
<td>Department for Transport through the Maritime &amp; Coastguard Agency (MCA)</td>
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<td>England &amp; Scotland</td>
<td>MGN 81 (M+F) - Guidelines for the Control and Management of Ships’ Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens</td>
<td>MGNs have been written due to the adoption of the 2004 BWM Convention, and the development of new supporting Guidelines. The MGNs provide information and interim guidance for use until the Convention has been implemented and the UK ratifies the Convention, after developing domestic legislation.</td>
<td><a href="http://www.mca.gov.uk/mca/safety-briefing/cbs-2002-080.pdf">http://www.mca.gov.uk/mca/safety-briefing/cbs-2002-080.pdf</a></td>
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**Ballast Water Management**

- IMO International Convention for the Control and Management of Ships Ballast Water and Sediments, London
- 2004 (BWM Convention);

**Marine Guidance Notes (MGNs):**

- MGN 81 (M+F) - Guidelines for the Control and Management of Ships’ Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens
- MGN 363 (M+F) - The Control and Management of Ships’ Ballast Water and Sediments

MGNs have been written due to the adoption of the 2004 BWM Convention, and the development of new supporting Guidelines. The MGNs provide information and interim guidance for use until the Convention has been implemented and the UK ratifies the Convention, after developing domestic legislation.

**Strategies and Reviews:**

- Ballast Water Management Strategy for North


### Invasive Alien Species

#### EUROPEAN REGULATORY FRAMEWORK
- Global Invasive Species Programme (GiSP);
- IAS – International obligations under the Convention on Biological Diversity (CBD);
- Management tools used to monitor IAS.
- EU Strategy on Invasive Alien Species

#### ENGLISH & SCOTTISH REGULATORY FRAMEWORK
- **Wildlife & Countryside Act 1981** as amended by the Countryside and Rights of Way Act 2000
- **Nature Conservation (Scotland) Act 2004**
- **Natural Environment and Rural Communities Act 2006**
- **Import of Live Fish Act 1980 and Import of Live Fish (Scotland) Act 1978**
- **Fish Health Regulations 1992; Fish Health (Amendment) Regulations 1997**

#### REGULATORY AUTHORITIES
- Defra through the Advisory Committee on Releases to the Environmental (ACRE). Also the Non-Native Species Secretariat within the Great Britain Non-Native Species (NNS) Programme Board. Driven through the national statutory nature conservation bodies, the Joint Nature Conservation Committee, the Scottish Environment Protection Agency, plant health inspectors and others.

#### Strategies and Reviews:
- Review of Non-Native Species Policy (Defra, 2003)
- Invasive Non-native Species Framework Strategy (Defra, 2008)

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### Fisheries

#### EUROPEAN REGULATORY FRAMEWORK

#### ENGLISH & SCOTTISH REGULATORY FRAMEWORK
- **Sea Fisheries Act 1968**
- **Sea Fisheries Regulation Act 1966 as amended by Environment Act 1995**
- **Sea Fisheries (Shellfish) Act 1967 as amended by: Marine and Coastal Access Act 2009 (England) & Marine (Scotland) Act 2010 (Scotland)**
- **Salmon and Freshwater Fisheries Act 1975**
- **Fishery Limits Act 1976 as amended by: Fishery Limits Order 1997 & 1999**

#### REGULATORY AUTHORITIES
- Inshore: Defra through Inshore Fisheries Conservation Authorities (IFCA) from HWM to 6 nm
- Offshore: Defra through MMO (6nm to UKCS)

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ANNEX 3 - REVIEW OF DOCUMENTS TO REGULATE BIOFOULING AS SPECIES INTRODUCTION VECTOR

Authors: Stephan Gollasch and Matej David (GoConsult)

INTRODUCTION

The International Maritime Organization (IMO) recognized that vessels are major introduction vectors of species and IMO consequently addressed the two prime ways how species become transported by vessels, i.e. ballast water (including sediments) and biofouling. The IMO Ballast Water Management Convention was adopted by IMO in 2004. Shortly thereafter biofouling as species transport vector became an agenda item and was addressed by the relevant IMO working groups with the aim to reduce the risk of the introduction of species with biofouling.

Biofouling includes large, multicellular organisms which are visible to the human eye (e.g. barnacles, mussels, tubeworms, or algae (Figure A3.1)) which are termed macrofouling. In addition microscopic organisms (e.g. bacteria and phytoplankton) occur, which produce the so called microfouling (also called “slime layer”).

Figure A3.1: Vessel hull being covered by biofouling, mainly with barnacles.

Anti-fouling systems, e.g. coatings, paints, surface treatments, or other are used on a vessel to control or prevent the attachment of organisms. However, all ships have some degree of biofouling, even those which may have been recently cleaned or had a new application of an anti-fouling coating system because biofouling begins within the first few hours of a ship’s contact with water.

In parallel to the development of the Ballast Water Management Convention, IMO also developed the International Convention on the Control of Harmful Anti-Fouling Systems on Ships (AFS Convention), which was already adopted in 2001. The AFS Convention focuses on preventing adverse impacts from the use of Tri-Butyl-Tin-(TBT)-containing antifouling paints, but it does not address the prevention of the transfer of aquatic species.

IMO continued working on a document to deal with the introduction of species with biofouling and released the 2011 Guidelines for the control and management of ships’ biofouling to minimize the transfer of invasive aquatic species (Biofouling Guidelines) and in 2012 the Guidance for minimizing the transfer of invasive aquatic species as biofouling (hull fouling) for recreational craft (Biofouling Guidance Document). Both are voluntary instruments.

In June 2013 Australia and New Zealand have released new anti-fouling and in-water cleaning guidelines, which were developed in consultation with industry stakeholders. These guidelines are
Policy and governance synthesis as a tool for stakeholders

closely linked to the AFS Convention and clearly require the prohibition of organotin compounds in anti-fouling systems, which is in accordance with the AFS Convention. The Australia and New Zealand guidelines are also in-line with the requirements of the IMO Biofouling Guidelines and the Biofouling Guidance Document to reduce the risk of species introductions.

In VECTORS Task 6.4.1 the two IMO biofouling documents related to species translocations were reviewed by firstly addressing commercial shipping and followed by a summary of the IMO recommendations for recreational craft. The applicability of the approaches recommended by IMO for Europe were in general evaluated briefly in the end of this document. In addition, the anti-fouling and in-water cleaning guidelines of Australia and New Zealand were considered to provide an example of how a regional agreement addressed the biofouling issues.

IMO BIOFOULING GUIDELINES

Although recently managers and policy makers have recognized the role biofouling played in species introductions by commercial vessels and recreational boats, no international convention exists to address this issue. However, at the IMO Marine Environment Protection Committee Session 62, in 2011, the 2011 Guidelines for the control and management of ships’ biofouling to minimize the transfer of invasive aquatic species were finalised and later adopted at IMO. The objectives of these are to provide practical guidance to related states, ship crews, shipbuilders, ship yards, anti-fouling paint manufacturers and suppliers and any other involved in shipping industry, on measures to minimize the risk of transferring invasive aquatic species with ships’ biofouling (IMO 2011).

These Guidelines recommend that every ship should have a Biofouling Management Plan and a Biofouling Record Book onboard and the reporting requirements are outlined below. As in-water cleaning may become particularly important, risk considerations of this method are also outlined below. The information provided here is based upon the Biofouling Guideline (IMO 2011).

As valid for many IMO guidelines the biofouling guidelines will periodically be reviewed to determine if these are sufficiently influencing biofouling management practices and therefore reducing the introduction risk of invasive aquatic species (IMO 2013).

IMO Biofouling Management Plan

It is recommended that every ship should have a Biofouling Management Plan (BMP). The intent of the plan should be to provide effective procedures for biofouling management. The BMP may be a stand-alone document, or may be integrated in part or fully, into the existing ships’ operational and procedural manuals and/or planned maintenance system. The BMP should be specific to each ship and included in the ship’s operational documentation. The purpose of the ship-specific BMP is to outline measures for control and management of ships’ biofouling and to include the following information as a minimum requirement:

- Describe the anti-fouling systems in place for different parts of the ship;
- Provide details on previous reports on the performance of the anti-fouling systems and the anti-fouling system certificate or statement of compliance or other documentation;
- Describe the ship’s operating profile, including: typical vessel speed; periods at sea compared with periods berthed, anchored or moored; typical operating areas or trading routes and planned duration between dry-dockings/slipping events;
- Identify the hull areas, niche areas and seawater cooling systems on the ship which are particularly susceptible to biofouling and provide a description of management actions required for each area;
- Describe the actions to be taken if the ship is operating outside the desired operating profile, or if excessive unexpected biofouling is observed, as well as any other actions which can be taken to minimize the accumulation of biofouling on the vessel;
- Describe the operation and maintenance of the anti-fouling system with timing of operational and maintenance activities as well as inspection schedule and procedures;
- Describe in-water cleaning and maintenance procedures and operation of on board treatment processes;
- Outline details of specific operational or safety restrictions, including those associated with the management antifouling system that affects the ship and/or the crew;
- Provide details of specific safety procedures to be followed during ship inspections;
- Describe the procedures for disposal of biological waste generated by the treatment or cleaning processes;
- Contain details of the types of documentation to be kept to verify the operations and treatments to be recorded in the Biofouling Record Book (see below);
- Document crew training and familiarization efforts.

The BMP should be updated as necessary.

**IMO Biofouling Record Book**

The Biofouling Record Book (BRP) should record details of all inspections and biofouling management measures undertaken on the ship to assist the ship owner and operator to evaluate the efficacy of the specific anti-fouling systems and operational practices on the ship in particular, and should be part of the BMP in general. The BRP may also assist interested authorities to quickly and efficiently assess the potential biofouling risk of the ship, and therefore may minimize delays to ship operations. The BRP may be a stand-alone document, or integrated in part, or fully, into the existing ships' operational and procedural manuals and/or planned maintenance system. IMO recommends that the BRP be retained on the ship for the life-time of the ship. The following information should be recorded in the BRP according to the biofouling activities taken:

- **After each vessel dry-docking:**
  - The date and location where the ship was dry-docked;
  - The date that ship was re-floated;
  - The hull cleaning efforts performed while dry-docked, including documentation of the areas cleaned, the cleaning method used and a description of the location of dry-dock support blocks;
  - Details of any anti-fouling coating system, including patch repairs, applied while dry-docked; and
  - Name, position and signature of the person in charge of the activity.

- **When the hull area, fittings, niches and voids below the waterline were inspected by divers:**
  - The date and location of the vessel when it was dive surveyed and the reason for the survey;
  - Details of the hull area or side of the ship surveyed;
  - General observations regarding biofouling (i.e. extent of biofouling and predominant biofouling types, e.g. mussels, barnacles, tubeworms, algae and/or slime etc.);
  - Description of the measures taken, if any, to remove or otherwise treat biofouling;
  - Any supporting evidence of the actions taken (e.g. report from the classification society or contractor, photographs and receipts); and
  - Name, position, signature of the person in charge of the activity.

- **When the hull area, fittings, niches and voids below the waterline were cleaned by divers:**
  - The date and location of the vessel when the cleaning/treatment occurred;
  - Details on the hull areas, fittings, niches and voids cleaned/treated;
  - Description of cleaning or treatment methods used;
  - General observations about the biofouling (i.e. extent of biofouling and predominant biofouling types; e.g. mussels, barnacles, tubeworms, algae and/or slime etc.);
  - Any supporting evidence of the actions taken (e.g. report from the classification society or contractor, photographs and receipts);
  - Documentation of permits required to undertake in-water cleaning, if applicable; and
  - Name, position and signature of the person in charge of the activity.

- **When the internal seawater cooling systems were inspected and cleaned or treated:**
Policy and governance synthesis as a tool for stakeholders

- The date and location of the vessel when the inspection and/or cleaning was conducted;
- General observations about biofouling of internal seawater cooling systems (i.e. extent of biofouling and predominant biofouling types; e.g. mussels, barnacles, tube worms, algae and/or slime etc.);
- Description of any cleaning or treatment undertaken;
- Methods of cleaning or treatment used;
- Any supporting evidence of the actions taken (e.g. report from the classification society or contractor, photographs and receipts); and
- Name, position and signature of the person in charge of the activity.

- For ships with an anti-fouling system fitted:
  - Record the operation and maintenance (e.g. regularly monitoring the electrical and mechanical functions of the systems); and
  - Document any instances when the system was not operating in accordance with the BMP.

- Periods of time when the ship was laid up and/or when a vessel was inactive for an extended time period:
  - The date and location where ship was laid up;
  - The date when ship returned to normal operations;
  - Description of the maintenance action(s) taken before and after the period laid up; and
  - Description of precautions taken to prevent biofouling accumulation (e.g. sea chests blanked off).

- Periods of time when the vessel was operating outside its normal operating profile:
  - The duration and dates when the vessel was not operating in accordance with its normal operating profile; and
  - The reason(s) for departure from normal operating profile (e.g. unexpected maintenance required).

- Details of official inspection or review of ship biofouling risk (for ships arriving internationally, if applicable):
  - The date and location of the vessel when the inspection or review occurred;
  - Details of the port State authority conducting the inspection/review and details of procedures followed or protocol adhered to and inspector/s involved;
  - The result of the inspection/review; and
  - Name, position, signature of the person in charge of the activity for the ship.

- Any additional observations and general remarks:
  - Since the ship was last cleaned, has the ship spent periods of time in locations that may significantly affect biofouling accumulation (e.g., fresh water, high latitude (Arctic and Antarctic) or tropical ports)?

IN-WATER CLEANING CONSIDERATIONS

In-water cleaning is an effective and important part of the biofouling management. It can introduce different degrees of environmental risk, depending on the nature of biofouling (i.e. microfouling versus macrofouling), the amount of anti-fouling coating system residue released and the biocidal content of the anti-fouling coating system. Microfouling can be removed with gentler techniques compared to macrofouling also minimizing the degradation of the anti-fouling coating system and/or biocide release. Microfouling removal may enhance a ship's hull efficiency, reducing fuel consumption and greenhouse gas emissions. Therefore, it is recommended that the ship's hull is cleaned when practical by soft methods in case significant microfouling occurs. In-water cleaning may also reduce the risk of spreading aquatic species by preventing or reducing the macrofouling accumulation. Before in-water cleaning is considered it may be appropriate for States to conduct a risk assessment to evaluate the risk of such activities and minimize potential threats to their environment, property and resources. Risk assessment factors could include:

- Biological risk of the biofouling organisms being removed from the ship (including viability of the biofouling organisms or the ability to capture biofouling material during removal measures);
- Factors that may influence biofouling accumulation, such as changes to the operating profile of the ship;
• Geographical area that was the source of the biofouling on the ship, if known; and
• Toxic effects related to substances within the anti-fouling coating system that could be released during the cleaning activity, and any subsequent damage to the anti-fouling coating system.

NATIONAL BIOFOULING MANAGEMENT APPROACHES

Although the above mentioned Biofouling Guidelines and Guidance Documents are not mandatory, biofouling related requirements of individual States develop. These refer to ships entitled to fly the flag, and to ships operating in the jurisdictional waters of these States.

Leading countries in biofouling aspects are Australia and New Zealand and both countries have jointly developed guidelines (IMO 2014) to address requirements of the AFS Convention, Biofouling Guidelines and Biofouling Guidance Documents, all prepared by IMO.

The guidelines developed jointly by Australia and New Zealand require that, in cases a hull cleaning is required, vessels and movable structures should be taken out of the water prior cleaning. However, when a removal outside water is not economically viable or practicable, the guidelines accept in-water cleaning as a potential management option for removing biofouling, provided that the risks are appropriately managed. A decision support tool, as outlined in Figure 2 (see further below) was developed to help authorities and owners or operators of vessels and movable structures, to decide whether or not in-water cleaning should be undertaken, and if so, what conditions should apply. This tool also describes the documentation that authorities may require to make decisions on in-water cleaning and this is explained further below.

The guidelines jointly developed by Australia and New Zealand are divided into two main parts: Part 1: Best practice guidance for the application, maintenance, removal and disposal of antifouling coatings at shore-based maintenance facilities to minimise environmental risk, and Part 2: Best practice guidance for in-water cleaning and maintenance of vessels and movable structures to minimise environmental risk.

The guidelines are based upon the following principles, which provide more details compared to the IMO documents:

• The risks posed by biofouling management measures should be balanced with possible risks of failing to manage biofouling;
• There are operational needs to manage biofouling on vessels and movable structures;
• The minimization of the biofouling accumulation on vessels and movable structures is preferable;
• It is preferable that biofouling is removed in the location where it was acquired before departing or moving to a new location;
• The release of potentially toxic chemicals and invasive aquatic species in the environment should be minimised; and
• Where operationally and economically practicable, vessels and movable structures should be removed from the water for cleaning and maintenance, in preference to in-water cleaning operations.

The Guidelines contain supporting information in different Appendices:

• Appendix 1: A decision support tool to determine the appropriateness of in-water cleaning in specific circumstances (see further below);
• Appendix 2: Description on anti-fouling coating types which are commercially available and how they work to prevent biofouling growth;
• Appendix 3: Information on in-water cleaning techniques;
Biofouling origin

The biofouling management decision is based upon the above mentioned criteria, also considering its origin because the geographic origin of biofouling organisms contributes to the biosecurity risk. If all biofouling was acquired in the same area where in-water cleaning is intended, cleaning may not pose a biosecurity risk as all biofouling species are already present in that area where they may be released due to the in-water cleaning measure. However, biofouling acquired from distant locations may contain invasive aquatic species that pose a biosecurity risk. To aid in assessing the risk, three origin categories are defined:

- **Regional biofouling:** biofouling acquired in the same location where in-water cleaning is proposed. ‘Regional’ is specified by the relevant state or territory government in Australia and local government in New Zealand. This category may be defined on the basis of biogeography, such as the distribution of (or specific pest management programs for) an invasive aquatic species or the location of high-value environments;
- **Domestic biofouling:** biofouling acquired from outside the region where in-water cleaning is proposed, but within the respective country’s waters. Examples of this would be in-water cleaning of a vessel or movable structure in eastern Australia whose biofouling may have been acquired in western Australia; or cleaning of a vessel in New Zealand in the South Island, whose biofouling may have been acquired from the North Island; and
- **International biofouling:** biofouling acquired from outside the waters of the country where in-water cleaning is proposed.

Log books to describe the voyage history (geographic locations visited and dates) of a vessel or movable structure since the last cleaning or full anti-fouling coating renewal should be kept on board. This information may be used by the relevant authority to identify possible origins of the biofouling on the vessel or movable structure when in-water cleaning is proposed.

Macrofouling represents a greater biosecurity risk as they may contain a diverse range of organisms and, at the same time, are more difficult to remove effectively without accidental release into the environment. The type of biofouling may be determined by inspection which may either be done by divers or remotely-operated cameras. The documentation of such an inspection in a Biofouling Record Book (see above) may be adequate evidence of the type of biofouling on a vessel or movable structure.

The following chapters highlight certain components of the Australia and New Zealand guidelines. For details regarding the other above mentioned components of the guidelines we ask the reader to consult the original documents (IMO 2014).

**Guidance on in-water cleaning**

This section outlines detailed in-water cleaning guidance as developed jointly by Australia and New Zealand. Please note also the decision support tool as provided further below (Figure A3.2):

- When regularly conducted, in-water cleaning is an effective measure to limit the biofouling. Regular (i.e. 6–12 monthly) in-water cleaning is recommended for all submerged surfaces, particularly propellers and other niche areas on vessels and movable structures;
- In-water cleaning to routinely remove mature and extensive macrofouling as a substitute for earlier and/or better maintenance practices cannot be recommended;
- In-water cleaning is only acceptable where contaminant discharges from the cleaning activity meet any standards or requirements set by the relevant authority;
- In-water cleaning of vessels or movable structures should ideally be carried out before departing to new destinations, not after arriving at those destinations;
- In-water cleaning should only be carried out on anti-fouling coatings that are suitable for in-water cleaning. Information on the suitability and ability of a coating to withstand in-water cleaning without damage and effects on service life, and on appropriate cleaning methods, should be obtained from the manufacturer of the coating;
- In-water cleaning should not be performed on vessels or movable structures that have reached or exceeded their planned in-service period. When the anti-fouling coating has reached the end of its service life the vessel or movable structure should be removed from the water and a new antifouling coating applied;
- In-water cleaning or treatment of biofouling should only be carried out using technology that does not harm the underlying coating or result in excessive release of contaminants. The capabilities of new technologies should be verified independently. Information on the suitability of particular cleaning or treatment methods can be obtained from the manufacturers of the coatings;
- When in-water cleaning involves removal of macrofouling of domestic or international origin, methods to ensure minimal release of biological material into the water should be used. In-water cleaning technologies should aim to, at least, capture debris greater than 50 micrometres ($\mu$m) in diameter, which will minimise the release of viable adult, juvenile and larval stages of macrofouling organisms. Any cleaning debris collected must be disposed of on land and in compliance with the waste disposal requirements of the relevant authority; and
- If suspected invasive or non-indigenous aquatic species are encountered during in-water cleaning or other vessel maintenance activities, the relevant authority should immediately be notified and the cleaning or maintenance activity stopped.

**Recommendations for decision making on in-water cleaning**

The Australian Department of Agriculture, Fisheries and Forestry (DAFF) provided further general recommendations about in-water cleaning in Commonwealth waters\(^8\) (DAFF 2013\(^9\)) and a decision support tool for in-water cleaning was developed. This was created to help relevant authorities making decisions about in-water cleaning practices in their jurisdictions. It will also help owners or operators of vessels and other movable structures to determine the types of information and documentation that relevant authorities may require of them to make decisions on in-water cleaning. Relevant authorities may require additional information for their risk assessment and decision making processes.

The decision on in-water cleaning is related to various aspects, including the origin of the biofouling and the type of fouling (micro- and macrofouling):

- Microfouling, regardless of origin, may be removed without the need for full containment of biofouling waste, provided the cleaning method is consistent with the coating manufacturer’s recommendations. Where microfouling is removed using a gentle, non-abrasive cleaning technique, the contamination risk is likely to be acceptable;
- Macrofouling of domestic origin may be removed without the need for full containment of biofouling waste following risk assessment by the relevant authority. If the relevant authority

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\(^8\) Commonwealth waters extend from the 3 nautical mile line (the limit of coastal waters) seaward to the 12 nautical mile line (the limit of the territorial sea).

determines containment of biofouling waste is required, the guidance provided above has to be followed. In either case, the cleaning method must be consistent with the coating manufacturer’s recommendations and contaminant discharges must meet any local standards or requirements;

- Macrofouling of regional origin may be removed without the need for full containment of biofouling waste provided the cleaning method is consistent with the coating manufacturer’s recommendations and the contaminant discharges meet any local standards or requirements; and

- Macrofouling derived from international locations should only be removed using cleaning methods that minimise release of all organisms, or parts of organisms, and anti-fouling coating debris, using the guidance described in above. The cleaning method must be consistent with the coating manufacturer’s recommendations and contaminant discharges must meet any local standards or requirements.

Should information and/or documentation required for making decisions on in-water cleaning not be available, the following default assumptions apply (as a worst case scenario):

- If the type of a coating (e.g. biocidal; biocide-free) cannot be reliably determined, then it should be assumed that the coating contains biocides;
- If the age of a coating cannot be reliably determined, then it should be assumed that the coating has reached the end of its service life;
- Where the type of biofouling on a vessel or structure is unknown, it should be assumed that macrofouling is present; and
- If the origin of the biofouling on a vessel or movable structure is unknown, then it should be assumed that it is of international origin. If the biofouling is likely to be from more than one origin category (e.g. regional and international) then decisions on in-water cleaning should be based on the most distant likely origin (i.e. international).

The decision support tool is to be used in conjunction with the main text of the DAFF anti-fouling and in-water cleaning guidelines (Figure A3.2, DAFF 2013). Australia encourages vessel owners/operators also to review the IMO 2011 Guidelines for the Control and Management of Ships’ Biofouling to Minimize the Transfer of Invasive Aquatic Species (MEPC.207(62)) for further guidance on biofouling management practices.

Exceptions to these recommendations

The DAFF (2013) guidelines also include provisions for exceptions from the recommendations, i.e.:

- The recommendations on in-water cleaning may not apply in locations where biosecurity controls have been implemented for invasive aquatic species management purposes;
- A need for in-water cleaning may arise during an emergency, to address an operational, health and safety or biosecurity hazard. Identification and handling of such situations is the responsibility of the relevant authority; and
- Decisions on situations not covered by the decision support tool are solely at the discretion of the relevant authority.

IMO BIOFOULING GUIDANCE DOCUMENT FOR RECREATIONAL CRAFT

Recognizing that all vessels can potentially transfer aquatic species, even trailered recreational craft that are normally kept out of the water, the Guidance for minimizing the transfer of invasive aquatic species as biofouling (hull fouling) for recreational craft was developed by the IMO Sub-Committee on Bulk Liquids and Gases (BLG) at its 16th session (February 2012) and this guidance document was adopted at IMO later that year. This guidance is for use by all owners and operators of recreational craft less than 24 meters in length (IMO 2012).
This IMO document provides general background information on biofouling, anti-fouling systems, peculiarities with niche areas, (in-water) cleaning and recording of biofouling activities and it is written for the owners of recreational craft.

One of the aspects being fundamentally different between commercial vessels and smaller recreational craft is that the latter are frequently taken out of water for storage or moved to other water bodies over land. Even if trailered craft is normally kept out of the water, it still has the potential to transfer invasive aquatic species from one area to another via the biofouling on the craft, its trailer or associated gear and equipment. To reduce this species introduction risk, the following measures should be followed after removing the craft from the water and before transporting it to another water body or storing it on land:

- Remove attached biofouling (e.g. seaweeds, barnacles, mussels) from the craft, gear, equipment and trailer;
- Drain hull compartments, pipework and outboard engines;
- Rinse the craft inside and outside with fresh water and, if possible, dry all areas before moving;
- Dispose of biofouling and waste water on land where it cannot drain back into the water or drains; and
- Inspect, clean and dry the trailer, gear and equipment after each journey or trip.

THE EUROPEAN SITUATION

The IMO biofouling guidelines and guidance documents could become an integral part of the EC’s Proposal for a Regulation of the European Parliament and of the Council on the Prevention and Management of the Introduction and Spread of Invasive Alien Species. This proposal will require Member States to identify the vectors of species introductions and develop management measures to avoid them spreading. It is assumed that the EU management measures for organisms moved by biofouling would be based upon the IMO guidelines and guidance documents. However, if and how the guidelines will
Figure A3.2: Decision support tool of the Australian Department of Agriculture, Fisheries and Forestry (DAFF) for in-water cleaning. For an explanation of the terms use consult the original publication (modified after DAFF 2013).
actually be implemented in the European Union is unclear. It is expected that it would be up to each national administration to identify how these guidelines are applied.

It could also be considered that the European Council develops their own guidelines for Member States on how to apply the IMO guidelines and guidance and further to develop separate biofouling guidance for ships working within the European Union and for those entering the waters of the European Union from the outside to promote harmonization of the implementation of any biofouling related measures.

CONCLUSIONS

Comprehensive Biofouling Guidelines and Guidance Documents were developed by IMO addressing both, commercial and recreational vessels. In addition, Australia and New Zealand have implemented guidelines to address the problems of species translocations with biofouling in their waters. All instruments to address biofouling have (so far) voluntary nature. However, proactive ship owners and operators may follow them.

Most of the requirements outlined in the Biofouling Guidelines and Biofouling Guidance Documents of IMO refer to documentation of anti-fouling measures and the docking situation of a vessel. These information are available for all vessels, but may today not be documented to the level of detail as suggested by these IMO documents or may not be recorded and carried by the vessel. Therefore, the requirements as set by these IMO documents could be followed so that an application of these voluntary instruments in Europe is possible. However, from interviews with European IMO delegates, it seems that the ballast water issue is clearly in the foreground so that biofouling will likely be addressed in Europe at a later stage.

Special consideration should be given to in-water cleaning. Without proper measures like collection and containment of the material removed from vessel hulls, this method may result in species introductions when organisms removed from the hull are released.

Noting that IMO addressed the ballast water issue in the beginning with voluntary guidelines and later recognized that a stand-alone convention is the more appropriate instrument, the same may also apply to the biofouling issue. This approach would give this important aspect in species translocations a much stronger recognition.

ANNEX 3 REFERENCES


IMO (2014) Anti-fouling and in-water cleaning guidelines, submitted by Australia and New Zealand to the Marine Environment Protection Committee, Session 66 as document MEPC 66/INF.23
ANNEX 4 – MODEL EVALUATION MATRICES, MODEL CATEGORIZATION, AND USE AND TRADE-OFF SUMMARY TABLES OF THE USE AND DEVELOPMENT OF INTEGRATED ECOLOGICAL AND ECONOMIC MODELS IN FISHERIES MANAGEMENT

Author: Rasmus Nielsen (DTU-Aqua)

INTRODUCTION

The Model Performance and Characteristics Matrix is used in the survey on international selected models used for quantitative and qualitative evaluation in the VECTORS project. The generic model evaluation matrix is presented together with explanatory notes for the rows in the model performance and characteristics model in Table A4.1. After this the individual model matrices is presented.

The original model matrix is developed further and additionally separated into a model categorization table including descriptors of the models and a model use and trade-off table. The first table tries to capture the characteristics of the model, the main objectives, the basic characteristics and the output. The second one describes the use of the models, i.e. academic, advice, management, and possible trade-offs, e.g. complexity, user friendliness, and distribution.

The rational is to identify key characteristics of models, which are actually widely used. Some characteristics might be not model inherent, but related to the network of the developer. A single developer, who is not yet embedded in a larger research network might have more difficulties in distributing her or his model than a large development group, which is well established and also connected to advice giving bodies. Other characteristics might be related to the programming language and the user interface. If the language is not freely available and if there is no easy user interface, then the distribution might also be limited. The present approach tries to look beyond all these single important characteristics to derive a more general understanding to be able to improve the further development of existing models, but also to make less well-known models accessible to a wider audience.

DESCRIPTION AND EXPLANATORY TEXT TO THE MODEL EVALUATION MATRICES WITH RESPECT TO THE COLLECTIVE EXPERIENCE WITH AND COLLECTIVE CONSENSUS ON THE MODELS
Table A4.1: Model performance and characteristics matrix template to collect information about individual model approaches

<table>
<thead>
<tr>
<th>Case Study / Model</th>
<th>Authors / Contact Persons*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aim:</strong> Management addressed, management objectives</td>
<td></td>
</tr>
<tr>
<td><strong>Aim:</strong> Corresponding advice needed/ addressed</td>
<td></td>
</tr>
<tr>
<td><strong>Institutional Set-up:</strong> (Bodies involved, needed partners);</td>
<td></td>
</tr>
<tr>
<td><strong>Type of Model</strong> (biol, econ, soc., long-term, short-term)</td>
<td></td>
</tr>
<tr>
<td><strong>Model Dimensions and Model Structure</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Usefulness of the Model (Pro, Cons, Problems)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Focus and Trade offs</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Data needed</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Data available Used in case study/model</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Status for application / implementation</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Model Platform and Programming Language (free, commercial)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Model output (format)</strong></td>
<td></td>
</tr>
</tbody>
</table>

1. Management addressed and/or relevant management the model can address; aim and management objectives addressed: biological or socio-economic objectives; Recipients: intended / realized management; Type of regulatory framework; Harvest rules addressed; Can the model address impact of technical measures?;

2. Corresponding Advice (biological and economic) needed: What type of advice: biological/economic/socio-economic (according to objectives, reference points, etc.)?; Which indicators are produced for advice? Time frame on short to medium term current advice and/or medium to long term strategic advice; whether and how the model has been used in advice (has it been used in relation to advice and management?); Results coming from the use and implementation of the model; Recipients: intended / realized; Other models use of output from the model?

3. Institutional set-up and platforms: This should be split up in relation to partly management/advice as here, but also in relation to who is involved and necessary to involve
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in developing, informing and implementing the model (see also needed partners below). In both cases it should indicate where and in which context the model was developed and/or used and/or where supposed to be used (should be used). Intended / realized. Has model output been validated or not?

4. Needed partners: Involved partners and/or needed partners for partly developing, informing, using and implementing the model (contributions and information from others (man., advice, science), needed partners, platforms, capacity building); Has the model been well scientific documented?

5. Type of model: Biological, Economic, Sociological, Bio-Economic, Socio-Economic. Level of integration of biology, economy, sociology of the model should be addressed. What are the links between the components, e.g. how are the economic and biological components linked to provide management advice? Also, to address this it should be informed what level and complexity of the systems the models address and was intended to address (complex or simple type model), time range in form of short to medium term advice/management or/and medium-long term strategic advice/management with respect to type of model; which level or part of the system does the model address (ecosystem/multi-species/single stock, economic system, sociological system); what spatial and temporal resolution does the model operate on; what type of model with respect to e.g. analytical tool/observation model, simulation model (scenario simulation), deterministic or stochastic model, iteration (MCMC) model, other; is the model capable of perform a projection or static scenarios)? Can the model consider uncertainty (and in given case on which parameters)?; Can sensitivity tests be performed (and in given case with which method and on which parameters)?;

6. Model dimensions and model structure: Which dimensions (e.g. fleets, species, area, season, etc.) are included in the model? What are the main components of the model? Are there separate components for, for instance, the biological and economic procedures?

7. Usefulness of the model and in which context they are useful and where detected problems (pro, cons, limitations, problems). This is mainly in respect of use and implementation but naturally also addresses the development of the models;

8. Focus and Trade-offs in what is (and can be) addressed in the models and case studies (main aim of the model and main questions to be answered and main scientific/advisory/management scenarios/options/problems to be addressed;

9. What data are accordingly needed; including specification of model variables and parameters – both endogenous and exogenous; Is it necessary to make any estimations or data processing needed before the model can be applied?

10. What data are available already; (For Europe in relation to DCF);

11. Status for the development, application, implementation and use of the model in the case studies (progress of linking biological and economic operating models or parts in the models). Have the model been used in advice and/or management? In given case how has it been used? If not, why has it not been used? Has it been used in relation to advice and/or management decisions? It is important to obtain information from the model developers on this as well as the progress and problems in this, and why it is so. There is a partly overlap in the contents of this bullet the bullets 1, 2, 3, and especially 6, but this cannot be avoided. Has the model been well documented scientifically? Is the model only developed and used for scientific purposes?

For each of the above bullets the answers are given according to a scaling of the degree / level (of the models), i.e. low, medium, high. As such each bullet (row or column) can be used as an axis in a multi-dimensional diagram showing the coverage of all the models according to this scaling.
MODEL CATEGORIZATION AND DESCRIPTORS SUMMARY TABLE A4.1

The model categorization summary Table A4.1 for each of the selected models include descriptors of the models. The summary table captures the types and basic characteristics of the models, as well as the main objectives and the output from the models. The table categorizes bio-economic models according to decision support needs of the user, i.e. the types of questions the user would be able to answer. It includes the purpose of the models and what type of information, and model we want to use to support our objective. In order to do this, the models are categorized according to a set of primary level descriptors covering management objectives and types of advice addressed. This is then further categorized according to a set of secondary level descriptors of the models covering:

- Dimensions / Structure: including stocks, fleets, spatial resolution, time step and biological structure; Complexity and Flexibility: including complexity, data need, quantitative or qualitative, flexibility, orientation (input/output), functions (endogenous/exogenous), values (market/non-market), and value chains;
- Model type: including simulation or optimization, linking or coupling between biological and economic operating models, behavioural models (tactical/strategic), parameter estimation, interactions;

The rationale is to identify key characteristics of models, which are actually widely used. The main focus has been on categorization of the bio-economic models according to management objectives and issues addressed, the management context, the model types and the extent to which biological, economic and social modules are linked. Additional focus has been placed on model dimensions and structure, data needs and available data, uncertainty and robustness, and finally how human behaviour is embedded in the models, and whether or not property rights are taken into account.

MODEL USE AND TRADE OFFS SUMMARY TABLE A4.2

The second overview and summary table describes the manner in which the models are used. This table identifies the primary uses of the models, i.e. academic, advice, management, and possible trade-offs such as complexity, user friendliness, and dissemination. The implementation aspects for most of the models have been completed in this summary table.

The extent to which any given model is used to provide management advice depends heavily on the complexity and flexibility of the model, the specialization and expertise needed to use the model, model transparency and portability, whether the model is theoretical or applied, and has a user-friendly interface. Some key characteristics of the models may not be model inherent, but related to the network of the developer. Other characteristics might be related to the programming language and the user interface.

The main trade-offs of the models and model clusters are apparent based on evaluation of the information contained in the summary tables. This includes evaluation of the trade-offs, pros and cons from the summary table with the examples extracted from the model matrices where such information is available. Among other things, the trade off evaluation relates to limitations in model use, e.g. whether a model is system specific or transportable (generic), whether it is simple or complex, whether it is specialized or flexible, whether it addresses short term tactical objectives or long term strategic objectives, and/or whether the emphasis is on biological/ecological or on socio-economic issues and aspects.

Also the summary table enable evaluation of the model use and its usefulness in relation to characteristics and trade-offs with respect to whether it is successful according to its purpose, whether “real” management decisions have actually been based on the model, and whether the model has been picked up by other users than the actual developer. If so, then what processes have led to this been happening and what sets models that are being used to inform management decisions apart from those that are not? The latter can be categorized according to user manual only, or ad-hoc collaboration, or
more formal collaboration within a dedicated course/project or a working group and whether or not new users are fully independent or the modeller is still involved in providing technical support.

Other characteristics might be related to the programming language and the user interface. If the language is not freely available and if there is no easy user interface, then the distribution might also be limited.

CONCLUSIONS

The FISHRENT, F-CUBE, BALTIC FLR, ISIS-FISH, DISPLACE and ATLANTIS models applied in the EU-FP7-Vectors of Change Project have been categorized according to a) the types of models, b) the dimensions and scales of economic models vs ecological models, c) the complexity of the models, d) the robustness of the models, e) the non-market values in the models, f) the cost- and price-dynamics in the models, and not least in the most recent period g) the use and main coverage of the models. The evaluation of the use of the models have focussed upon a) level of implementation, e.g. implementation into management advice, b) complexity and flexibility c) trade-offs, d) indicators and reference points, e) communication of results, and f) stakeholder involvement. The evaluation results are given in the individual model evaluation matrices and the summary overview tables for the selected models below.

With respect to the types of the evaluated models this among other includes categorization according to simulation type models (what if? effect evaluation of alternative scenarios) or economic optimization type models (what is best? one economic optimal solution to an object function) or both, model evaluation of biological impacts on stocks and socio-economic impacts on fisheries, types of management strategies evaluated (output or input), biological or economic dynamic endogenous parameters and exogenous variables included (profit, harvest, sea days, capacity, gross value added, employment, etc.) given some constraints and a given management type applied (output or input), deterministic or stochastic type models through implementation of uncertainty (process, observation, estimation, model, implementation), etc.

With respect to the model complexity and dimensions and scale the categorizaton and evaluation covered systems dynamics and dimensions, biological operating modules (single species / multispecies, intrinsic or extrinsic assessment or surplus production, population dynamic parameters included such as S-R, growth, maturity, mortality, migration, etc., and biological interactions / multispecies, feed-back mechanisms, external drivers and constraints such as stock abundance, nutrients, food/prey, predators, hydrographical factors, etc.), economic operating modules (single or multiple fleet/vessels, fleet and effort dynamics, capacity, fisheries dynamic parameters such as production functions for landings dynamics, price dynamics, cost dynamics, fishermen behaviour, incentives, technical interactions, feedback mechanisms, etc., and external drivers and constraints such as management, political incentives, oil price, fish price, consumer incentives, etc.).

Also the evaluation of model complexity and dimensions and scale has covered short term behaviour, long term strategic behaviour, spatial flexibility and whether the models are spatial explicit, seasonal flexible and explicit, whether they are input or output driven models (e.g. input regulation: need to include vessel / fleet activity in dimensioning; or output regulation: need to include quota and catch information on stock level in dimensioning), and with respect to management objectives, indicators and reference levels.

With respect to model trade-offs and trends a row of characteristics are obvious. The level of implementation into management advice is limited. The main reasons are likely the lack of clear formulation of use and needs for management and management questions to be addressed, lack of precise objective for using the models and the essential information needed to use the model for this is not always precisely defined. The models are generally complex and extensive data demanding models with a high number of parameters jeopardizing robustness. In general, specialists are needed to operate the models, i.e. in general not user friendly models as they have been developed mainly with research
Policy and governance synthesis as a tool for stakeholders

purpose and most often not with a primary advice purpose. The models cover both short to medium
term tactic management advice and broader long term strategic management advice.

With respect to pros, cons and trade-offs in increasing model complexity and level of detail to capture
realism in relation to purpose and use and robustness of advice generated by the models certain
features are central. The linkages between ecological and economic model parts are essential, e.g.
linked through fishing mortality (F) linked to effort. Also, it is central whether the models are fully
integrated and highly detailed dynamic coupled models with cyclic full feed-back loops or only linked to
each other where one model uses output from another model as input. Here it is important whether the
models are integrated and detailed and fully dynamic. The resources and information required to
implement the models is a major issue, i.e. the knowledge base, model and data requirements, data
availability, etc. to develop and parameterise the models. There is a trade-off according to complexity,
number of parameters, data demand, precision, use and implementation and generality of the models.
Also there are trade-offs in relation to inability to quantify uncertainty or model human behaviour
(simulation of fishermen behaviour).

Most models are multi-stock, multi-fleet, and multi-national i.e. mixed fisheries based. Also most models
are flexible and generic, and not specific to particular region. Some models are spatial explicit allowing
for marine spatial planning evaluation in relation to fishery as well as in relation to broader cross sector
marine management evaluation with respect to impact on fishery. Many of the tactic models do not have
high enough resolution in space and time to obtain realistic prediction on variability in space and time of
resources and fisheries. Only one model cover the full ecosystem (holistic models), but lack of data and
functional relationships for processes for the many parameters jeopardize precision and it can only be
used for long term strategic purposes.

Among the models evaluated the following characteristics were obvious:

- The models are multi-stock-and-multi-fleet-based considering mixed fisheries aspects
- Only 1 are going beyond multispecies into ecosystem considerations
- All incorporate socio-economic parameters
- Only 2 have high implementation
- Most of them are used in national advice frameworks
- They have been published in peer-reviewed literature
- Only 1 was judged to be user friendly
- Most of them can only be operated by the developer, but most are flexible in use
- They are all complex
- The models are relatively new
INDIVIDUAL MODEL EVALUATION MATRICES

FishRent Bio-Economic model, North Sea saithe fishery

<table>
<thead>
<tr>
<th>Case Study / Model</th>
<th>North Sea saithe fishery, FishRent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authors / Contact Persons*</td>
<td>Sarah Simons</td>
</tr>
<tr>
<td>Aim: Management addressed, management objectives</td>
<td>Bio-economic implications of alternative policies (e.g. harvest control rules, area closures) under changes in stock development (e.g. recruitment variability, species distribution) and/or changes in economic pressures (e.g. fish prices, fuel prices)</td>
</tr>
<tr>
<td>Aim: Corresponding advice needed/ addressed</td>
<td>Short, medium and long-term multi-stock and multi-fleet model. Biological advice: Median SSB values, probability of SSB being above a certain reference point, forced or stochastic recruitment possible, instantaneous age-specific fishing mortality rates. Socio-economic advice: Fleet size adjustments, Effort allocation in space and time, net profit, net present value, gross value added, crew costs.</td>
</tr>
<tr>
<td>Institutional Set-up: (Bodies involved, needed partners);</td>
<td>Further developed by the Thünen Institute of Sea Fisheries and LEI. Applied and documented within the FP7 EU Project &quot;VECTORS&quot;.</td>
</tr>
<tr>
<td>Type of Model (biol, econ, soc., long-term, short-term)</td>
<td>A multi-species, multi-fleet bio-economic simulation and optimisation model with integrated stochastic age-structured population dynamics. Species seasonal migrations to feeding and spawning grounds are included. Monthly, seasonal or annual time step possible. Short-, medium-, and long-term predictions. Resolved on ICES Rectangle level. The optimisation of net profits determines the effort adjustment and the dis- and investment behaviour of fleet segments, which in turn affect the level of catch rates and discards.</td>
</tr>
<tr>
<td>Model Dimensions and Model Structure</td>
<td>Currently five fleet segments from Germany, Denmark, France and England are included in the model. The stock development of North Sea cod and saithe are modeled explicitly. All ICES rectangles of the North Sea and Skagerrak are included and the model runs on a monthly basis. All dimensions can be enlarged or decreased. Current running time ca. 40 min. The model consist of a population dynamics module, an economic (costs and profit), policy (e.g. TAC, area closures), behaviour (dis-investment), price (fish/fuel) and interface (Catch, discard and landings calculation, effort choice) module.</td>
</tr>
<tr>
<td>Usefulness of the Model (Pro, Cons, Problems)</td>
<td>Pros: multidisciplinary tool, multi-species, multi-fleets, monthly, seasonal or annual timestep, provides valuable indicators, forced and/or stochastic recruitment can be used to analyse economic response of multiple fleet segments to changes in stock development, strongly integrates economics of the fleet, the impact from fisheries on stock development and their spatio-temporal interplay. Cons: data is needed in the right format, investment function needs to be improved, GAMS licence is needed (but for the future the aim is to re-write the model in R)</td>
</tr>
<tr>
<td>Focus and Tradeoffs</td>
<td>Focus on the strong integration of economic and biological components of the fishery system, without making the model too complex</td>
</tr>
<tr>
<td>Data needed</td>
<td>Economic data (capital, fix, variable, crew and fuel costs, fuel consumption), fish and fuel price data, landings weight/value data, spatial data, biological data (maturity, distribution, F, SSB, recruits, TSB), catch-effort data, and management data. Data must be collected in relation to the scenarios.</td>
</tr>
<tr>
<td>Data available Used in case study/model</td>
<td>IBTS survey data, ICES assessment data and EU DCF data</td>
</tr>
<tr>
<td>Status for</td>
<td>Model has been used to re-evaluate the current harvest control rule for</td>
</tr>
</tbody>
</table>
Policy and governance synthesis as a tool for stakeholders

<table>
<thead>
<tr>
<th>Application / Implementation</th>
<th>North Sea saithe (paper submitted to the ICES Journal). Further developed and applied within the FP7 EU Project VECTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Platform and Programming Language (free, commercial)</td>
<td>GAMS (license needed), R. There is a web-based version available <a href="http://www3.lei.wur.nl/fishrent/">http://www3.lei.wur.nl/fishrent/</a> but with simplified biology, the aim is to re-write the model completely in R to make it freely available</td>
</tr>
<tr>
<td>Model Output (format)</td>
<td>Catch and effort estimates per month, scenario, fleet segment, species, age class, area; costs, crew wages, revenues, profit gross cash flow and number of vessels per scenario, year, fleet segment; SSB, recruitment estimates per species, month, area; instantaneous fishing mortality rates per species, age class, month, area; probability of SSB being above a certain reference point</td>
</tr>
</tbody>
</table>

ANNEX 4 REFERENCES


FishRent Bio-Economic model, North Sea flatfish and shrimp fisheries

<table>
<thead>
<tr>
<th>Case Study / Model</th>
<th>North Sea flatfish and shrimp fisheries, FishRent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authors / Contact Persons*</td>
<td>Katell Hamon and Heleen Bartelings</td>
</tr>
<tr>
<td>Aim: Management addressed, management objectives</td>
<td>Impact on fisheries of:</td>
</tr>
<tr>
<td></td>
<td>- changes of spatial use,</td>
</tr>
<tr>
<td></td>
<td>- changes of species distribution,</td>
</tr>
<tr>
<td></td>
<td>- what if simulation of climate change</td>
</tr>
<tr>
<td></td>
<td>- ITQ management</td>
</tr>
<tr>
<td></td>
<td>- MEY optimization</td>
</tr>
<tr>
<td>Aim: Corresponding advice needed/ addressed</td>
<td>Short, medium multi-stock and multi-fleet model. Socio-economic advice: Fleet size adjustments, Effort allocation in space and time, ITQ management, MEY optimization, net profit, net present value, gross value added, crew costs.</td>
</tr>
<tr>
<td>Institutional Set-up: (Bodies involved, needed partners);</td>
<td>Further developed by LEI and the Thünen Institute of Sea Fisheries. Currently applied and documented within the FP7 EU Projects “VECTORS”, “COEXIST”, “Myfish”, and “SocioEC”.</td>
</tr>
<tr>
<td>Type of Model (biol, econ, soc., long-term, short-term)</td>
<td>A multi-species, multi-fleet bio-economic simulation and optimisation model with either a global population module or an integrated age-structured population dynamics module. The choice between biological modules can be made based on available data. Monthly, seasonal or annual time step possible. Short-, medium-, and long-term projection. Resolved on ICES Rectangle level. The optimisation of net profits determines the effort adjustment and the investment and disinvestment behaviour of fleet segments, which in turn affects the level of catch rates and discards. Trading in ITQ’s can be included. MEY optimization can be included.</td>
</tr>
<tr>
<td>Model Dimensions and Model Structure</td>
<td>Currently several segments targeting flatfish and shrimp from Netherlands, Germany and England are included in the model explicitly. All ICES rectangles of the North Sea are included and the model runs on a yearly basis. All dimensions can be enlarged or</td>
</tr>
</tbody>
</table>
Case Study / Model | North Sea flatfish and shrimp fisheries, FishRent
---|---
**Usefulness of the Model (Pro, Cons, Problems)**<br>**Pros:** multidisciplinary tool, multi-species, multi-fleets, monthly, seasonal or annual timestep, spatial resolution, provides valuable indicators, can be used to analyse economic response of multiple fleet segments to changes in stock development, strongly integrates economics of the fleet, the impact from fisheries on stock development and their spatio-temporal interplay.<br>**Cons:** investment function needs to be improved, GAMS licence is needed to run the model

**Focus and Trade-offs**<br>Focus on the strong integration of economic and biological components of the fishery system, without making the model too complex

**Data needed**<br>Economic data (capital, fixed, variable, crew and fuel costs, fuel consumption), fish and fuel price data, landings weight/value data, spatial data, biological data (maturity, distribution, F, SSB, recruits, TSB), catch-effort data, and management data. Data must be collected in relation to the scenarios.

**Data available**<br>The following data was used: IBTS survey data, ICES assessment data and EU DCF data, Catch and effort data per fishing segment and rectangle

**Status for application / implementation**<br>The model was documented in Saltz et al., 2011. Applications of the model have been developed in Coexist (2013) and VECTORS (unpublished).

**Model Platform and Programming Language (free, commercial)**<br>Combination of GAMS (commercial), R (free). There is a web-based version available (http://www3.lei.wur.nl/fishrent/) but yet without the age-structured biological module.

**Model output (format)**<br>Gdx files, graphs, R-files and SQL database

### ANNEX 4 REFERENCES


### North Sea demersal fishery, F-Cube, F-CubeEcon (FLR)

**Case Study / Model**<br>Fcube – mainly used for the North Sea demersal fisheries so far, but applications to other ICES areas are being developed

**Authors / Contact Persons**<br>Clara Ulrich*, clu@aqua.dtu.dk

**Aim: Management addressed, management objectives**<br>Fleet and métier based forecast, tailored to providing mixed-fisheries considerations to the annual ICES single-stock TAC advice. Can also be translated into effort quota, as effort is one input. Suitable for catch quotas and discards ban scenarios. Can be used to help designing flexible Harvest Control Rules to avoid conflicting single-stock management objectives.

**Aim: Corresponding**<br>Primary focus and use is on biological short/medium-term advice through scenarios simulation. An update of economic impact
<table>
<thead>
<tr>
<th>Case Study / Model</th>
<th>Fcube – mainly used for the North Sea demersal fisheries so far, but applications to other ICES areas are being developed</th>
</tr>
</thead>
<tbody>
<tr>
<td>advice needed/ addressed</td>
<td>assessment is being plugged in. The development of Fcube has been rooted the actual regional fisheries management and advice in the North Sea since 2006. It has been built as an overall flexible framework that has evolved following management questions and needs.</td>
</tr>
<tr>
<td>Institutional Set-up: (Bodies involved, needed partners);</td>
<td>Used by ICES as part of annual advice and for ad-hoc mixed-fisheries requests. The overall framework is also being used by STECF for e.g. addressing management issues of the cod LTMP. Much work done in integrating the model together with annual data updates in the DCF frame, and improving the reliability and consistency of data time series (ICES data call merging data needs for both single-stock and mixed-fisheries advice since 2012). Model integrated within several EU projects, currently mainly FP7 MYFISH and SOCIOEC.</td>
</tr>
<tr>
<td>Type of Model (biol, econ, soc., long-term, short-term)</td>
<td>Fcube estimates catch potentials for distinct fleets and metiers based on traditional catch and effort information, thus estimating the potentials for single species TAC under- or over-shoots. Initially biological deterministic short-term forecast, reproducing and building on ICES single-stock advice. Modularly extended towards stochastic medium-term simulations (single-species MSE linked with Fcube as implementation error through over/under quota catches) and economic impact assessment. Flexibility to add any user-defined parameter uncertainty in the script (e.g. catchability)</td>
</tr>
<tr>
<td>Model Dimensions and Model Structure</td>
<td>Annual and non-spatial. Unlimited number of fleets, metiers and stocks. All implemented in R/FLR scripts and functions.</td>
</tr>
<tr>
<td>Usefulness of the Model (Pro, Cons, Problems)</td>
<td>Pros : Simple principles applied, simple scripts to understand and use, standard computational power. modular and flexible R code, that has adapted to ongoing issues. Used within the current advisory system and known by clients and stakeholders. Integrated with annual data updates within ICES/STECF data calls. Full coherence between fleet data and stock data using ICES data calls and InterCatch DB. Useful for short-term investigations. Does not rely on many assumptions beyond those usual in short-term forecast. Cons : by not including fishermen behaviour assumptions, the model is not suitable for long-term analysis or optimisation. Not spatially explicit. Scripts rather than stand alone software, that needs user knowledge.</td>
</tr>
<tr>
<td>Focus and Trade offs</td>
<td>Fleet and metier based multi-stock management, as opposed to single species management. No apriori assumption on fishermen behaviour, but such module could be plugged in the script if available for the case study (e.g. RUM-based changes in effort allocation across metiers etc). No individual analysis, but specific vessels with specific fishing patterns can be addressed through specific fleets segments (e.g. Fully Documented Fleets in the North Sea)</td>
</tr>
<tr>
<td>Data needed</td>
<td>Single stock assessment and advice, but can be also adapted to stocks without analytical assessment. Fleet and metier catch and effort data as available from e.g. ICES InterCatch, STECF databases or directly from national institutes. DCF Economic data</td>
</tr>
<tr>
<td>Data available Used in case study/model</td>
<td>Much focus on integrating the model with its data flow and improving data availability and consistency. North Sea demersal as primary case study (stocks assessed within ICES WGNSSK plus some bycatch species). To be used for West of Scotland and Iberian Waters (GEPETO project) advice from 2014.</td>
</tr>
<tr>
<td>Status for application /</td>
<td>Beyond its current use, the model and its data flow are being continously developed to address further issues, such as medium-term</td>
</tr>
</tbody>
</table>
Fcube – mainly used for the North Sea demersal fisheries so far, but applications to other ICES areas are being developed. Implementation projections, economic impact assessment and inclusions of new areas and species. Model Platform and Programming Language (free, commercial) R and FLR, free, open source and platform-independent. Can be then linked and integrated in any FLR modelling. Model output (format) Outputs mainly stored as FLStocks and FLFleets objects plus additional R arrays and dataframes, that can be easily summarised and plotted afterwards, or integrated in other framework. Additional outputs of model computations can be easily provided.

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Baltic FLR Model multi-stock and multi-fleet bio-economic fishery management evaluation model coupled to the SMS multi-species model

<table>
<thead>
<tr>
<th>Case Study / Model</th>
<th>Baltic FLR Model – Coupled to SMS Fleet-based Management Strategy Evaluation for multi stocks (coupled to SMS stochastic multi-species model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authors / Contact Persons*</td>
<td>François Bastardie, <a href="mailto:fba@aqua.dtu.dk">fba@aqua.dtu.dk</a>, J. Rasmus Nielsen, <a href="mailto:rm@aqua.dtu.dk">rm@aqua.dtu.dk</a>, Morten Vinther, <a href="mailto:mv@aqua.dtu.dk">mv@aqua.dtu.dk</a>, DTU-Aqua</td>
</tr>
<tr>
<td>Aim: Management addressed, management objectives</td>
<td>Evaluation of short- and medium term fleet management with spatial explicit effort allocation for testing the robustness of long term management plans under various fishermen reactions; Biological objectives addressed in multi-species context; Fleet reaction to management can be addressed when established;</td>
</tr>
<tr>
<td>Aim: Corresponding advice needed/ addressed</td>
<td>Short and medium term, LTMP, multi-fleet based advice; Partial fishing mortalities by fishery/métier; Stock MSY advice based on multi-species interactions; Advice aimed towards ICES and EU STECF and National Administrations; Model scientific published and used in scientific research Projects, but not implemented and used in actual advice yet; Applied in EU STECF Advice Report on Baltic cod LTMP for the eastern and western Baltic cod stocks in 2011-2012.</td>
</tr>
<tr>
<td>Institutional Set-up: (Bodies involved, needed partners);</td>
<td>Development, establishment and publication of the model (scientific documentation): university and fisheries research institutes (DTU Aqua and research partners); Model published in scientific journals; Intended implementation into advice: ICES and EU STECF and National administrations; Applied in EU STECF Advice Report on Baltic cod LTMP in 2011-2012.</td>
</tr>
<tr>
<td>Type of Model (biol, econ, soc., long-term, short-term)</td>
<td>Spatial and bio-economic stochastic simulation framework which combines a spatial fishing behavior model at the ICES square resolution to spatial population availability; Short term to medium term scenario evaluation of cod stocks in a multi-fisheries context;</td>
</tr>
<tr>
<td>Model Dimensions and Model Structure</td>
<td>Multi-stock-multi-fleet: Operating with aggregation of fishing effort by fleets/metiers (e.g. EU DCF metiers). Biological OM on stock level and resource availability information from research surveys. Age based model. Seasonal explicit (quarterly basis) and spatial explicit: Need information on spatio-temporal disaggregation of the fishing activities and the resources, basically at the ICES square level.</td>
</tr>
<tr>
<td>Usefulness of the Model (Pro, Cons, Problems)</td>
<td>Cons: Calibration. Complex. Data demanding. Can only be operated by a specialist (or the model developers). Pros: Exploitation patterns specific to fleets; Economic outcomes and fishing mortality by fleets. Spatial modeling. Coupled to the SMS model accounting for trophic interactions. The model is able to integrate the combined effect of fleet, stock and management dynamics and to project the relative effect of different ‘what if’ scenarios (via performance metrics). High level of detail and data information use. Spatio-temporal</td>
</tr>
</tbody>
</table>

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Policy and governance synthesis as a tool for stakeholders

<table>
<thead>
<tr>
<th>Focus and Trade offs</th>
<th>Management Strategy Evaluation framework making use of the FLR libraries dedicated to such evaluations. Account for fleet-specific fisheries behavior scenarios including effort displacement in reaction to closure, technological creeping and entry/exit dynamics;</th>
</tr>
</thead>
</table>
| Data needed | • Multi-countries STECF/DCF landings (weight and value) and effort data per ICES rectangle  
• Capacity  
• Scientific research surveys mapping the resource  
• Gear specifications (optional)  
• Stock assessment data  
• Stomach content data and survey indices for multi-species interactions  
• Account statistics (or annual variable and fixed cost structure from EU AER)  |
| Data available Used in case study/model | The model has so far been applied by EU STECF to evaluate the consequence of the cod, sprat, and herring interlinked dynamics on the revenues of several fleets within the Eastern Baltic sea. |
| Status for application / implementation | Model developed and tested; Model published in international peer reviewed scientific journals; Model applied in advice (EU STECF); |
| Model output (format) | Partial fishing mortality by stock, effort, value of catch and profit by fleet. Usual stock indicators (R, F, SSB) calculated on multi-species assessment basis. |

ANNEX 4 REFERENCES


**ISIS-Fish Bay of Biscay demersal fishery**

<table>
<thead>
<tr>
<th>Case Study / Model</th>
<th>Demersal fishery in the Bay of Biscay / ISIS-Fish</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Authors / Contact Persons</strong></td>
<td>Stéphanie Mahévas* &amp; Michel Bertignac</td>
</tr>
</tbody>
</table>
| **Aim: Management addressed, management objectives** | Hake restoration plan  
Multiple species management plan (in discussion): Bmsy and Fmsy for Hake, Sole and Nephrops  
Spatial management measures, technical management measures can be addressed by the model |
| **Aim: Corresponding advice needed/ addressed** | quantitative comparisons of consequences of various management measures (more specifically MPA and selectivity measures) for model Hake, Sole and Nephrops using model outputs (see below) and reference points (Bmsy and Fmsy)  
the model has not yet been used in advice. We project to couple the model with SS3 for Hake in order to perform MSE. |
| **Institutional Set-up: (Bodies involved, needed partners);** | Ifremer (Nantes, Brest), some implication of economist within Benthis project  
Interactions with stakeholders within RAC and a regional project (Coselmar) |
| **Type of Model (biol, econ, soc., long-term, short-term)** | bio-economic spatially explicit model  
- length-structure population dynamics for Hake and Nephrops  
- Sole population dynamics should be included  
- fishing exploitation (métier, RUM for fishermen behavior in reaction to past and management restrictions)  
The model is deterministic but we used statistical framework mainly based on sensitivity analysis to simulate various scenarios for uncertain process (like recruitment for instance) and to provide range of variation of outputs  
a specific module of the tool is dedicated to global sensitivity analysis (Morris, LHS, etc.. methods can be easily performed) and uncertainty analysis  
10-years simulation |
| **Model Dimensions and Model Structure** | 2 species (3 in 2014), french fleets, spanish fleets  
spatial resolution: ICES rectangle  
temporal resolution: month  
Area: 8a and 8b (Bay of Biscay) |
Policy and governance synthesis as a tool for stakeholders

Case Study / Model | Demersal fishery in the Bay of Bisacy / ISIS-Fish

Usefulness of the Model (Pro, Cons, Problems)

- reproducing spatial interactions between marine populations and fishing activities (technical interactions, bycatch, discards, ...)
- standardizing fishing effort (through technical characteristics, fishing behavior, ...)
- anticipating fisheries dynamics and status when changing management;
- better understanding of the fisheries;
- uncertainty analysis to assess the robustness of the measure to reach management objectives

difficulties to estimate accessibility

Focus and Trade offs

- focus on hake and nephrops

Data needed

- Fish biology and life traits, state of the studied stocks, fish and fishing areas, fishing activity, management options. All these parameters are estimated outside the model using logbooks, VMS, scientific survey, ICES evaluations.

Data available

- except for accessibility and some economic parameters (cost at métier scale), data needed are available

Status for application / implementation

- calibration in progress, should be operational in June 2014

Model Platform and Programming Language (free, commercial)

- ISIS-Fish (free) in Java

Model output (format)

- Biomass per length group, per rectangle, per month
- Catch per métier, per fleet, per rectangle, per month
- Discards per métier, per fleet, per rectangle, per month
- F per métier, per fleet, per rectangle, per month
- Total F
- Revenues per métier, per fleet, per month or per year (net or gross)
- Various indicators derived from above variables (csv files)

ANNEX 4 REFERENCES


Mahévas, S., Bertignac, M. Mehault, S., Zimmerman, F. (In prep) Consequences of change in selectivity versus the establishment Marine Protected Areas on the hake-Nephrops fishery in the Bay of Biscay
### ISIS-Fish Bay of Biscay pelagic fishery

<table>
<thead>
<tr>
<th>Case Study / Model</th>
<th>Pelagic fishery in the Bay of Biscay /ISIS-Fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authors / Contact Persons*</td>
<td>Sigrid Lehuta*, Youen Vermard, Stéphanie Mahévas &amp; Pierre Petitgas</td>
</tr>
</tbody>
</table>

**Aim: Management addressed, management objectives**

- Anchovy management plan and spatial and seasonal closures
- Multiple species trade off: fishery targeting Anchovy, sardine, seabass and tuna sequentially.

**Aim: Corresponding advice needed/ addressed**

Quantitative comparisons of the consequences of various management measures (more specifically MPA and harvest control rules) for anchovy

**Institutional Set-up:**

- Ifremer (Nantes), implication of biological oceanographers on larval dispersion and economists particularly regarding fuel costs.
- Interactions with stakeholders within a regional project (PPDR)

**Type of Model**

Bio-economic multi-fleet, multi-species spatialised model.
- Spatially interacting fish and fishing dynamics.
  - Matrix model for anchovy (stage-structured)
  - Surplus production models for seabass, sardine and tuna
  - Random utility model to predict effort distribution on métiers in reaction to management

**Focus on short- to medium-term forecasts (10 years).**

**Model Dimensions and Model Structure**

- 4 species, 5 populations
- 4 french fleets (pelagic trawlers and purse seiners), 1 spanish fleet (purse seiners)
- Spatial resolution : ½ ICES rectangle (0.5° x 0.5°)
- Temporal resolution : month
- Area : 8a, b and c (Bay of Biscay)

**Usefulness of the Model (Pro, Cons, Problems)**

- Usefulness :
  - anticipating fisheries dynamics and status when changing management;
  - better understanding of the fisheries;
  - uncertainty analysis to assess the robustness of the measure to reach management objectives

**Difficulty to predict Anchovy recruitment and spatial distribution.**

**Focus and Trade offs**

- Focus was made on Anchovy biology and spatial dynamics in relation with the evaluation of spatial closures. Time series of spatialised lavae survival obtained from a bio-physical model of larval drift, growth and survival were used to force the model and improve the description of recruitment variability.
- Low level of details on the other populations (no spatialisation, surplus production models).
- Emphasis was also put on the choice of métier (target species and area of practice) in reaction to the regulatory, ecological and economic context, through the first integration of random utility models in the simulator.

**Data needed**

- Fish biology and life traits, state of the studied stocks, fish and fishing areas, fishing activity, management options

**Data available Used in case study/model**

- Logbooks, VMS, scientific survey, ICES assessment reports, outputs of bio-physical model.
- Except for accessibility and some economic parameters (cost at métier scale), data needed are available.

**Status for application /**

- The model was used to evaluate recovery plans for anchovy as well as to identify robust indicators of management impact. Results were...
Case Study / Model: Pelagic fishery in the Bay of Biscay /ISIS-Fish

**Implementation**
disseminated within the scientific community only so far. Intention is to propose the model for use in RACs and STECF.

**Model Platform and Programming Language (free, commercial)**
ISIS-Fish (free) in Java

Database available: http://www.isis-fish.org/download.html /Pelagic fishery of the Bay of Biscay

**Model output (format)**
Time series of:
- Abundance/Biomass per age group, per area, per month
- Catch per species, per métier, per fleet, per area, per month
- Revenues per métier, per fleet, per month or per year (net or gross)
- Various indicators derived from above variables (csv files)

**ANNEX 4 REFERENCES**


**ISIS-Eastern English Channel (7D)**

Case Study / Model: Eastern English Channel (7D)

**Authors / Contact Persons**
Sigrid Lehuta, Loïc Gasche, Stéphanie Mahévas, Paul Marchal

**Aim: Management addressed, management objectives**
- Harvest Control Rules for Sole, Plaice, data-limited species
- Catch quota, multi-species evaluations, discard reductions
- Simulate interactions between human activities (fishing, sediment extraction, windfarms)
- Spatial management measures
- Identify management scenarios providing higher robustness to uncertainties.

**Aim: Corresponding advice needed/addressed**
Quantitative comparison of management scenarios and evaluation of associated robustness.
This model does not aim at replacing current stock assessment measures. It is set up as a tool supporting stock assessment and giving a broader scale to the evaluation.

**Institutional Set-up:**
(Bodies involved, needed partners)
IFREMER (Nantes, Boulogne-sur-Mer), institutions involved in the vectors and Socioec projects. Implication of economists and some stakeholders within the Socioec project.
**Case Study / Model**  
**Eastern English Channel (7D)**

<table>
<thead>
<tr>
<th><strong>Type of Model</strong> (bion, econ, soc., long-term, short-term)</th>
<th>Bio-economic multi-fleet, multi-species spatialised model. Spatially interacting fish and fishing dynamics. Matrix models for fish populations (age-structured) Predictive models of effort distribution on métiers (gravity models and Random Utility models under development) for fleet dynamics Focus on short- to medium-term forecasts (10 years).</th>
</tr>
</thead>
</table>

| **Model Dimensions and Model Structure** | Eastern English Channel (ICES area 7D)  
Temporal resolution: month  
In order to rationalise complexity, 2 biological models, aiming to address different management questions, are currently in development in parallel and aim at being combined in the future:  
- Impact of fishing and aggregate extraction on flat fish and habitats  
Spatial resolution: 0.125° x 0.125° cells (1/32nd of an ICES statistical rectangle)  
Species: Sole and Plaice (age-structured), proxies for Benthic communities dynamics  
- Multi-species evaluation of management measures from the new FCP  
Spatial resolution: 0.25° x 0.25° cells (1/8 of an ICES rectangle)  
Species: Sole, Plaice, Cod, Whiting, Scallops, Seabass (age-structured), Squid.  
Fleets: French fleets operating with bottom trawls, nets, beam trawls and dredges in the Eastern channel |

| **Usefulness of the Model (Pro, Cons, Problems)** | Usefulness:  
- Better understanding of spatial interactions between activities and populations  
- Evaluation of management measures including technical and spatial measures (Management Strategy Evaluation)  
- Evaluation of robustness of proposed management strategies  
- Outputs comparable to those of stock assessment working groups.  
Weaknesses:  
- Complexity (particularly due to spatial aspects) and associated simulation duration  
- Need for hypotheses on spatial distribution of fish populations |

| **Focus and Trade-offs** | Focus is on spatial interactions between uses and resources:  
- Benthos, flat fish, fishing and aggregate extraction in the first case  
- Demersal fish and fishing activities in the second case  
Trophic relationships and other causes of mortality (other fleets) are not explicit but rather included as external mortality factors or increased area attractivity.  
Benthos communities are represented at highly aggregated level (biomass pool).  
Variability at individual level is not considered (neither for fish or fisherman). |

| **Data needed** | Fish biology and life traits, state of the studied stocks, fish population and fishing areas, fishing activity, management options, position and |
Policy and governance synthesis as a tool for stakeholders

<table>
<thead>
<tr>
<th>Case Study / Model</th>
<th>Eastern English Channel (7D)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>intensity of other activities occurring in the area. Assessment reports, scientific surveys, log-book data.</td>
</tr>
</tbody>
</table>

| Data available Used in case study/model | Data needed is generally available, but not always at the scale that is needed for the model (spatial distribution of populations: known only at the time of the scientific surveys, economic data: available at annual scale). Accessibility of fish population to fishing is usually unknown and calibrated. |

| Status for application / implementation | - Non-spatial management measures tested on an early version of the model  
- Calibration, sensitivity and uncertainty analysis methods has been specifically developed to be adapted to such complex model  
- Calibration of the models in progress. |

| Model Platform and Programming Language (free, commercial) | ISIS-Fish (Java, free) http://www.isis-fish.org/en/index.html |

| Model output (format) | Time series of:  
- Abundance/Biomass per species, per age group, per area  
- Catch per species, per métier, per fleet, per area  
- Discards per species, per métier, per fleet, per area  
- F per species, per métier, per fleet, per area  
- Revenues, per fleet, per métier  
- Profits, per fleet, per métier (csv files) |

ANNEX 4 REFERENCES

Gasche L., Mahévas S., Marchal P. (In Press) Supporting fisheries management by means of complex models: can we point out isles of robustness in a sea of uncertainty?

Gasche L., Lehuta S., Mahévas S., Marchal P. (In Prep.) Can spatial management of human activities help robustly reaching management goals?


DISPLACE Individual Vessel Based multi-fleet and multi-stock Bio-Economic Model

<table>
<thead>
<tr>
<th>Case Study / Model</th>
<th>DISPLACE, a dynamic, individual based model for spatial planning and fishing effort displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authors / Contact Persons*</td>
<td>François Bastardie, <a href="mailto:fba@aquadtu.dk">fba@aquadtu.dk</a> , J. Rasmus Nielsen, <a href="mailto:mi@aquadtu.dk">mi@aquadtu.dk</a> , DTU-Aqua; <a href="http://www.displace-project.org">www.displace-project.org</a></td>
</tr>
</tbody>
</table>
| Aim: Management addressed, management objectives | Evaluation of short- and medium term fleet and vessel-based management on effort allocation, cost- and energy efficiency according to management plans;  
Biological objectives addressed;  
Maritime spatial planning and bio economic consequences of fishing effort displacement can be addressed when estab-lished; |
| Aim: Corresponding advice needed/ | Short and medium term, LTMP, multi-fleet and multi-stock based advice on efficient effort allocation: Partial fishing mortalities by fishery/métier/vessel given efficiency in effort allocation; |
**Case Study / Model** | **DISPLACE, a dynamic, individual based model for spatial planning and fishing effort displacement**
---|---
**addressed** | Advice aimed towards ICES and EU STECF and National Administrations; Model scientific published and used in scientific research projects but not applied, implemented and used in actual advice yet; **Institutional Set-up:** (Bodies involved, needed partners): Development, establishment and publication of the model (scientific documentation): university and fisheries research institutes (DTU Aqua and research partners); Model published in scientific journals; Intended implementation into advice: ICES and EU STECF and National administrations; **Type of Model** (biol, econ, soc., long-term, short-term) | Spatial and individual vessel based bio-economic simulation framework which combines a spatial fishing behavior model at high resolution and spatial population models; Short term to medium term scenario evaluation of multi-stock and multi-fisheries ecological-economic systems; Need detailed information on spatio-temporal disaggregation of the fishing activities, the resources and possibly the various utilizations of the sea. **Model Dimensions and Model Structure** | Operating with individual vessels belonging to fleets and fisheries (e.g. EU DCF metiers), Biological OM on species and stock level covering several stocks (in e.g. mixed fisheries) with high resolution spatio-temporal abundance and resource availability information from research surveys. Length and age based model. **Usefulness of the Model (Pro, Cons, Problems)** | Cons: Complex model that needs very detailed data; Need some computational power and programming skills to be operated; Difficulties in accessibility of data, high complexity and uncertainty in the parameterization e.g. data and processes with various time and spatial scales. Pros: Bi-directional model i.e. account for fish and fishermen reactions in the assessment of management actions; Highly spatially resolved; Make use of the newly available information such as VMS data; Parameterization facilitated by a set of routines written in the R language. **Focus and Trade offs** | IA and possibly MSE of MPs with respect to effort allocation, energy use and cost-efficiency in the catching sector; Account for biological and economic incentives/logics in fisheries behavior via decision choice modeling; Computation of a variety of economic indicators of interest for fisheries sustainability, particularly regarding fuel consumption; Legitimate approach in the current regulation context that promotes the development of marine protected areas and individual quotas. **Data needed** | • High resolution catch (weight and value) and effort from trip based log-book information and Satellite VMS information (i.e. logbook coupled to VMS data). • High resolution resource availability data from e.g. disaggregated research survey or combined fishery information on disaggregated resource availability (at least on ICES Square). • Stock assessment and fishbase data. • STECF landings data per ICES square. • Various maritime spatial uses. **Data available Used in case study/model** | The model has been used so far to evaluate the efficiency of effort allocation scenarios on the whole Danish fisheries based on logbooks, VMS, EU DCF, and STECF data coupled to the dynamic of a range of North Sea and Baltic Sea commercially important species. **Status for** | Model developed and tested; Model published in international peer
ANNEX 4 REFERENCES

www.displace-project.org


**ATLANTIS – Baltic Sea**

<table>
<thead>
<tr>
<th>Case Study / Model</th>
<th>The Baltic Sea ATLANTIS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Authors / Contact Persons</strong></td>
<td>Artur Palacz (<a href="mailto:arpa@aqua.dtu.dk">arpa@aqua.dtu.dk</a>), J. Rasmus Nielsen (<a href="mailto:rm@aqua.dtu.dk">rm@aqua.dtu.dk</a>), Asbjørn Christensen, Henrik Gislason, Francois Bastardie</td>
</tr>
<tr>
<td><strong>Aim: Management addressed, management objectives</strong></td>
<td>Understanding the trade-offs in analyses and evaluation of fisheries management strategies such as spatial closures under scenarios of change in climate, eutrophication and fishing pressures. The model will address both the fish stock biological and broader socio-economic objectives behind strategic marine spatial planning and adaptive ecosystem-based fisheries management.</td>
</tr>
<tr>
<td><strong>Aim: Corresponding advice needed/ addressed</strong></td>
<td>The aim is to understand the broader cyclic feedback between the ecosystem and the anthropogenic pressures in relation to marine spatial planning. The model output will provide long and medium term strategic advice concerning closed areas for fishing, windmill parks, large marine constructions, Natura 2000 areas, or evaluating ecological indicators relevant to EU MSFD (&amp; DK WFD). Model results include estimates of net biological production of pelagic and benthic groups, and fisheries catch and revenue by fleet. The model results can be linked to e.g. physical-biological, bio-economic and socio-economic models (ERGOM, IBM DISPLACE, etc).</td>
</tr>
<tr>
<td><strong>Institutional Set-up: (Bodies involved, needed partners);</strong></td>
<td>Model developer: B. Fulton, CSIRO Mar. Res., Hobart, (AUS). Model implementation in the Baltic Sea: DTU-Aqua (University of Hamburg (D), Aarhus University (DK) and CSIRO) under the EU FP7 Vectors of Change project and the Danish Strategic Research Council IMAGE/MAFIA project together with data contributions from e.g., HELCOM, Baltic NEST institute, Stockholm Resilience Center, Finnish Game and Fisheries Research Institute.</td>
</tr>
<tr>
<td><strong>Type of Model (biol, econ, soc., long-term, short-term)</strong></td>
<td>End-2-End Bio-Geo-Chemical Model with a hydrodynamic module, several pelagic and benthic ecosystem modules, fisheries management module and a broader socio-economic module. It covers the whole marine ecosystem, and it can fully integrate biological, social and economic aspects of the management cycle. Links between different components are dynamic and spatially (horizontal polygons, vertical layers) and seasonally explicit and are based on two-way coupling. It is a highly complex deterministic model. However, the user has the flexibility to choose among multiple modules of varying complexity including choice of different functional responses. The multi-species interactions are non-linear across all trophic levels resolved by age and stock structure. There is a detailed exploitation module which includes dynamics of fishing fleets, effort allocation and selectivity. Due to the modular construction management evaluation can involve different agents (e.g. also...</td>
</tr>
</tbody>
</table>
### Case Study / Model

The Baltic Sea ATLANTIS

- tourism, transport and energy).

### Model Dimensions and Model Structure

The Baltic model resolves processes in three spatial dimensions based on 29 polygon-shaped boxes delineated across up to seven vertical layers. Temporal resolution is flexible (days to quarters). We define 33 biological functional groups (species/groups from bacteria and phytoplankton to fish, seabirds and marine mammals). There are separate but fully coupled biological and socio-economic procedures / modules.

### Usefulness of the Model (Pro, Cons, Problems)

Medium to long term strategic management strategy evaluation to analyse trade-offs and in which direction the systems tend to move towards given different management options. Cannot provide statistical robust short-term projections for ecosystems states and key species. Model forces: flexibility of options for processes of predation, reproduction, growth, gape limitation, migration, invasive species, etc. as well as processes for monitoring, assessments, indicators, and fisheries economic analysis. Model limitations: Complexity and the large number of parameters complicate model informing (long build-up time hindered by cumbersome parameterization). Lack of balancing routines makes the process of model calibration long. Model simulations of scenarios potentially computationally demanding.

### Focus and Tradeoffs

Useful framework to combine management input (i.e. what can we do) with a biophysical ecosystem model (i.e. what do we know) that captures key uncertainties. In a policy context, both the management input and the ecosystem model are then subject to the values of the public (i.e. what do we care about). On a strategic level the model is good for visualizing, for instance, trade-offs between harvest maximization and ecosystem structure.

### Data needed

- Being the most complex marine ecosystem model it requires much data ranging from physical and biogeochemical concentrations and fluxes, through life history parameters and population abundance and distribution, up to information on fishing fleet dynamics and economic value of ecosystem goods and services.
- Dimensions/Groups: See above, Type of Model and Dimensions.
- Hydrographical variables and parameters: Fields, fluxes, bio-geochemical processes, nutrient cycles (T, Sal, Oxygen, N, etc., etc.);
- Biological variables and parameters: Biomass, production (growth, reproduction, fecundity), diet (consumption, etc.), mortality (predation, fishery), migration, motility, habitat association, habitat dependency, etc. for different species and groups;
- Fisheries parameters: Effort, catch, revenue, etc. for different fleets and fisheries (metiers);

### Data available Used in case study/model

- No model results are yet available. As far as data used as model inputs are concerned, they are available from a number of sources.

### Status for application / implementation

ATLANTIS has already been developed and applied in a number of marine ecosystems. The Baltic implementation is in an advanced stage. Currently, the model is being informed with data available from in situ and remote sensing monitoring, and where applicable, with results from previous or parallel modelling studies.

### Model Platform and Programming Language (free, commercial)

ATLANTIS is written in C++ programming language. The model code is available from CSIRO Marine research upon request to Beth Fulton, under the terms and conditions set by CSIRO.

### Model output (format)

Model output will be available in the standard large oceanographic data format of NetCDF. However, specific data requests will be processed to make results available in csv or xls format if needed.
ANNEX 4 REFERENCES


IMAGE/MAFIA Project. Integrated management of agriculture, fishery, environment and economy. Danish Council for Strategic Research. Project IMAGE 09-067259/DSF.

J. Rasmus Nielsen, Artur Palacz, Asbjørn Christensen, Henrik Gislason, Kerstin Geitner, Francois Bastardie (DTU-Aqua), Marc Hufnagl (University of Hamburg), Marie Maar (Aarhus University - Bioscience), Martin Lindegren (Scripps Institute of Oceanography). The Baltic ATLANTIS Model: Modules (physical, biological, management) - Application, implementation and scenario testing. Oral presentation. EU-FP7-Vectors of Change Project, WP IMAGE/MAFIA project Annual Meeting. September 2013, Dragør, Denmark.


### INDIVIDUAL MODEL CATEGORIZATION AND DESCRIPTORS SUMMARY TABLES

#### FishRent, North Sea Saithe, North Sea Flatfish, and Western Waters

<table>
<thead>
<tr>
<th>Category of Models</th>
<th>Modules</th>
<th>Value Chain</th>
<th>Functionality</th>
<th>Behavioural/Non-Functional</th>
<th>Non-market</th>
<th>Econ</th>
<th>Tactical</th>
<th>Strategic</th>
<th>Input/Output</th>
<th>Recruitm.</th>
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<th>Prices</th>
<th>Costs</th>
<th>Market</th>
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### Baltic FLR

<table>
<thead>
<tr>
<th>Primary Level Descriptors</th>
<th>Categories and Types of Models</th>
<th>Structure Spatial Resolution Data</th>
<th>Structure Quantitative Complexity Fleets Qualitative Orientation</th>
<th>Value Chain Values Coupling Parameter (Output) Functions</th>
<th>Modules Model Estimation Optimization Behavioural Models</th>
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<tr>
<td>Full fishery</td>
<td>Single Spec.</td>
<td>TAC, Mix. Fishery</td>
<td>TAC, Multi-Species Fish Community/County</td>
<td>TAC, National/International</td>
<td>TAC, Cross-Sector/Regional/Cross-Border</td>
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<td>VMS Track Stock</td>
<td>Stock Subarea Stock Area Region Ecosystem Season Year Multiple years Age Size Biomass Simple Complexity High Non-marketing</td>
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<td>TAC, National/International</td>
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### ISIS-FISH

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<th>Primary Level Descriptors</th>
<th>Categories and Types of Models</th>
<th>Structure Spatial Resolution Data</th>
<th>Structure Quantitative Complexity Fleets Qualitative Orientation</th>
<th>Value Chain Values Coupling Parameter (Output) Functions</th>
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### DISPLACE

<table>
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<tr>
<th>Model Type</th>
<th>Policy and governance synthesis as a tool for stakeholders</th>
<th>Level</th>
<th>Descriptors Secondary</th>
<th>Categories</th>
<th>Types of Models and of Models</th>
<th>Structure Spatial Resolution and Structure Time Resolution</th>
<th>Biological Structure Coupling</th>
<th>Parameter Modules (Output)</th>
<th>Functions</th>
<th>Complexities Fleets Flexibility (generic/specific)</th>
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### Baltic ATLANTIS

<table>
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<tr>
<th>Model Type</th>
<th>Policy and governance synthesis as a tool for stakeholders</th>
<th>Level</th>
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DELIVERABLE 60.6 Page 123 VECTORS
## COMPILED MODEL USE AND TRADE OFFS SUMMARY TABLE

Model use overview according to main coverage of use and types of use, as well as major trade offs in relation to the use.

<table>
<thead>
<tr>
<th>Model</th>
<th>Model Use and Type of Use</th>
<th>Main Coverage of Use</th>
<th>Management Advice</th>
<th>Level of Implementation</th>
<th>Level of Model Development</th>
<th>Trade-offs</th>
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<tbody>
<tr>
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<td>Data Coll. Sing.</td>
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<td>Data/Costs</td>
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</table>

**Explanation:**
- Model Use and Type of Use: Data Collection, Data/Costs, Single stock, Multi-species, Fishery, Mixed Fisheries (TAC, Effort, Profit, Revenue, of TAC, Annual Value, Revenue, Socio-Econ, Other)
- Main Coverage of Use: Explanation: Academic, Applied
- Management Advice: Implementation and purpose, Academics, Purpose, Applied
- Level of Implementation: Level of development and implementation, fully integrated or not
- Level of Model Development: Implementation and purpose, Academics, Purpose, Applied
- Trade-offs: Academic, Purpose, Applied

**Explanation, Academic:**
- P: Published, Updated in peer-reviewed literature
- R: Published, Updated in review
- F: Published, Updated in food

**Explanation, Trade-offs:**
- Academic: Open-access, software implementation, Closed Model, and Free ware, licenses, software needed
- Implementation and purpose: Academic, Purpose / Applied in advice [Level of development and implementation, fully integrated or not]
ANNEX 5 – SUPPORTING FISHERIES MANAGEMENT BY MEANS OF COMPLEX MODELS: CAN WE POINT OUT ISLES OF ROBUSTNESS IN A SEA OF UNCERTAINTY?

Authors: Loïc Gasche, Stéphanie Mahévas, Paul Marchal (IFREMER)

INTRODUCTION

The Eastern Channel is a very important area because of its high biodiversity and the many fisheries it sustains [1], the most emblematic being the flatfish fishery. Sole (Solea solea) is one of the most economically valuable flatfish species in this area [2]. Fishing mortality applied to sole being high [3], there are risks that the sole population may be over-harvested. This may have critical consequences for the sole population, bycatch species and the economic viability of fishing vessels. The level of risk is highly dependent on the level of fishing effort, but also on our level of knowledge on environmental and biological parameters. For instance if natural mortality (a parameter that is usually very difficult to determine) is higher than what is commonly deemed to be the correct value, then fishing mortality is overestimated and fishing regulations will not have the expected impact.

The ICES (International Council for the Exploration of the Sea) stock assessment working groups have traditionally dealt with uncertainties by means of a precautionary approach. When possible a limit spawning biomass and/or fishing mortality are defined, beyond which the risk of recruitment impairment is high [4]. In addition, more conservative reference points have also been defined, based on a precautionary approach (PA points). These PA points aim to prevent reaching the critical limit, despite uncertainty in the ecosystem state or in the fishing effort [4]. Total Allowable Catches (TACs) should be adjusted yearly depending on the estimated state of the stock so that these limit reference points are not reached.

Even if flatfish populations in this area have been studied in depth, many uncertainties remain concerning their biology, their dynamics, or the fishing pressure they are subject to. Therefore, current management cannot guarantee that management goals will be reached. Indeed, the method currently used by ICES working groups does not explicitly take uncertainties into account and is only based on past ecosystem states, not anticipating situations that have not been observed yet. One possible way to circumvent these limitations is to model the ecosystem of interest and our uncertainties on ecosystem parameters, then to test the performance of management measures. If management measures can be found that always allow reaching management goals, then such management measures can be considered robust to uncertainties. In this paper, we propose to determine whether simple changes made to current management measures can allow reaching management goals with a higher robustness to uncertainties.

Uncertainties and risks have been increasingly taken into account in fisheries management since the beginning of the 1990s [5,6] and now pervade modern fisheries management [7]. Many methods dealing with risks in fisheries management have been developed and have been reviewed in [8] and [7]. Most quantitative methods are based on a Bayesian approach, as advocated in [9-12]. This probabilistic approach is based on the use of available a priori information on the shape of probability density functions that are attributed to model parameters.

However, using probability density functions is possible only if enough knowledge is available to estimate them precisely; otherwise it only amounts to adding more uncertainties to the model. This is especially the case with complex ecosystem models where sources of uncertainty [6,13-15] impacting model outputs are even more difficult to identify, as the number of modelled processes increases. In addition, ecosystems are usually complex, nonlinear and strongly influenced by poorly known ecological variables [16,17]. Among these systems, marine ecosystems have enormous biological uncertainty [9] and exploited populations in general are known to exhibit large levels of natural variability [18]. Therefore, in some cases it may not be possible or desirable to give probability density functions to model parameter values when dealing with such ecosystems.
Choosing to not define probability density functions makes the use of methods commonly used to deal with risk less tractable. However, methods have been developed within Decision Theory that aim at allowing decision making under severe uncertainty. One of these methods is the information-gap decision theory [19,20]. The info-gap method has started to permeate ecological modelling, with recent applications to conservation [21-23]. However, these practical applications have so far been restricted to rather simple models with analytical solutions and many limitations of this approach have been evidenced [24-25].

To determine whether management measures can allow robustly reaching management goals for sole and plaice (Pleuronectes platessa) in the Eastern Channel, we build an ISIS-Fish [26-29] model of ICES area 7D. This spatialized fisheries dynamics model allows us to represent both fish populations and fleets targeting them, and model management scenarios. From this model, we apply a method based on decision theory so as to find out if management goals on these species can be reached despite uncertainties. First, the input parameters space of our model is explored by means of sensitivity analysis techniques. This allows us to identify and rank parameters that most influence model outputs and whose uncertainty should be tested against management measures in priority. Once enough model runs have been performed, we split combinations of model parameters between those giving output variables equal to or above our management goals and those that do not allow reaching management goals. So as to identify combinations of management parameters and ecological parameters needed to reach management goals, supervised classification is performed by means of classification trees on the dataset obtained with sensitivity analysis. This classification allows us to identify management parameter values that are most desirable so as to reach management goals, and what level of uncertainty on environmental parameters can be tolerated without compromising the achievement of management objectives.

CASE STUDY DESCRIPTION AND MODEL EVALUATION

ISIS-Fish

ISIS-Fish was designed to simulate and evaluate policies in the context of mixed fisheries (multi-species multi-fleet fisheries) and to take into account the spatial and seasonal heterogeneities in the distribution of resources and fishing activities [28]. This fishery model is based on three submodels: (i) a fishing activity dynamics model, (ii) a population dynamics model and (iii) a management dynamics model. Each submodel is spatially and seasonally explicit, with a monthly time step. The three submodels interact only if they overlap in space and time. The modelled area is represented by a grid, the resolution of which, in latitude and longitude, is chosen with respect to the dynamics being described and the available knowledge of the studied fishery. Within this region, zones (i.e. sets of contiguous grid cells) are defined independently for each population, each fishing activity, each management measure. Seasons are defined as sets of successive months. It is also possible to take into account fish price as well as fixed and variable costs in ISIS-Fish [27] to better model fishers behaviour. In our model, fish price is the only economic variable needed to determine the choice of fishing areas.

The Eastern Channel

Twenty-six exploited species can be found in the Eastern Channel, but also feeding, spawning and nursery grounds, as well as migration routes. Most catches come from the French and the English fleets, the English fishing activity having decreased a lot in the past decades with only a few ports maintaining a fishing fleet on the South-Eastern coast of England. On the contrary, the French fleet in this area still comprised 641 ships in 2005 that landed more than 90000 tons of fish, worth 218M euros [30]. The harbour of Boulogne-sur-Mer is the biggest fishing harbour in this area (ICES area 7D) with 171 active fishing vessels in 2009 [31]. The majority of landings are demersal species, especially common sole, scallops and whiting. Plaice is an important bycatch of fishing vessels targeting sole and...
is also directly targeted by fleets from the Netherlands and Belgium. Sole and plaice are mostly caught by beam-trawlers and netters.

Populations of sole and plaice are managed by means of TACs which build to some extent on catch limits recommended by ICES. Until the end of 2010 these catch limits aimed to keep the fishing mortality below precaution fishing mortality ($F_{pa}=0.4$ for sole and $F_{pa}=0.45$ for plaice). In 2011 a transition framework to maximum sustainable yield (FMSY) was implemented. This transition framework is based on a harvest control rule (HCR) spanning a 5-year period. The goal is to reduce the fishing mortality from current levels to the fishing mortality providing the maximum sustainable yield (FMSY). So as to reach FMSY by the end of the HCR, the level of fishing mortality tolerated (and therefore the associated catch limit) is progressively decreased from $F_{2010}$ to FMSY. Year-to-year variation in catch limits is bounded to 15% [4].

**The Eastern Channel model**

This study is based on an ISIS-Fish model of the English Channel by [32]. This model is deterministic: a given set of parameter values always gives the same values for the output variables. We performed 10-year simulations so as to model a 2008-2017 period that encompasses the 2010-2015 period of the ICES transition framework to MSY. This allows us to force some input parameter values to their estimated value for the first three years modelled (2008-2011) and then test transition scenarios and determine their consequences on the ecosystem.

**Exploitation**

This model focuses on the French flatfish fishery. Only French gillnetters and English or Belgian beam trawlers are explicitly taken into account and the modelling assumption is made that the travelling time from their home harbour to fishing grounds is negligible. It is considered that they fish all year long in ICES areas 7D and 7E and fleet (i.e. group of boats with same characteristics belonging to the same harbour) parameterisation is the same for both areas. They target sole (*Solea solea*) and their main bycatch is plaice (*Pleuronectes platessa*). An important notion when defining fishing activities in ISIS-Fish is that of métiers. For a given fishing vessel and a given month of the year, the métier practised by the vessel is defined by the gear used, the target species and the fished area [33,34]. Some fishing units have the same métier all year long, others change of métier (i.e. change of fishing area and/or gear and/or target species) depending on the season. A succession of métiers in a year defines a fishing strategy. Métiers, as well as entire fishing strategies can be common to groups of vessels. Fishing units with the same fishing trip duration, the same number of trips per month and belonging to the same harbour belong to the same fleet [28]. Notions of fleet and métier are not totally correlated; a given métier can be common to ships belonging to various fleets. Métiers, fishing strategies as well as fleets are defined based on real data (e.g. commercial logbook data, fishers interviews, observer data, etc.), the level of detail depending on the available information and the modeller's needs [29]. In our model métiers parameterisation differs between ICES area 7D and ICES area 7E, but in general trawlers target both species with almost the same intensity while netters clearly focus on sole. These two species are the only ones explicitly represented in the model, other species caught by this fishery being grouped together in a single group. Our goal being to study flatfish fisheries, we are mostly interested in the Eastern Channel (ICES area 7D). However, fishing activities and fish stocks in the Eastern and Western part of the Channel being linked, we chose to model both areas and emphasize results obtained on the Eastern Channel. In our model, fishers select their métier dynamically by means of a gravity model. The attractiveness of each choice is estimated yearly from fishing habits and past outcomes of the fishery [27]. Once the catch limit has been reached for a species a set of conditions are applied in an attempt to realistically model fishers' behaviour: for a given métier i) if the species only is a bycatch species then fishing goes on and this species is discarded, ii) if the species is the target species then the métier stops and fishers look for another métier for the remaining months of the year. The choice of an alternative métier depends on the ease of implementation of the métier: métiers within
the same strategy (i.e. monthly choice of métiers for a fleet during the year) using the same gear are preferred to métiers where a change in fishing gear is needed or métiers outside the strategy (that can correspond to no fishing activity). Discarded fish have a chance to survive that is species-dependent but age-independent and discarded fish that survive are returned to the abundance of their year class.

**Populations**

Both species are assumed to be distributed homogeneously over the whole modelled area. Each species is split in two populations, one for area 7D and one for area 7E. Biological parameters, and in particular weight-at-age, maturity, initial fish abundance, correspond to those estimated for year 2008 by the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK) [35]. Fish catchability was calibrated so that, for each population, fishing mortality at age for year 2008 in our ISIS-Fish model corresponds to that estimated by the working group for year 2008 in the 2011 stock evaluation. In our model, the spawning biomass of sole in the Channel seems to be within acceptable biological limits, but with a high fishing mortality. No reliable stock recruitment relationships could be fitted to these stocks. We used spawning biomass precautionary thresholds (as suggested by [14]) that were defined by the ICES. We forced reference values of recruitment for years 2008, 2009 and 2010 (Table A5.1) to values estimated by ICES [35]. From year 2011 onwards, recruitment was fixed as the geometric mean of past recruitment values [35].

**Management**

We chose to focus only on the current transition scenario to MSY and to test a wide range of values for parameters defining this management scenario. This corresponds to situations where managers have already chosen how to manage a resource or an ecosystem, but where uncertainties remain on the best way to apply the chosen scenario. This allows us to find which particular range of parameter values gives maximum efficiency to the management measure. It also permits determining whether a range of parameter values allows reaching some robustness to uncertainties on biological parameters.

For the first three years of simulation, populations are managed using TACs. TAC values for these years correspond to those that were applied in 2008, 2009 and 2010 (Table A5.2). As a single TAC level was used to manage plaice in areas 7D and 7E, this TAC was split so that a TAC level could be attributed to each population. Plaice TAC in area 7D was set to 3500t for years 2008 and 2009 and to 3400t for year 2010, as recommended in ICES stock evaluations [3,36,37]. The remaining part of the total TAC was attributed to plaice in 7E. This allowed us to get 2010 TAC levels for all simulated populations and simulate harvest control rules thereafter. From 2011 onwards TAC values are determined for each population by a harvest control rule (HCR) that controls the transition towards MSY. Every year during the transition period a value of maximum fishing mortality to be applied to the ecosystem is computed as a combination of the 2010 fishing mortality and the fishing mortality that would give the maximum sustainable yield. Transition duration being 5 years the proportion of F2010 in the computed F decreases by 20% every year and the proportion of FMSY increases by 20%. The TAC level computed by the HCR is determined by other conditions in addition to those on fishing mortality: (i) Spawning biomass has to be above a minimum level (MSY Btrigger), (ii) TAC value cannot change by more than 15% from one year to the next, and (iii) the computed fishing mortality has to be below Fpa. A minimum landing size is also implemented for each species: 27cm for plaice and 24cm for sole.

The database used in this paper, including HCR and gravity model java code, can be downloaded from the ISIS-Fish website (http://www.isis-fish.org/download.html), as well as the latest version of the ISIS-Fish model.

**METHODS**

**Decision Theory**
The info-gap decision theory [19,20] aims at allowing decision making under severe uncertainty. This theory allows comparison between various courses of action \( (q \in Q) \), depending on states of Nature \( (u \in U) \). "u" is called the “ambient uncertainty” in the info-gap theory. The reward function \( R(q,u) \) gives the expected outcome for a given course of action \( q \) and a given state of Nature \( u \). When using a model to compute \( R(q,u) \), the model gives the value of \( R(q,u) \) associated to parameter values used to perform the simulation. The decision maker has to choose a critical value \( (r_c) \) below which the reward function should not drop (in case a high value of the selected output variable is desirable, for instance a high fish biomass). The robustness function \( (\delta(q,r_c)) \) is the greatest horizon of uncertainty that can be tolerated (on Nature’s state or on variables controlled by human activities) while being sure that the reward function did not cross \( r_c \). The Info-Gap theory proposes several functions of uncertainty to compute the robustness function. In practise, the most popular one consists in testing parameter values around the reference parameter values set in the model that increasingly differ from these reference values, until a combination of values is reached for which \( R(q,u) < r_c \). The distance between the last parameter values tested for which \( R(q,u) < r_c \) and the reference values corresponds to \( \delta(q,r_c) \). As a result, the decision maker knows for each possible action and state of Nature the level of uncertainty that can be tolerated. Thus, it is possible to choose the action that seems most appropriate to the situation, depending on management goals, local knowledge of the fishery and the environment, and the level of risk that is accepted by stakeholders. If the probability of occurrence of the various ecosystem states is not known, then a minimax approach [38] or other aspects of the Theory of Games [39] can be applied.

Many limitations of the info-gap approach have been underlined by Sniedovitch [24,25] and are reviewed in [40]. One of these is that it is performed around a given reference point and therefore is inherently local and not suitable to situations of severe uncertainty. This particularly is an issue in fisheries science where reference model parameterisations (corresponding to our knowledge of the state of an ecosystem) often poorly meet management goals. When this happens, then \( \delta(q,r_c) \) is very small, and many other values of the parameters could lead to acceptable reward \( R \). So this approach seems to be very conservative and cautious and does not fully allow the exploration of the input parameters space and the identification of an area in the input parameters space that gives acceptable results. Therefore, we choose to define a priori the window in the input parameters space that we wish to explore and perform the exploration by means of exploration techniques from sensitivity analysis.

**Applying Info-gap to a complex model**

To our knowledge, the Info Gap Theory has only been applied to analytical models. In the context of complex models (with no analytical solution), deriving the robustness function is a great challenge. The ISIS-Fish model belongs to this family of complex models. The model can be used to simulate the reward function \( R(q,u) \) for each selected couple \( (q,u) \) in \( Q \times U \). Many model runs have to be performed to explore the robustness of \( R \) to uncertainty in \( q \) and \( u \). Therefore, we propose a pragmatic approach to apply Info-Gap theory to complex model, following two main steps: 1) a sensitivity analysis of the simulation model performed on the input parameters space \( Q \times U \); 2) a classification trees analysis fitted to the model’s outputs (simulated for the previous step) to discriminate the sensitive parameters and their range of variation accounting for reward \( R(q,u) \) above the critical value \( r_c \).

**Perform sensitivity analysis**

A good exploration of the input space can rely on the powerful tools provided by sensitivity analysis techniques. Many sensitivity analysis techniques are available to modellers [41,42].

Most sensitivity analysis techniques can be divided into two parts: a method to explore the parameter space and a method to rank parameters according to their levels of sensitivity. Following [43,44] we
chose to focus on a global sensitivity analysis method associated to a variance decomposition method, instead of a one-at-a-time (OAT) method. The difference between local and global sensitivity analysis techniques is that global techniques study variations of the output variable over the entire range of values of the input parameters [45,46]. The main asset of global sensitivity analysis is that it allows us to measure interaction effects, which can be of great importance in complex ecosystem models.

We identified 81 parameters from our model on which to perform sensitivity analysis (Figure A5.1, Step 0). These parameters can be split into three groups: biological parameters, technical parameters and management parameters. Biological and technical parameters (Table A5.3) correspond to states of Nature with various levels of uncertainties and management parameters (Table A5.4) allow us to test various management scenarios.

We chose to explore a window corresponding to +/- 50% of the reference value of each parameter (Figure A5.1, Step 1). This range of values agrees with observations from [47] who noted that managers can rarely measure stock levels accurately and typically use confidence intervals of 50%.

From a biological point of view, exploring the same range of values for all parameters makes little sense. This window probably does not allow us to take into account the total variability of all parameters, as some may naturally vary within a greater range, but should be wide enough to contain most variability. On the other hand, this window may be too wide for some well-known parameters with little natural variability. This has to be taken into account when studying sensitivity analysis results. Indeed, some parameters may be identified as important because an unrealistically wide range of values was tested for them. By contrast, other parameters may be identified as little impacting only due to a too narrow range of values tested in the analysis.

The selected window in the input parameters space was explored by means of Latin Hypercube Sampling (LHS, [48]) using the “sensitivity” package [49] from R [50] (Figure A5.1, Step 2). Latin Hypercube Sampling is a probabilistic sampling procedure that incorporates many of the desirable features of random sampling and stratified sampling [51]. Then a variance decomposition method gave us for each input parameter $X_j$ a coefficient $S_{\tau j}$ corresponding to $S^{opt} \tau j$ in [52], indicating whether $X_j$ is a sensitive input parameter or not for the output variable studied. Parameters with $S_{\tau j}$ close to or equal to zero can be removed from the uncertainty analysis as they do not influence the model output. Model outputs we studied are biomass, spawning biomass, fishing mortality and catch. Spawning biomass and fishing mortality were studied in priority as they are variables commonly studied by ICES working groups. Classification trees were then built on management parameters and natural parameters most influencing model outputs.

Point out isles of robustness with classification trees

Once the input parameters space has been explored, one has to find the boundary between input parameter values leading to acceptable outputs (relative to management goals) and input values leading to failures (Figure A5.1, Step 3). As we use a complex model to compute values of $R(q,u)$ this boundary cannot be found analytically, but has to be identified from a limited number of simulations. Very powerful methods have been developed for machine learning that allow identifying the hyperplane separating input values from a dataset in two (or more) groups depending on resulting outputs, but these methods are either black boxes or provide results that are too difficult to interpret for our needs. Therefore we chose to focus on classification trees [53] which allow for simpler representations of results by means of successive univariate splits of the set of input parameter values.

A classification tree is built step by step. At each step, a split is performed on a parameter belonging to the set of parameters on which the tree is built. A split separates the dataset (values of $R(q,u)$ simulated by the model and associated parameters) into two parts according to values of this parameter. When building a tree, the rule to perform a split is that some measure of discrepancy
between the two datasets given by the split is maximized. Therefore the tree is built from the most important node (i.e. combination of a splitting parameter and a splitting value for this parameter) to the least important one. Classification stops when some criteria defined by the user are reached. For instance, classification can stop when the information gain given by a split (i.e. the increase in discrepancy between the two datasets obtained) is lower than a defined threshold. The terminal nodes of a tree are small datasets that are parts of the initial dataset on which the tree was built. They are called leaves. For a given tree, the path leading from a node (usually the first node) to a leaf is called a branch of the tree (Figure A5.2).

### Step 0: Model
- Complex marine ecosystem model (ISIS-Fish in our case)
- Reference settings of model parameters (here 81 parameters corresponding to Biology, Fishing and Management)

### Step 1: Definition
- Input parameter space explored (here +/- 50% around the reference values)
- Reward functions (here Biomass, Catch, Spawning Biomass, Fishing Mortality)
- Thresholds for the reward functions ($r_c$) (here ($SS)\beta_{\text{dim}}, F_{\text{MSY}}$, etc.)

### Step 2: Sensitivity analysis (ISIS-Fish/R)
- Exploration of the input parameter space
- Identification of key parameters impacting the robustness of management measures

### Step 3: Classification Trees (R)
- Identification of areas in the input parameter space where management goals are always reached
- Translation of these results in possible management options
Figure A5.1: The general approach used to identify areas of interest in the input parameters subspace. Once the model has been built and parameters identified (step 0) output variables to be studied and thresholds corresponding to these variables can be chosen and the input space to explore defined (step 1). Then the input parameter is explored and important parameters identified (step 2). Classification trees are used to classify input parameters values depending on the output values they gave when exploring the input parameter space (step 3).

Figure A5.2: Successive use of trees for input parameters space exploration. The first tree (called the main tree) is built on management parameters only, as they are the main concern in the study. When management parameters do not allow robustly reaching management goals, trees (called subtrees) are built for each leaf of the main tree. The second set of trees is built on parameters identified as important by the sensitivity analysis. Results of interest are parameters values corresponding to branches (either of the main tree only or both the main tree and a subtree) leading to robust leaves.

Our goal being to determine the extent to which management measures can allow reaching management goals robustly, we perform classification in two successive steps for each output variable (Figure A5.2). Let \( \{R_1, R_2, \ldots, R_M\} \) be the set of all output variables studied. Let \( Q \) be the set of all management parameters in the model: \( Q = \{X_{q,1}, X_{q,2}, \ldots, X_{q,M}\} \). Let \( U \) be the set of parameters corresponding to important states of Nature (fish biology and fleet characteristics) identified at step 1: \( U = \{X_{u,1}, X_{u,2}, \ldots, X_{u,M}\} \).

A classification tree (the main tree) is built based only on management parameters belonging to \( Q \). Each leaf of the tree may contain either successes (values of \( R(q, u) \) above some threshold) or failures, or a mix of both. A leaf can be considered “robust” when it contains only successes, i.e. all realisations
belonging to this leaf correspond to successful management configurations, whatever the state of Nature. In practice, as the classification relies on model simulations only robust nodes with a high weight (i.e. containing many simulations) should be considered. The concept of robustness can be adapted, depending on the willingness of managers to tolerate risk, so that a node may be considered to be robust if its proportion of successes is above some threshold. Here, we fixed that threshold to 99% of successes as node boundaries can sometimes be difficult to identify very accurately and therefore a few failures can be included in a node that would otherwise be robust. At the end of this first step, leaves are classified into two classes: “robust leaves” if leaves are identified within the tree based on management that allow always reaching management goals or “not robust leaves” for others. Leaves that are not robust are used to perform a second stage of classification.

For each leaf that is not robust, we performed a second classification on parameters belonging to U. This allows us to grow subtrees in a limited amount of time while knowing that important parameters are tested. If a robust terminal node is identified within a subtree associated to a leaf of the main tree, then we know within which range of values of \( U = \{X_{u,1}, X_{u,2}, ..., X_{u,M}\} \) management parameter values corresponding to that leaf will allow reaching management goals. This approach has two assets: (i) if management parameters tested are consistent with current management measures then we know what level of uncertainty or variability on natural parameters can be tolerated while still reaching management goals at the end of the period; (ii) if current management parameters do not correspond to those identified by the tree then we know how (and to what extent) current management should be altered to have a chance to reach management goals considering the uncertainty on management parameters.

The method we chose to build classification trees is that of conditional trees [54] that allows overcoming usual problems of possible overfitting, selection bias, or input parameters scaling.

We assessed tree and subtrees instability (i.e. tree structure changing when slightly modifying the dataset used to build it) by means of re-sampling techniques. For the main tree and subtrees corresponding to leaves of the main tree, we built sets of 500 trees with subsets containing 95% of the dataset. From all these trees, we identified the tree appearing most often and focused on it, making the hypothesis that all trees would converge to this tree type provided the dataset is big enough. We also compute average splitting values and standard deviations from the 500 replicates so as to have clear indicators of tree variability (see Supporting Information S1 for more details about this method). If tree variability is too high (it is especially the case for subtrees, as they are built from a subset of the main dataset corresponding to their associated leaf), it makes little sense to focus only on one particular tree type. In this case, results from the most common tree types can be provided.

RESULTS

Sensitivity analyses

Results from the sensitivity analysis are presented in Figure A5.3, where each column stands for an output variable and each row for a different input parameter. Only rows should be compared as the intersection of a row and a column represents the amount of the total variance of a particular output variable explained by an input parameter. The naming of the various input parameters appearing in Figure A5.3 is detailed in Table A5.3 and Table A5.4. Parameters are presented individually in Figure A5.3 whereas parameters with similar values for all populations appear only once in Table A5.3 and Table A5.4. Besides FMSY and Fpa we re varied jointly in the sensitivity analysis and appear as a single parameter FMSY Fpa in Figure A5.3.
Figure A5.3: Results of the sensitivity analysis. Each row corresponds to one of the 81 input parameters tested and each column to an output variable. Output variables are biomass (B), Spawning Biomass (SSB), Fishing mortality (F) and Catch (Y). Results have to be studied in columns, black cells indicating important parameters for a given output.

The goal being to reduce the model, we focus only on the most sensitive parameters that really stand out compared to the others. These input parameters are listed from the most important to the least important in Table A5.5 and Table A5.6. First order interactions between parameters were also tested. Interactions are pretty straightforward, the most sensitive parameters producing the strongest interactions. Interactions do not especially drive output variables in our model. Fishing mortality is the output variable most impacted by interactions, but even in this case the most sensitive interaction is always less than 0.1 times as impacting as the most important parameter. We therefore focus only on main effects when presenting our results. It is interesting to note that the most important parameters impact the four studied populations whereas less important parameters are specific to only some of these populations. Also, small interactions between areas 7D and 7E appear, as sometimes populations from one area can be slightly impacted by parameters defined for the other area.

The first thing that stands out from these results is that all studied output variables except fishing mortality are mostly impacted by biological parameters, technical parameters having a lower impact on the outputs. Management measures have little impact on all output variables, even those directly related to fishing. The parameter of our harvest control rule that most influences output variables is the target value of fishing mortality FMSY (and the associated Fpa). However the effects of the FMSY parameter are limited to fishing mortality and effects of management on biomass or spawning biomass are low.
Interestingly, while fishing mortality is driven by catchability and technical parameters, catch appears to be impacted almost only by biological parameters. Fish mean weight-at-age alone explains up to 60.0% of the total variance of the catch which leaves little variance to be explained by other parameters. This importance of fish weight may be linked to the fact that we study biomass and catch in tons, and not abundances or catch in numbers. Besides fish mean weight-at-age is a parameter with relatively small variability, and testing 50% around this parameter’s reference value may artificially give it an important weight.

Mean weight is the input parameter most impacting model output variables, and is followed by natural death rate and catchability (Table A5.5 and Table A5.6). Recruitment has noticeable impact only for sole in area 7D, and this impact is moderate.

In our model, beam-trawling is the most impacting fishing activity, with high $S_{TFB}$ s for both its target factor (TFB) and selectivity (SBT). It impacts both populations of plaice, as well as fishing mortality of Sole in area 7E. The effects of netting are limited to sole in area 7D and can be noted only for fishing mortality (moderate $S_{TFB}$ s for SNS7D and TSN7DS). Biomass and spawning biomass of plaice in area 7D are also impacted by the target factor of the “other métiers” group of our model, that bundles together all the lesser operated métiers.

**Conditional Tree analysis**

Conditional trees can be built according to the previously presented method for all output variables studied in the sensitivity analysis. However, only the most important variable for conservation, spawning biomass, will be discussed here for populations of sole and plaice in area 7D. The management goal, for both sole and plaice, is that spawning biomass must remain above 8000t.

**Sole 7D**

The tree structure obtained when building the main tree (Figure A5.4) on the entire training dataset corresponds to that identified when creating a large number of trees on a smaller subset (see Supporting Information S2 for more details about the tree-building process). Therefore we can infer that our dataset is big enough to ensure good tree stability and that all trees built from subsets would converge to that particular tree provided we had enough data. As no leaf of this tree is robust, i.e. they all contain some failures, a subtree was built for each of the six leaves of the main tree to determine if management measures allow reaching management goals within a certain range of values of natural parameters, as shown in Figure A5.2. Among all subtrees corresponding to a leaf of the main tree, only some subtrees are of interest (robustness + high weight), we therefore decided to focus on those. For each subtree, we compute mean splitting value and standard deviation around these values because there can be variations in the splitting values at each inner node. Branches of interest can be identified within subtrees that lead to leaves that are robust and have a high weight. Besides, it appears that these particular branches are much more stable than other branches of subtrees. Table A5.7 shows for each leaf of the main tree built on management measures parameters and split values corresponding to interesting subtree branches that would allow robustly reaching management goals. A very interesting thing to observe is that for all subtrees all important branches identified correspond to boundaries on natural parameters that contain the reference model parameterisation (which corresponds to value 0.5). Therefore all robust nodes identified in Table A5.7 can be reached by means of changes made to management measures. The distance between the reference model parameter value (supposed current “real” state of the system) and the split parameter value identified by the classification tells us how much uncertainty or variability can be tolerated around the reference parameter value to ensure reaching management goals.
Figure A5.4: Main tree built on management measures for sole in subarea 7D. The criterion separating successes from failures is a 8000t spawning biomass threshold. Splitting variables (and values) are sorted by importance, from the top to the bottom of the tree (the most important corresponding to node 1). Values appearing on branches of the tree are the splitting values. The black and grey squares at the bottom of the tree are the terminal nodes or leaves.

Leaf 6 of the main tree (top centre of Table A5.7) is of particular interest as both management and natural parameter values leading to the robust node are compatible with reference model parameterisation (Table 8). This means that current management measures should allow reaching a spawning biomass of sole above 8000t by 2018, provided reference model parameterisation correctly represents the environment. As our model cannot correctly represent the environment, we look at conditions imposed on environmental parameters by subtree branches. In both cases, only two conditions on environmental parameters are imposed: one on recruitment and the other on mean weight-at-age. The first branch identified tells us that it is possible to reach management goals if (i) mean weight-at-age of sole in area 7D is no more than 32% lower than reference model sole mean weight-at-age and (ii) recruitment until 2018 is no more than 12% lower than recruitment used to perform simulations in our model (which is the geometric mean of recruitment values estimated for the previous years). The second option identified corresponds to a mean weight no more than 24% lower than reference and to a recruitment no more than 22% lower than reference recruitment value. If a 22% variation around a mean recruitment and a 24% variation in mean weight are deemed sufficient to encompass both natural variability and our uncertainties, then management measures can be left the way they are. If a greater margin is needed on natural parameter values, then management parameters have to be modified.

Moving from leaf 6 to leaf 3 imposes reducing $F_{mFpaS7D}$. Results for leaf 3 (Table A5.9) allow greater uncertainties on recruitment than those for leaf 6. In this case, reducing the target fishing mortality of the management measure by 26% or more will allow tolerating recruitments up to 37% lower than the reference recruitment of our model, but lower uncertainties can be tolerated on mean weight-at-age, and natural death rate now also has to be taken into account.

Results for other leaves of the main tree are rather similar, and correspond to different combinations of the most important management parameters (target F, MSY $B_{trigger}$ and transition duration). There can be variability in results obtained between leaves, and sometimes stricter conditions on environmental parameters are not observed in leaves where they could be expected (e.g. when the value of $F_{mFpaS7D}$ is increased). This illustrates the fact that some results obtained may be too conservative and that some uncertainties remain about the position of the boundary separating acceptable parameter combinations from unacceptable parameter combinations.

**Plaice 7D**

Table A5.10 shows that, similarly to what was observed for sole, it is the value of fishing mortality targeted by the harvest control rule that mostly determines whether management goals will be reached
or not. For plaice, this parameter is associated to the duration of the transition period and to the survival rate of discarded fish.

Leaf 4 (see S3 for more information about trees built for plaice) if of great interest as it is the only one that contains values of current management parameters, and natural parameters that are compatible with our perception of plaice life cycle. The two options identified in leaf 4 are quite similar, except for the uncertainty that can be tolerated on fish mean weight. This shows that when building trees both split value were identified as having rather similar abilities to split a node into two other nodes, and we cannot say that one value really is better than the other. The goal being to be robust to uncertainties, only the value of 0.366, corresponding to a maximum 13% variability on fish mean weight should probably be considered (Table A5.11). Uncertainties on parameters such as fish mean weight-at-age or age at maturity usually being lower than uncertainties on recruitment, management goals may still be reachable with the current management (even if the 0.501 threshold on FmsyFpa leaves no room for variation on this parameter, the reference value being 0.5).

Values of FmsyFpa above 0.501 (leaf 12 and leaf 13) are associated to survival rates of discarded fish above 0.251, which means that more than 13% of discarded plaice have to survive. Even if this were true, other conditions on natural parameters are not fulfilled except for one branch of leaf 13. This combination of parameters appearing in leaf 13 but not in leaf 12 where management is tighter makes little sense and illustrates tree instability and the need for a bigger training set and a more thorough tree exploration.

Other leaves correspond to other combinations of management and natural parameters. Even if many natural parameters do not agree with our reference model parameterisation, split values for catchability and sometimes fish mean weight are close to model values, and little changes in these parameters could make management goals reachable for a wider range of management scenarios.

**DISCUSSION**

**Management Implications**

For sole as well as plaice, no combinations of management measures could be identified that always allow reaching management goals accounting for “Nature uncertainty”. However, the sole population in area 7D is in a good enough state to make the 8000t spawning biomass goal recommended by working groups reachable for a rather wide variety of management parameters values and states of Nature. In particular, management goals on spawning biomass can be reached with current management, provided mean weight-at-age and recruitment of sole do not vary too much. This seems acceptable for mean weight, as it is not a highly variable parameter. On the contrary, variations in recruitment higher than 22% seem likely to happen for sole in the Eastern Channel [55]. In this case, the model suggests strongly reducing the target fishing mortality (division by more than two of FMSY and Fpa) so as to be able to withstand much stronger variations in recruitment.

For plaice in area 7D the spawning biomass threshold chosen by the working group is also Bpa=8000t, which corresponds in the evaluation to a fishing mortality threshold Fpa=0.45. However, this goal is harder to reach for the plaice population in 7D than it was for sole. This can be seen with the much smaller ranges of values of management parameters that allow reaching management goals. However, tolerable ranges of values of natural parameters are rather broad, and these parameters are not known for their high variability (in particular, recruitment is not one of them, and could have been an issue otherwise [56]). Therefore, management goals could be reached, provided plaice stocks are carefully managed. Trees built for plaice are also less stable than those of sole. This instability may have two causes: (i) too few model simulations reach management goals, i.e. the state of the stock is so bad that only a fraction of parameter values tested yield acceptable results or (ii) uncertainties in the life traits of the modelled species are so high that parameters importance and split values cannot be assessed correctly. These two aspects may be linked, bad stock state possibly leading to more variability.
These results are coherent with what is known of the history of sole and plaice stocks in the English Channel. Indeed, mean fishing mortality estimated by working groups for sole remained between 0.3 and 0.6 since 1989 whereas plaice fishing mortality evolved between 0.45 and more than 1.2 (most values being equal to or above 0.6) during the same period [57]. Target and precautionary fishing mortalities for both species being rather similar, it can be said that plaice was more overexploited than sole. Management goals being difficult to reach for plaice our model cannot correctly predict successes, which increases tree instability. As the state of the stock improves, tree stability and therefore our ability to make correct predictions will increase. It is nonetheless worth noting that despite model simplicity and uncertainties our results are coherent with what is known about the studied fish stocks.

Results presented in this article only concern spawning biomass, but similar analyses were performed for the other output variables mentioned previously. The goal here is not to look for the most robust management method, which makes little sense if the analysis is not multivariate. For instance, the best way to maximize spawning biomass is to stop fishing, and there is no need for a complex model to determine this. The interest here is to find management measures that allow reaching management goals on various (and possibly conflicting) output variables and determine how all these constraints on management can be combined. In particular, the key point is to find management measures that allow keeping biomass to acceptable levels while guaranteeing a high enough income to fisheries. A first insight can be obtained by looking for conditions ensuring that catches of flatfish species do not go below a certain level. As it is possible to model fishing costs and fish price in the ISIS-Fish model, it would be possible to look for conditions allowing reaching given economic goals, provided these criteria can be found. Here, we chose to study output variables separately and then look for similarities or discrepancies in management measures manually. But multivariate classification methods exist, and would be an ideal choice here provided hypotheses they are based on and types of results they provide are compatible with our needs. These multivariate techniques could also be used to perform multi species analyses, so that we make sure changing management measures on a species does not negatively impact another species. Here, this problem did not arise since sole is only impacted by “sole” parameters and plaice by “plaice” parameters (Table A5.8, Table A5.9, Table A5.11).

Caveats

The main limit of techniques we used is that many model simulations are needed. Otherwise reliability of sensitivity analysis results decreases, as large parts of the input space can be left unexplored, and results obtained with classification trees can become highly unstable if they cannot be trained properly. Here, we could perform many simulations because we used a “simple” model (one run takes about one minute on one core), but this method could be harder to apply to a more complex model with longer simulation times. However, the quick increase in available computing power opens very interesting prospects concerning the exploration of complex models input parameters spaces.

Another limit of the method we used is that we built classification subtrees from the main tree obtained when using the whole training dataset. Even if the main tree’s type corresponds to the most common tree type identified, it could be interesting to grow subtrees from the leaves of a mean tree that would account for tree variability. This would allow us to take variability on management parameters into account when building subtrees. As standard deviations can also be computed, this would allow us to determine margins of uncertainty around split values. Depending on the needed level of robustness to uncertainties this would permit testing hypotheses and finding areas considered safe at the needed level of confidence. Another possible concern about classification trees is the size of the sub areas they can distinguish in the input parameters space. Would they be able to find “isles of robustness in a sea of non-robustness”? No extensive tests were run so as to answer this question but we think the method would still be appropriate in this case, even if it may not be the most suitable one. In this case, no constraints should be applied to the tree building process, so simulation time may increase a lot and trees may become much larger than those presented in this paper. This would also make results a lot harder to interpret and translate into applicable management measures.
Concerning the model itself, the weight of the "Other Métiers" group (i.e. métiers not explicitly taken into account in the model) in the sensitivity analysis shows that additional information could have been obtained, had the fishing activity been modelled in more details. This may illustrate the fact that our model is overly simplified and does not take into account enough parameters (at least when modelling the fishing activity). Indeed, we only model explicitly two species and three fleets corresponding to two gear types. Besides, fishing, management and population zones are defined at the scale of the ICES area. Therefore, only large-scale changes can be tested. As few ecosystem compartments are modelled, we only focus on a limited number of processes. Adding information to the model may greatly change its behaviour, especially because of interactions between parameters that cannot be observed in the current simple model. Changing the way in which the model represents the studied processes could also have notable impacts. Indeed, [40] state that not taking model structural uncertainty into account is one of the main flaws in the info-gap approaches that have been implemented so far. The same hypothesis is made in our study, i.e. that parameter variability is more impacting than structural uncertainty. We made this hypothesis mostly because our ISIS-Fish model is based on equations that are commonly used by stock assessment working groups, thus our results should at least be coherent with those given in stock evaluations. Nonetheless, structural uncertainty of our model should (at least partly) be assessed in order to determine whether model structure strongly impacts conclusions drawn, or if they depend (as we supposed in this study) on variations of input parameters.

We use a three-years “forcing” period at the beginning of our model, so as to use available information to better represent the studied ecosystem. This allows us to set management parameters to their real value during that period. We also chose to set recruitment to values estimated by working groups for that period. This could partly explain why recruitment little impacts values of output variables in the sensitivity analysis. Besides, we deal with long-lived species, so there can by a many-years delay between changes in recruitment and the observation of impacts on other parameters caused by these changes. For other biological parameters this forcing period was not used and they therefore are fixed to the calibrated 2008 value, with a 50% level of uncertainty. So on the one hand no uncertainties are associated to recruitment for the first tree years, whereas there is uncertainty in the estimation made by working groups, and on the other hand other biological parameters are given a fixed value with high uncertainties during that period. As all past values can be estimated with some level of certainty, it would seem more logical to force all biological parameters for the first tree years to their estimated values and give them low uncertainty levels corresponding to the accuracy of the estimation. Then for values from 2011 onwards either calibrated or mean values can be used, with much higher levels of uncertainty depending on the level of natural variability and uncertainty corresponding to these parameters.

The question of the range of parameter values to explore is linked with these levels of variability and uncertainty. We chose to perform sensitivity analysis on a 50% window around our model reference parameterisation, while 20% variations are commonly tested when performing sensitivity analyses [? ,? ]. As variability can be very high on some parameters and very low on others, this method could be improved. Indeed, it gives too high a weight to parameters the variability of which is overestimated and lessens the weight of parameters with higher variability. A next step in the modelling process is to perform sensitivity analysis on the domain of variation of parameters tested.

Model simplicity and modelling choices we made prevented us from testing spatial management measures. In addition to model changes that we discussed, our goal now is to better represent fish populations and fleets targeting them in our model. In particular, decreasing the scale at which processes are modelled may allow us to test spatial management measures. Combining these measures to those already included in our model, we hope to find out if spatial management measures such as MPAs can allow reaching management objectives with a higher robustness to uncertainties on the state of the ecosystem.
Management Strategy Evaluation

The approach we used is very close in essence and in goals to that implemented when performing a management strategy evaluation (MSE). Indeed, when performing MSE, the goal is to assess the consequences of a set of management procedures against key performance measures [60]. Similarly to what we wanted to do, the MSE approach does not seek to prescribe an optimal strategy, but rather to provide decision makers with sound information on which to base their decisions. Providing sound information implies identifying strategies that are robust to uncertainty and natural variation [61], as was done in our approach. MSEs can be based on various interacting models, from very simple ones to very complex ones.

The main difference between our approach and common MSE is that we did not just test management scenarios but let parameters controlling the Harvest Control Rule vary within a chosen range of values. Therefore, despite strong environmental drivers in our model (possibly coming from choices made when performing sensitivity analysis), our method is able to find a range of management parameters and values that allow reaching management goals. Therefore, instead of determining whether a scenario is robust or not, we can identify a subspace of management parameters values that are robust to uncertainties. Besides we can also define ranges of variation on natural parameters that can be tolerated and still allow reaching management goals, an information of potentially great importance. Therefore, within the range of management parameters values that can yield robust outcomes, managers can choose the combination of values that seems best depending on their goals and their willingness to take risks.

Such results could be discussed with stakeholders so as to determine the opportuneness of various management measures and to better perceive which situations would lead to failures to reach management or economic goals, and potential solutions to avoid them. This method also allows identifying particular input parameters on which uncertainties should be reduced in priority to allow for better forecast. If the cost of a reduction in uncertainty on some parameters is known (e.g. the price to pay to get additional samples) then it can be balanced against the cost of not robustly reaching management goals and choices can be made depending on managers’ priorities. Once these important parameters have been identified an adaptive management procedure [62,63] targeting them in particular could be set up. An interesting feature of the method is that there is no need to identify a priori sources of uncertainty impacting input parameters. Uncertainty is treated as a whole and identification of sources of uncertainty is only an optional step that can be made by the user.
### TABLES

**Table A5.1: Recruitment (in number) values used for the first three simulated years and after**

<table>
<thead>
<tr>
<th>Recruitment Population</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>after</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole 7D</td>
<td>2.395e7</td>
<td>5.298e7</td>
<td>2.817e7</td>
<td>2.353e7</td>
</tr>
<tr>
<td>Plaice 7D</td>
<td>1.157e7</td>
<td>2.343e7</td>
<td>1.498e7</td>
<td>1.216e7</td>
</tr>
<tr>
<td>Sole 7E</td>
<td>2.379e6</td>
<td>2.885e6</td>
<td>4.301e6</td>
<td>4.301e6</td>
</tr>
<tr>
<td>Plaice 7E</td>
<td>5.560e6</td>
<td>1.006e7</td>
<td>5.007e6</td>
<td>5.007e6</td>
</tr>
</tbody>
</table>

**Table A5.2: TAC values used for the first three simulated years**

<table>
<thead>
<tr>
<th>TAC Population</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole 7D</td>
<td>6593t</td>
<td>5274t</td>
<td>4219t</td>
</tr>
<tr>
<td>Plaice 7D</td>
<td>3500t</td>
<td>3500t</td>
<td>3400t</td>
</tr>
<tr>
<td>Sole 7E</td>
<td>765t</td>
<td>650t</td>
<td>618t</td>
</tr>
<tr>
<td>Plaice 7E</td>
<td>1550t</td>
<td>1146t</td>
<td>874t</td>
</tr>
</tbody>
</table>
Table A5.3: Biological and technical parameters tested, for every population, métier or gear.

<table>
<thead>
<tr>
<th>Parameter Name</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchability</td>
<td>Q</td>
</tr>
<tr>
<td>Mean Weight</td>
<td>MW</td>
</tr>
<tr>
<td>Recruitment</td>
<td>RE</td>
</tr>
<tr>
<td>Natural Death Rate</td>
<td>NDR</td>
</tr>
<tr>
<td>Growth Rate</td>
<td>K</td>
</tr>
<tr>
<td>Asymptotic Length</td>
<td>Linf</td>
</tr>
<tr>
<td>Time at the Origin</td>
<td>T0</td>
</tr>
<tr>
<td>Price</td>
<td>P</td>
</tr>
<tr>
<td>Selectivity Beam Trawl</td>
<td>SBT</td>
</tr>
<tr>
<td>Selectivity Net</td>
<td>SN</td>
</tr>
<tr>
<td>Selectivity Other Gears</td>
<td>SO</td>
</tr>
<tr>
<td>Target Factor Beaming</td>
<td>TFB</td>
</tr>
<tr>
<td>Target Factor Netting</td>
<td>TFN</td>
</tr>
<tr>
<td>Target Factor Other Métiers</td>
<td>TFO</td>
</tr>
<tr>
<td>Proportion of effort allocation coming from habits</td>
<td>habit</td>
</tr>
</tbody>
</table>

50% variations were tested around the reference value. Each biological parameter exists in five versions, one for each population: sole 7D (S7D), plaice 7D (P7D), S7E or P7E and one for the “Other” group. Technical parameters are either defined at the population scale (S7D, etc.) or at the area scale (7D, 7E, or both: 7DE).
### Table A5.4: Management parameters tested.

<table>
<thead>
<tr>
<th>Parameter Name</th>
<th>Abbreviation</th>
<th>Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Landing Size for Sole</td>
<td>MinSizeS7DE</td>
<td>24cm</td>
</tr>
<tr>
<td>Minimum Landing Size for Plaice</td>
<td>MinSizeP7DE</td>
<td>27cm</td>
</tr>
<tr>
<td>Duration of the transition framework</td>
<td>Trans</td>
<td>5yrs</td>
</tr>
<tr>
<td>Survival rate of discarded fish</td>
<td>PropSurv</td>
<td>0.25</td>
</tr>
<tr>
<td>Maximum yearly TAC variation</td>
<td>varTAC</td>
<td>0.15</td>
</tr>
<tr>
<td>Targeted fishing mortality at MSY, Sole 7D</td>
<td>FmsyS7D</td>
<td>0.29</td>
</tr>
<tr>
<td>Targeted fishing mortality at MSY, Plaice 7D</td>
<td>FmsyP7D</td>
<td>0.23</td>
</tr>
<tr>
<td>Targeted fishing mortality at MSY, Sole 7E</td>
<td>FmsyS7E</td>
<td>0.27</td>
</tr>
<tr>
<td>Targeted fishing mortality at MSY, Plaice 7E</td>
<td>FmsyP7E</td>
<td>0.19</td>
</tr>
<tr>
<td>Precautionary fishing mortality, Sole 7D</td>
<td>FpaS7D</td>
<td>0.4</td>
</tr>
<tr>
<td>Precautionary fishing mortality, Plaice 7D</td>
<td>FpaP7D</td>
<td>0.45</td>
</tr>
<tr>
<td>Precautionary fishing mortality, Sole 7E</td>
<td>FpaS7E</td>
<td>0.4</td>
</tr>
<tr>
<td>Precautionary fishing mortality, Plaice 7E</td>
<td>FpaP7E</td>
<td>0.45</td>
</tr>
<tr>
<td>HCR Trigger Biomass, Sole 7D</td>
<td>MsyBtS7D</td>
<td>8000t</td>
</tr>
<tr>
<td>HCR Trigger Biomass, Plaice 7D</td>
<td>MsyBtP7D</td>
<td>8000t</td>
</tr>
<tr>
<td>HCR Trigger Biomass, Sole 7E</td>
<td>MsyBtS7E</td>
<td>2800t</td>
</tr>
<tr>
<td>HCR Trigger Biomass, Plaice 7E</td>
<td>MsyBtP7E</td>
<td>2500t</td>
</tr>
</tbody>
</table>

50% variations were tested around the reference value, except for the survival rate of discarded fish. Survival rates from 0 (no survival of discarded fish) to 0.5 (survival of 50% of discarded fish) were tested because of large uncertainties on this parameter and because the reference model value is 0. Parameters “Trans”, “PropSurv” and “varTAC” have similar reference values for all populations so they are only given once.
### Table A5.5: Input parameters most impacting output variables

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Spawning Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Weight (MW)</td>
<td>Mean Weight</td>
</tr>
<tr>
<td>Catchability (Q)</td>
<td>Maturity Ogive (MO)</td>
</tr>
<tr>
<td>Natural Death Rate (NDR)</td>
<td>Catchability</td>
</tr>
<tr>
<td>Natural Death Rate</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S7D</th>
<th>P7D</th>
<th>S7E</th>
<th>P7E</th>
<th>S7D</th>
<th>P7D</th>
<th>S7E</th>
<th>P7E</th>
</tr>
</thead>
<tbody>
<tr>
<td>RES7D</td>
<td>SBTP7D</td>
<td>MOS7E</td>
<td>SBTP7E</td>
<td>RES7D</td>
<td>SBTP7D</td>
<td>QS7D</td>
<td>SBTP7E</td>
</tr>
<tr>
<td>MOS7E</td>
<td>TFB7DP</td>
<td>QS7D</td>
<td>TFB7EP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Parameters are sorted from the most impacting to the less impacting, and the proportion of total output variance explained by these parameters is given at the bottom of each column.

### Table A5.6: Input parameters most impacting output variables (continued).

<table>
<thead>
<tr>
<th>Fishing Mortality</th>
<th>Catch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchability</td>
<td>Mean Weight</td>
</tr>
<tr>
<td>Natural Death Rate</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S7D</th>
<th>P7D</th>
<th>S7E</th>
<th>P7E</th>
<th>S7D</th>
<th>P7D</th>
<th>S7E</th>
<th>P7E</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOS7D</td>
<td>SBTP7D</td>
<td>MOS7E</td>
<td>SBTP7E</td>
<td>RES7D</td>
<td>MWS7E</td>
<td>QS7E</td>
<td>QP7E</td>
</tr>
<tr>
<td>FmsyFpaS7D</td>
<td>TFB7DP</td>
<td>FmsyFpaS7E</td>
<td>TFB7EP</td>
<td>MOS7E</td>
<td>MWS7D</td>
<td>FmsyFpaS7D</td>
<td>PropSurvP7E</td>
</tr>
<tr>
<td>MOS7E</td>
<td>MOS7E</td>
<td>QS7D</td>
<td>MOS7E</td>
<td>FmsyFpaS7D</td>
<td>PropSurvP7D</td>
<td>QS7D</td>
<td>TFB7EP</td>
</tr>
<tr>
<td>QS7E</td>
<td>QS7D</td>
<td>FmsyFpaS7D</td>
<td>QS7E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Parameters are sorted from the most impacting to the less impacting, and the proportion of total output variance explained by these parameters is given at the bottom of each column.
Table A5.7: Results of the classification performed with conditional trees for sole

Each block corresponds to a leaf of the main tree and gives conditions on management parameters that are needed to reach it. The lower part of each block corresponds to branches identified from subtrees and gives conditions on environmental parameters that are to be added to those on management to reach a robust terminal node. Cells that are compatible with the reference model parameterisation (i.e. containing value 0.5) are in bold type.

<table>
<thead>
<tr>
<th>Leaf 3</th>
<th>Leaf 6</th>
<th>Leaf 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{\text{MSYFpaSD}} &lt; 0.241$</td>
<td>$0.241 &lt; \text{MSYpa} &lt; 0.584$</td>
<td>$F_{\text{MSYFpaSD}} &gt; 0.584$</td>
</tr>
<tr>
<td>trigger &lt; 0.605</td>
<td></td>
<td>trigger &lt; 0.568</td>
</tr>
<tr>
<td>TransitionS7D &lt; 0.75</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subtree 1</th>
<th>Subtree 1</th>
<th>Subtree 2</th>
<th>Subtree 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Split Value</td>
<td>Standard Deviation</td>
<td>Mean Split Value</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>MWS7D &gt; 0.317</td>
<td>0.0006</td>
<td>MWS7D &gt; 0.172</td>
<td>0.0009</td>
</tr>
<tr>
<td>RES7D &gt; 0.131</td>
<td>0.003</td>
<td>RES7D &gt; 0.383</td>
<td>0.002</td>
</tr>
<tr>
<td>NDRS7D &lt; 0.801</td>
<td>0.007</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A5.8: Management parameters values identified from leaf 6 and environmental variability they allow dealing with. For sole in subarea 7D.

<table>
<thead>
<tr>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.22 &lt; F_{\text{MSYSD}} &lt; 0.31$</td>
</tr>
<tr>
<td>$0.30 &lt; F_{\text{paSD}} &lt; 0.43$</td>
</tr>
<tr>
<td>$\text{MSY}<em>B</em>{\text{SD}} &lt; 8840t$</td>
</tr>
<tr>
<td>TransitionS7D &lt; 7.5yrs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{MWS7D} &gt; \text{MWSD}_{\text{ref}} - 24%$</td>
</tr>
<tr>
<td>$\text{RES7D} &gt; \text{RESD}_{\text{ref}} - 22%$</td>
</tr>
</tbody>
</table>
Table A5.9: Management parameters values identified from leaf 3 and environmental variability they allow dealing with. For sole in subarea 7D.

Management

\( F_{\text{MSYSD}} < 0.22 \)
\( F_{\text{paSD}} < 0.30 \)

Environment

\( MWSTD > MWSD_{\text{ref}} - 18\% \)
\( RESSTD > RESD_{\text{ref}} - 37\% \)
\( NDRSTD < NDRSD_{\text{ref}} + 10\% \)

Table A5.10: Results of the classification performed with conditional trees for plaice.

Leaf 4

\( MSYpa<0.501 \)
\( \text{PropSurvP7D}<0.759 \)
\( \text{TransP7D}<0.52 \)

<table>
<thead>
<tr>
<th>Subtree 1</th>
<th>Mean Split Value</th>
<th>Standard Deviation</th>
<th>Mean Split Value</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWP7D&gt;0.258</td>
<td>0.0005</td>
<td></td>
<td>MWP7D&gt;0.445</td>
<td>0.003</td>
</tr>
<tr>
<td>QP7D&lt;0.720</td>
<td>0.0003</td>
<td></td>
<td>QP7D&lt;0.549</td>
<td>0.0001</td>
</tr>
<tr>
<td>MOP7D&gt;0.259</td>
<td>0.02</td>
<td></td>
<td>MOP7D&gt;0.206</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Leaf 13

\( F_{\text{MSYFpaPO}} > 0.86 \)
\( \text{PropSurvP7D}>0.251 \)

<table>
<thead>
<tr>
<th>Subtree 1</th>
<th>Mean Split Value</th>
<th>Standard Deviation</th>
<th>Mean Split Value</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWP7D&gt;0.665</td>
<td>0.005</td>
<td></td>
<td>MWP7D&gt;0.529</td>
<td>0.002</td>
</tr>
<tr>
<td>QP7D&lt;0.587</td>
<td>0.006</td>
<td></td>
<td>QP7D&lt;0.458</td>
<td>0</td>
</tr>
<tr>
<td>MOP7D&gt;0.253</td>
<td>0.002</td>
<td></td>
<td>MOP7D&gt;0.310</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Leaf 12

\( 0.501<F_{\text{MSYFpaPO}}<0.86 \)
\( \text{PropSurvP7D}>0.251 \)

<table>
<thead>
<tr>
<th>Subtree 1</th>
<th>Mean Split Value</th>
<th>Standard Deviation</th>
<th>Mean Split Value</th>
<th>Standard Deviation</th>
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<tr>
<td>MWP7D&gt;0.665</td>
<td>0.005</td>
<td></td>
<td>MWP7D&gt;0.667</td>
<td>0.006</td>
</tr>
<tr>
<td>QP7D&lt;0.587</td>
<td>0.006</td>
<td></td>
<td>QP7D&lt;0.458</td>
<td>0.08</td>
</tr>
<tr>
<td>MOP7D&gt;0.253</td>
<td>0.002</td>
<td></td>
<td>MOP7D&gt;0.240</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Each block corresponds to a leaf of the main tree and gives conditions on management parameters that are needed to reach it. The lower part of each block corresponds to branches identified from subtrees and gives conditions on
Table A5.11: Management parameters values identified from leaf 4 and environmental variability they allow dealing with. For plaice in subarea 7D

<table>
<thead>
<tr>
<th>Management</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>FMSY P7D &lt; 0.23</td>
<td></td>
</tr>
<tr>
<td>FpaP7D &lt; 0.45</td>
<td></td>
</tr>
<tr>
<td>TransP7D &lt; 5.1yrs</td>
<td></td>
</tr>
<tr>
<td>PropSurvP7D &lt; 0.38</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environment</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MWP7D &gt; MWP7Dref - 13%</td>
<td></td>
</tr>
<tr>
<td>QP7D &lt; QP7Dref + 22%</td>
<td></td>
</tr>
<tr>
<td>MOP7D &gt; MOP7Dref - 25%</td>
<td></td>
</tr>
</tbody>
</table>
ANNEX 5 REFERENCES


ANNEX 6 - THE SUITABILITY OF FISHERENT AS A TOOL FOR MANAGEMENT EVALUATIONS

Author: Sarah Simons (vTI-SF)

BACKGROUND

Reasons for management failures

Numerous examples of stock depletion and fisheries collapse are found in the literature despite a range of attempts to manage fisheries (Garcia and Charles, 2007; Caddy and Cochrane, 2001; Garcia et al., 1997; Sutinen and Sobol, 2003; Caddy and Agnew, 2004; Hilborn et al., 2003; Abernethy et al., 2010; Delaney et al., 2007; Holden and Garrod, 1996; Österblom et al., 2011). The report from the Food and Agriculture Organization of the United Nations, FAO (2009) states that the proportions of overexploited, depleted and recovering marine fisheries remain high at 19%, 8% and 1% respectively. The environmental damage caused by the fishing industry has been the subject of debate for many years now (Garcia and Charles, 2007).

The main reason for these failures is that managers traditionally have laid an emphasis on fish population dynamics and protection of the environment, while making simplistic assumptions about fishermen’s nature and attitudes when defining management policies (Garcia and Charles, 2007; Graham, 1935; Grant, 1986; Allen and McGlade, 1986; Charles, 1995; Sutinen and Sobol, 2003; Charles, 2008; Hilborn, 1985). For instance, from the 1970s onwards there was a widespread use of TACs as a control measure (Armstrong et al., 2008). As TACs revealed to be ineffective in controlling fishing morality in European waters the precautionary approach to fisheries management was introduced in the 1990s, involving biological reference points (FAO, 1995). The result was that in Europe at least, there were significant cuts in TACs across many fish stocks. However, there were no parallel measures to control fishing effort or to improve gear selectivity sufficiently to achieve the desired reductions in fishing mortality. Rapid TAC uptake led to increased discarding and misreporting, resulting in widespread deterioration in the quality of the fishery data on which scientific assessments were based. This in turn undermined the confidence of fishermen in scientific assessments, which they knew to be often based on flawed fishery data (Armstrong et al., 2008).

Until now, most management advances have been made in the technical area of developing Harvest Control Rules (HCRs), often overlooking the effect that these have on fishermen and on the feedback effect of changes in harvest patterns on the population dynamics (Hilborn et al., 2001; Wilen et al., 2002; Wilen, 1979; Haynie and Pfeiffer, 2012). Fisheries have generally been managed by rules of ‘how much can be taken’ rather than by evaluating and controlling ‘how, when and where’ people fish. Before changing regulations managers often ignored important questions such as: What is the economic impact of a catch quota, area closure, or effort restriction on fishermen? How much is their income reduced and which alternatives could compensate for any deficit? In the face of such management constraints, fishermen develop strategies that allow them to maintain or increase catch rates by increasing the number of fishing days, using cooperative effort, personal skills or technical modifications to vessels and equipment (Charles, 1995; Ruttan, 1998; Salas, 2000; Hanna and Smith, 1993; Salas and Gaertner, 2004).

Furthermore, traditional fisheries management advice focused on an individual fish stock as the unit to be managed, the current European system includes many stock assessments that are performed each year to provide scientific advice for managing the fisheries. Thus, science is concerned mainly with the fish stocks, and the management advice applies instead to the vessels fishing those stocks (Reeves et al., 2008). In particular, age-based assessment models are used for many European stocks and allow a detailed description of historical trends in biomass of, and recruitment to, the stock of interest (Reeves et al., 2008). By contrast, the activities of the fishing vessels exploiting that stock are lumped into a single quantity in these models namely the fishing mortality (measure of the rate at which fish are being removed from a stock by fishing) (Lassen and Medley, 2001). Fishing mortality is a function of fishing
activity and hence it is important to consider the way in which any changes in fishing activity will alter the fishing mortality. Ultimately, there is an urgent need to improve understanding of fishing mortality in such a way that the information can be used alongside the biological stock parameters in fisheries management advice.

Moreover, up to now the spatial component of collected fisheries data, both from commercial and research sources, is mainly ignored by stock assessments. To date, there has been little attempt to incorporate the inherent spatial variability of a stock’s age-structure, maturity, selection or growth patterns and commercial catch data into a stock assessment framework (Booth, 2000). Ignoring these spatial trends can often provide inaccurate relative abundance estimates (Swartzman et al., 1992; Booth, 2000; Nishida and Chen, 2004) and lead to misleading interpretations of the various aspects of a species’ biology, such as its distribution, growth, reproductive and feeding patterns. As fishermen respond in terms of effort re-allocations to changing patterns of movement and behaviour in fish (Eastwood et al., 2008; Branch et al., 2005; Hall, 1988; Ogden and Quinn, 1984; Poulard and Léauté, 2002; Vignaux, 1996; Whitmarsh and Young, 1985), such changing fishing behaviour will impact fishing mortality rates. Thus, the location and intensity of fishing is thus an important issue for fisheries management.

The case of the North Sea saithe fishery

The North Sea saithe (Pollachius virens) (Linaeus, 1758) fishery provides a useful case study, because it illustrates the need for a greater understanding of fishing mortality and in particular its link with fishing activity. Saithe is of major economic importance for North Sea fisheries, with annual landings values of around 15 million Euros (Anderson and Guillen, 2009). It is targeted by Norwegian, French, German, British, Danish and, to a small extent, Swedish trawlers (ICES, 2012). Adult saithe are distributed in the northern North Sea along the shelf edge and the Norwegian Trench. Juveniles mainly occur in coastal areas such as the western Norwegian fjords until they enter the fishery aged 2-3 (ICES, 2012). Thus, discards of young saithe are negligible (ICES, 2012). When compared to other fisheries bycatch in the North sea saithe fishery is quite low (ICES, 2011).

In this fishery annual Total Allowable Catches (TACs) are the primary management measure. However, other measures, particularly restrictions considering the spatio-temporal component of fishing effort are ignored (ICES, 2010; ICES, 2013b). Additionally, since 2009 EU fleets targeting saithe are falling under the effort regime of the cod management plan, if their cod catch exceeds 5% of their total catch (ICES, 2010). However, the advisory system has not kept pace with this change as the existing stock assessments provide a means of giving advice on annual TACs, but not yet on fishing effort. Since 2002 TACs of that plan were not exhausted (ICES, 2011; ICES, 2012) and landings were stable for the last 20 years at about 100 000 t per year (ICES, 2012). Therefore saithe was regarded to be a good managed fish stock (BFAFI, 2007). However, SSB of saithe has declined in the last few years (ICES, 2012). Besides the declining SSB values, saithe has exhibited lower growth rates and recruitment has been below average since 2006 (ICES, 2012). These factors, when taken together, indicate a decline in stock productivity. This questions the sustainability of the current management plan for North Sea saithe (ICES, 2012). ICES re-evaluated the management plan in 2012 using a standard Management Strategy Evaluation (MSE) approach (ICES, 2012) which excludes economic aspects and the spatio-temporal interaction between stocks and fleet segments (ICES, 2013b). In fact, there has never been an impact assessment for the plan that takes into account fishermen behaviour or the economic performance of the fleet under different management plan options and scenarios.

The need for a management evaluation tool

The performance of fisheries management relies to a large extent on how well one is able to evaluate and forecast the combined biological and economic impacts of management measures (Charles, 1995; Hilborn and Walters, 1992; Salas and Gaertner, 2004; Sutinen and Sobol, 2003; Wilen, 1979; Wilen et al., 2002; Hilborn, 1985; Hilborn, 2007; Poos, 2010). Nowadays it is widely acknowledged (e.g. FAO,
Policy and governance synthesis as a tool for stakeholders

2003; Kempf, 2010; Nomura, 2008; Pikitch et al., 2004) that a more integrated perspective is needed which embraces the numerous issues related to stock conservation, economic and social objectives of fisheries. However the way to operationalize such a concept remains controversial as pointed out in Sanchirico et al. (2008). There is a growing interest in using bio-economic models as a tool for policy analysis to better understand pathways of development and to assess the impact of alternative policies on the natural resource. Bio-economic models aim to combine the fleet dynamics and fish population dynamics. These models can provide a better and more comprehensive indication of the feedback effects between socio-economic activity and natural resources (Prellezo et al., 2012).

Numerous bio-economic models have been developed by the community of fisheries scientists and economists since the early works of Gordon (1953) and Schaefer (1957). Until the beginning of this century, however, the biological and the economic components of these models are still unequally considered, depending on the main field of expertise of the lead scientist in charge of their development (e.g. Begossi, 1998; Dorn, 1998; He et al., 1997; Holland, 2000; Seijo and Defeo, 1994). Fishery economists typically focused on such processes as price setting, fleet, effort, and cost dynamics, but with limited efforts to account for the complexity of fish population dynamics, which were often included as an aggregated production function (Bastardie et al., 2010; Clark, 1980; Ganguly and Chaudhuri, 1995; Garcia and Charles, 2007; Garza-Gil, 1998; Sumaila et al., 2008; Tyedmers et al., 2005). By contrast, fishery scientists involved in stock assessments have developed management procedures using detailed age-structured models building in recruitment dynamics, but with little consideration for cost and price dynamics or for the economic processes driving fleet and effort dynamics (Horwood et al., 1990; Marchal, 1997; Punt and Butterworth, 1991). They generally tend to conflate a fishery system with an ecosystem, viewing the act of fishing as an (often negative) external influence. For instance, the model from Ulrich et al. (2011), which is tailored to providing mixed-fisheries considerations to the annual ICES single-stock TAC advice, does not consider any fishermen behaviour assumptions. Also, the model developed by Da Rocha et al. (2010), which was applied to evaluating recovery plans, assumed costs to be a source of uncertainty and fleet size (the number of vessels participating in the fishery) to be constant. Similarly, Pelletier et al. (2009) developed the “ISIS-Fish Model” to evaluate the bio-economic sustainability of multispecies, multi-fleet fisheries under a range of policy options but did not include the age structure of the populations and the entry or exit of vessels. In another model developed by Poos et al. (2010), marketable fish was represented as a homogeneous group, whereas, in real fisheries, the marketable catch consists of several size classes that may differ in value and directly affect economic performance and the related fleet dynamic consequences.

Thus existing bio-economic models focus on either fisheries economics or biology without considering how the dynamics of the fish stocks affects fishermen and vice versa (van Putten et al., 2012). Especially, the development of models focusing on population dynamics has been often favoured, while models describing the interactions between resources, fleets and management have been given much less attention (Marchal et al., 2013). For instance, climate-induced changes such as a shift in species distributions may seriously affect fishing activities (Pörtner et al., 2001; McLean et al., 2001), but research is generally focused on the biological system rather than the effect on fisheries (Haynie and Pfeiffer, 2012; IPCC, 2003). Even the few existing inferences from biology-focused models that have been used to predict the effect of climate change on fisheries (Brander, 2007; Cheung et al., 2010; Ianelli et al., 2011; Klyashtorin, 1998; Köster et al., 2003; Lehodey et al., 2006; Perry et al., 2005), neglect to incorporate how fisher men respond to these changes. However, understanding for example patterns of fishing effort has equal relevance for wider ecosystem management (Greenstreet et al., 1999 as the understanding of biological aspects, because it potentially has a greater impact (Kaiser et al., 2002). Even though, the vast majority of models ignore spatial-temporal variations of fishing effort and fish abundance. As a consequence, the understanding of how spatial resource distribution and availability, as well as stock-, season-, and area-specific regulations affect fishermen’s decision is poorly understood (Hilborn, 2007).
Ultimately, an integrated modelling approach is needed which not only includes information about organisms and their environment, but also includes social and economic perspectives in order to understand what motivates fishermen’s actions and how do these actions change the rest of the system. Such a model would thus need to highlight different aspects, shifting across disciplines and representing the various components in fisheries and their interactions (Garcia and Charles, 2007; Garcia et al., 1997).

Objectives within the VECTORS Project

The modelling approach conducted in VECTORS addresses the need of such an integrative model and evaluates various management strategies. The first objective was to create a model that not only equally includes biological and economic components, but also their spatio-temporal interactions. For this purpose biological components were integrated into an existing, complex, spatial explicit, economic model that is called FishRent (see Deliverable 3.3.1.). The second aim was to show the potential of the model by applying it to a case study, namely the North Sea saithe fishery. Thereby it is important to mention that although focusing on the North Sea saithe fishery, it was taken care that this model is applicable to other fisheries as well (e.g. FishRent was also used for the flatfish fishery). The idea was to use this model in order to identify major drivers of the considered fishery plus their impacts on fleet and population dynamics. Further it was used to explore the spatio-temporal dynamics of fish stocks and fleet segments and especially the distribution of fishing effort (see Deliverables of WP 2.3. and WP 3.3.). Additionally, alternative management strategies for the North Sea saithe fishery were tested under different biological and economic circumstances (see description of the B1 and A2 scenarios). Consequences of alternative HCRs (see deliverables of WP 2.3.; WP 3.3.), area closures (see deliverables of WP 3.3; WP 6.4), and discard prevention strategies (see deliverable of WP 6.4.) in the light of the upcoming discard ban of the Common Fisheries Policy, were explored for that fishery.

DESCRIPTION OF THE MODELLING APPROACH

FishRent in its improved form is a dynamic feedback model and is composed of several sub-modules (Figure A6.1). Different to previous models, this model not only considers a possible effort re-distribution, it does account for the fact that economic conditions (e.g. revenues and fishing costs) will determine fishing effort and that management regulations itself will alter relative profitability and hence subsequent effort decisions by fleet segments, which in turn will impact the commercial fish stock.
Net profits and costs

It is a model of a fishery system which focuses on the economic drivers, among which the profit earned by the fleet segments is the main driver (Figure A6.2). Profit generated from other non-explicitly modelled species or areas are taken into account in the model as a fixed proportion of the revenue. In the model profit depends on the amount of landed fish, prices for the landed fish and the costs of fishing. Costs of fishing include fuel costs that vary directly with effort (assuming a fuel price of 0.6 Euro per litre), variable costs, crew costs, capital costs (e.g. depreciation and interest payments) and fixed costs (e.g. administrative costs, insurance and maintenance costs). In the model crew costs are determined as a percentage of the difference between revenues and fuel costs. Thereby it is assumed that the skipper wage is 8% of the predicted crew costs per vessel, the steersman’s wage is 5% and the wages for the rest of the crew (on average 3 members) is 4% per person. Capital costs involving depreciation and interest payments are defined as a fixed share of the number of vessels. Besides these costs modelled profit, furthermore, depends on the interest rate for capital invested in the fleet.
Figure A6.2: Conceptual model design with arrows that explain the interaction between the sub-modules. The effort allocation pattern is changed until profit of all fleet segments is maximised. When profit is maximised the last effort allocation pattern is used in the Cobb-Douglas function to calculate catch, which in turn is used to calculate fishing mortality and SSB for the next step.

**Investment**

The economic response of the fleet is modelled through a dynamic investment and disinvestment function (number of vessels), which evaluates the change in the fleet capacity given the economic outcome of the fishery two years ago (eq.1). Thereby the break-even-revenue ($BER_{t,j}$) is an important variable. It considers revenues and costs with salary to the skipper/owner of the vessel included in the crew costs, and provides the value of gross revenue, where net profit is zero. It is assumed that the fleet changes, i.e. investment and disinvestment take place, proportionately to the relation between the break-even-revenues and the realised revenues. In particular, at the end of each year the number of vessels ($FLE_{t,j}$) in $j$th fleet segment is adjusted in terms of exit (eq.1a) or entry (eq.1b) of vessels depending whether gross revenues ($R_{t,j}$) pass below (unprofitable fishery) or exceed (profitable fishery) break-even-revenues two years before, respectively. This leads in some years to quite substantial changes in the number of vessels. Thus, parameters have been introduced to limit the fluctuation in investment and disinvestment (change in the number of vessels). In particular, a maximum percentage of 10% in disinvestment ($d^{max}_{j}$) and a maximum change of 5% in investment ($i^{max}_{j}$) is applied (eq. 1). As these two limits are different, it creates an asymmetric investment and disinvestment behaviour. To avoid a continuous growth of fleet size while vessels in the fleet segments have a low activity, the days-at-sea of a fleet segment ($DAS_{t,j}$) have to achieve a certain minimum level of days-at-sea per vessel ($das^{min}_{j}$) before the fleet size can be expanded (eq.1b). This minimum level is based on the historical average level of days-at-sea for the modelled fleet segments.
If \( BER_{t-2,j} > R_{t-2,j} \)

\[
(1a) \quad Inv_{t,j} = \text{MAX} \left[ \frac{d_{j}^{\text{max}} \times FLE_{t-1,j}}{R_{t-1,j} - BER_{t-1,j} \times FLE_{t-1,j}} \right]
\]

If \( BER_{t-2,j} \leq R_{t-2,j} \) and \( DAS_{t-1,j} < das_{j}^{\text{min}} \)

\[
(1b) \quad Inv_{t,j} = \text{MIN} \left[ \frac{i_{j}^{\text{max}} \times FLE_{t-1,j}}{R_{t-1,j} - BER_{t-1,j} \times FLE_{t-1,j}} \right]
\]

Where \( Inv_{t,j} \) is the number of vessels that is entering (eq. 1a) or leaving (eq. 1b) the fleet/fishery.

**Fishing effort**

It is presumed that fishermen seek to maximise profits by setting an optimal level and spatio-temporal distribution of fishing effort, which in turn impacts the fish stock. Each year, the applied CONOPT solver (for the detailed description of the CONOPT algorithm see (Drud, 1991)) uses various levels of fishing effort for each fleet segment, ICES rectangle and for each month within the historical minimum and maximum levels of each fleet segment (Figure A6.2). This effort level is used in the Cobb-Douglas production function (see Salz et al. (2011) and Simons et al. (2014a)) and with regard to the cost, revenue and overall profit function (Figure A6.2). The solver then selects the effort level for each ICES rectangle, month and fleet segment that results in the maximum overall annual profit of all modelled fleet segments (Figure A6.2).

**Population dynamics**

The selected optimal effort level used in the Cobb-Douglas production function provides a catch estimate, which is then used in the Pope’s approximation (Pope, 1972) to calculate the number of individuals of \( i \)th age at time \( t \):

\[
(2) \quad N_{t,i,k} = N_{t-1,i-1,k} e^{-M_{t}} - \sum_{j} \left( \frac{C_{t-1,i-1,k,j}}{s_{i,k,j}} \right) e^{-\frac{M_{t}}{2}}
\]

Where \( N_{t,i,k} \) is the number of fish of \( i \)th age in \( k \)th area at time \( t \), \( C_{t,i,k,j} \) is the catch in numbers of \( i \)th age, in \( k \)th area and \( j \)th fleet segment at time \( t - 1 \) and \( s_{i,j,k} \) is the catch share for \( i \)th age, in \( k \)th area and \( j \)th fleet segment (constant over time). The catch share serves to estimate the total catch of a species considering the catches of non-modelled fleet segments. \( M_{t} \) is the instantaneous natural mortality rate for \( i \)th age derived from ICES (2013b). In turn, the estimated number of individuals is then used in equation 3 to calculate the age-specific instantaneous fishing mortality

\[
(3) \quad F_{t,i,k} = -\ln \left( \frac{N_{t,i,k}}{N_{t-1,i,k}} \right) - M_{t}
\]
In the model individual fish grows according to the van Bertalanffy weight-at-age function (von Bertalanffy, 1938). For the case study the parameters used in this function were estimated directly from weight-at-age data of the North Sea saithe and cod stock (ICES, 2013b). Once a year, stochastic recruitment (the number of fish of age three (saithe) and age one (cod) at the beginning of the year) is calculated via a Beverton and Holt stock-recruitment function (Beverton and Holt, 1957).

\[
R_t = \frac{a \times SSB_t}{c + SSB_t} \times e^{(0.5 CV - 0.5 CV^2)}
\]

With SSB as the overall SSB for a species at the peak of the spawning period. The parameters \(a\) (190.9 for saithe and 97.4 for cod) and \(c\) (76.4 for saithe and 14.6 for cod) are species-specific and were estimated via the non-linear least-squares approach with data of the North Sea saithe and cod stock (ICES, 2013b). \(D\) is a standard normal deviate and \(CV\) is the coefficient of variation (CV = standard deviation/mean), estimated based on historical stock sizes at age 3 for saithe and at age 1 for cod from 1967-2012 (ICES, 2013b). Each time the stochastic recruitment model is employed, 1000 stochastic iterations are run. This means that for each time step/year 1000 random iterations from the probability distribution in the stock-recruitment function are run. For saithe the number of fish that recruit to each ICES rectangle within the defined feeding grounds is assumed to be an equal fraction of the entire number of recruits. For cod recruits are distributed equally among the ICES rectangles in which cod initially occurred. At the end of each year, all fish of \(i\)th age are moved to the next age class. All fish older than the maximum age are accumulated in the last age class (plus group at age 10s).

### Seasonal movement

Although simulations of species seasonal movements can only be a stylised representation of real movements, due to insufficient empirical information, there are reasons why they should be considered when evaluating alternative management scenarios. First, they are useful to demonstrate the impacts of directional movement of fish relative to the economic response of fleet segments. Second, species seasonal migration patterns influence the distance between the fishing grounds and ports of fleet segments, which through fuel use, investments and available time for fishing directly affect profits.

For saithe seasonal migrations to feeding and spawning grounds and dispersal to adjacent areas were simulated, while for cod only dispersal was simulated. In the model, at the end of each monthly time step, fish movements occur and the number of individuals in each age group in each area is adjusted according to

\[
N_{t,i,a} = N_{t-1,i,k} \left[1 - \sum_{\forall l \neq k} \left(dis_{k,l} + seas_{k,l}\right)\right] + \sum_{\forall k \neq l} N_{t-1,i,l} \left(dis_{l,k} + seas_{l,k}\right)
\]

Where \(dis_{k,l}\) and \(seas_{k,l}\) are the dispersal rate and the seasonal migration rate from ICES rectangle \(k\) to contiguous ICES rectangle \(l\), respectively. Individuals can only move north, south, east or west. Dispersal of fish between contiguous ICES rectangles was equal for each species and each age group and was set to 0.1 indicating that 10% of the fish population in each ICES rectangle is moved north, south, east and west to each contiguous ICES rectangle each month. The seasonal migration rate allows a directional movement of fish in addition to the random component of movement modelled as dispersal. The migration parameter \(seas_{k,l}\) was set to 0.023 for saithe and to 0 for cod. This implies that for instance for saithe each month 2.3% of fish in ICES rectangle \(k\) is moved to one contiguous
ICES rectangle in addition to and independent of whatever movement occurs as a result of dispersal. The value for the movement parameter of saithe were set such that the density of the fish stock during the feeding and spawning period, respectively, approximates observed relative densities from scientific survey data of the International Bottom Trawl Survey (IBTS) for this stock during these times of the year (1st and 3rd quarter) (Figure A6.3).

In the model, from November to January it is assumed that three years or older saithe migrate from the feeding grounds to their spawning grounds given to a predefined moving matrix (Figure A6.3). In February the spawning event is assumed to happen for both species and saithe stays on its spawning ground (Figure A6.3). From March to May modelled individuals are assumed to migrate from the spawning ground to the feeding grounds (Figure A6.3). Individuals stay at their feeding grounds from June to October, before they migrate to the spawning ground between November and January (Figure A6.3).
EVALUATION OF THE MODELLING APPROACH

The modelling approach and application of FishRent within VECTORS (WP2.3; WP3.3; WP6.4) confirm the need for integrating the dynamic interplay between biological and economic components of a system into models that are used for management evaluations. This study integrated biological processes into an already existing complex economic model in order to use that model for management strategy evaluations. In this model, costs and prices influence revenues and profits, which in turn will impact the fishing behaviour in terms of effort level, effort distributions and entry or exit of vessels. The fishing behaviour influences the fishing mortality, which in turn affects the stock size and ultimately the stock dynamics. On the other hand, biological factors such as maturation, growth or recruitment affect the stock dynamics, stock size and ultimately the fishing behaviour. Additionally spatial components such as seasonal migrations or dispersal of species and steaming costs between home ports and fishing grounds of individual fleet segments are considered as well. Ultimately, the model in its current status captures essential mechanisms that are required when evaluating alternative management strategies.

The indirect effect of fuel costs on stock size

The findings of this modelling approach suggest that costs and in particular fuel costs have a considerable effect on how fishing effort is distributed in space and time, affecting fishing mortality and hence stock size. For instance, results of Simons et al. (2014a) (see also Deliverable of WP3.3.) declare that increasing fuel prices cause a general reduction in fishing effort in terms of days at sea, being beneficial for the fish stock. Moreover, in Simons et al. (2014b) (see also Deliverable of WP3.3.) the spatial component was considered and it was found that fleet segments do not fish in high cpue areas if costs are too high. Depending on the areas where fishing effort is displaced to, the effect on stock size will vary. In the tested case study, fishing effort was shifted to areas that were closer to home ports of fleet segments when fuel prices were increased. In turn, through the shift fishing was directed increasingly to mainly young saithe, resulting in a decline of SSB when the low number of young saithe reached older age classes in subsequent years.

This is an important finding which shows that economic drivers such as fuel prices affect stock dynamics indirectly through modifications of the fishing behaviour. Moreover, it demonstrates that resultant catch rates will reflect not just the total and contemporary fish abundance; they also depend on economic variables such as fuel prices and fuel costs.

Sampson (1991) has already discussed the effect of fuel costs on the distribution patterns of fishing effort. He further discussed its impact on the relationship of catch rates and fish abundances. However, there is no study of a modelling framework, which includes the full feedback mechanism between changing fuel prices, fishing efforts and stock dynamics. Most studies (e.g. Holland and Sutinen, 1999; Holland and Sutinen, 2000; Hutton et al., 2004; Poos, 2010) focus only on the fishermen’s response in terms of changing fishing effort patterns without making the link back to the stock dynamics. Moreover, costs are often modelled in an oversimplified way. For instance, in the model from Pezzey et al. (2000), which was used to explore the effect of marine reserves, cost of effort are constant. Sanchirico and Wilen (2001) and Sanchirico and Wilen (2002)’s models include patch-specific costs representing variable costs. In the ECOSEED model of Beattie et al. (2002), each fishing ground is assigned an economic value that encompasses revenues per fleet and per biomass pool and existence values of species pools, as well as fixed costs and operating costs. In contrast, in the model presented here costs are not attached to patches or fishing grounds, but relate to different components of fishing effort such as vessels or days at sea.

Results were compared to observed effort distributions. In fact, the predicted effort shift had been observed for the German fleet in recent years (ICES, 2011). Scientists are not sure about the reasons for that shift, but when asking a German saithe fisherman he stated: “In the past we steamed to the Shetlands, fished there, and steamed back to Cuxhaven. Nowadays the fuel costs are too high and it is
not any longer possible. I would need to steam four days per trip, this means four times 6,000 litre fuel, which are 24,000 litre and about 15,000 Euro only for steaming. That’s why we take the shorter ways to Hanstholm. If you fish in the Skagerrak you are sometimes only 3, 4, 5 hours away from Hanstholm. This is substantially more cost-effective.” (Interview, 2014). However, he also named a second reason why he had shifted his effort: “In the past we stored the fish in large boxes with up to 6 tons of fish per box. In these boxes the fish was kept fresh for a long time. Nowadays we have smaller boxes, where the fish is kept fresh fewer days.....If you steam up to the north and catch fish you know that it lasts 5 to 6 days and then the fishery will be over, because then the first fish starts to taint and if you have a totally bad looking fish you will not get a lot of money for it. In the past we could stay for 14 days....When using the larger boxed around 20 persons were needed to land the fish, while with smaller boxes we can do it on our own, which is more cost effective...Nowadays the costs of landing fish when using large boxes will be around 25% of the revenue, but when using smaller boxes and doing it on our own its 10-12% of the revenue.” (Interview, 2014).

The interaction between economic factors such as fuel prices on fishing behaviour and ultimately on the stock dynamics is especially relevant for stock assessments, where it is still often falsely assumed that catch is proportional to stock abundance. This assumption suggests that fishermen always fish in areas of high fish abundance regardless of the associated costs. Thus, this model is helpful in interpreting the catch rates correctly. However, the model should not be used to predict the precise spatio-temporal effort distribution as fleet segments are assumed to have a perfect knowledge about potential catch rates.

Fishermen’s knowledge of and response to changing species distribution

Not only economic variables also biological processes impact the fishing behaviour and hence the fishing mortality. In this modelling approach it is argued that fishermen do recognize, locate and respond to changing species distribution. For the case study the focus was laid on the spatial contraction behaviour of saithe, seasonal migrations of species and the northward distribution shift of cod.

In the study for WP3.3. it was assumed that the stock contracts spatially when the overall stock size declined. Fleet segments followed the stock and were increasingly fishing in areas where the stock was concentrated. This in turn increased the fishing pressure on the stock and hence increased the fishing mortality rate. Assuming that fleet segments do follow this pattern it is consistent with real observations. In particular, in the Northern Atlantic cod fishery the stock contracted as well when overall stock size was declining and fleet segments followed this pattern, resulting finally in a stock collapse (DeYoung and Rose, 1993; Rose et al., 1994; Rose and Kulka, 1999). This collapse was mainly due to the fact that catch rates, which were used as a proxy for stock abundance in the stock assessment, were masking the actual decline of the stock and hence TACs were not reduced. However, in the simulations presented here the impact on the stock was less fatal, because it was assumed that SSB is perfectly known and hence TACs were reduced and successfully protected the stock.

Moreover, in the study of WP3.3. fleet segments tended to follow the seasonal migration pattern of saithe resulting in higher fishing mortality rates when the stock was concentrated on spawning or feeding grounds. The predicted spatio-temporal variability in fishing effort distributions is consistent with real observations of seasonal effort distributions (ICES, 2011), supporting the assumption that fishermen are able to “predict” the seasonal pattern of species distributions. The predictions are also consisted with the response of a German saithe fisherman when asking him how his fishing effort is distributed throughout the year. He said that he knows where and in which season of the year its best to fish. He further said that he has gained this knowledge over years through experiences. He said: “Nowadays it became rare that we explore a new area, because you already know most of the North Sea region and you know where saithe is during specific seasons.” (Interview, 2014). Up to now seasonal migrations of species are rarely taken into account in models that are used for management...
evaluations. However, this finding stresses the need for including them, as results have shown that seasonal migrations do considerably determine the vulnerability of the fish stock to the fishery. Including seasonal movements of species becomes especially relevant when evaluating spatial management strategies such as area closures (Guénette et al., 1998; Pelletier and Magal, 1996; Apostolaki et al., 2002). For instance, the study for WP6.4 has shown that in the case of seasonal patterns, the adequate timing of the closure is an important factor for its efficiency.

In the study for WP2.3, WP3.3 and WP6.4 a northward distribution shift of cod was assumed. This distribution shift resulted in a higher spatial overlap making it harder for saithe fishermen to avoid cod bycatch. In the model it was assumed that fishermen are able to locate the changed spatial overlap of species. As a result they actively avoided areas of high cod-bycatch, but started to fish in areas of high saithe concentrations. This in turn increased the fishing pressure on the saithe stock. The assumption that fishermen have noticed and respond to the changed distribution of cod is supported by the interviewed German saithe fisherman, who said: “Cod moved. It moved to areas or depths where it usually has never been. 25 years ago until 1990 we fished in the German Bight...the fish that was before in the English Channel is now around Helgoland, because the water became warmer....everything that was around Helgoland is now up around Hansholm. It is the experience that you have gained over years and you know eventually the areas...it is not the area it is the depth... You have to go fairly for depths. If you are too shallow you will have quickly 1000, 1500, 2000 kg cod in your net. Saithe also goes into shallow waters...which it almost never or hardly did in the past...hence you have a mixture of cod and saithe. Therefore it is the best if you start specifically fishing in areas where you know that there is few cod...you have that knowledge...that is the experience you have.” (Interview, 2014).

These three examples have shown that predictability of the spatial and temporal patterns of fish stocks has important implications for the spatial distribution of fleet segments, the fishing effort and ultimately the fishing mortality. The finding that fishermen do monitor, locate and respond to changes in stock dynamics is relevant to fishery managers, because they need to design management plans that take this bio-economic interplay into account. This finding might be helpful for them, because it shows how a potential response of fleet segments to changes in stock distributions could look like. Further the potential feedback of changed fishing behaviour on the stock size is demonstrated. However, this assessment is limited by the knowledge, information and data of biological changes that is available.

**Implications for the North Sea saithe fishery management**

For North Sea saithe there exist a long-term management plan including a HCR with an constraint of 15% for annual TAC changes (ICES, 2013a). Moreover, fleet segments targeting saithe are not allowed to have cod catches that exceed 5% of their total catches, otherwise they will fall under the effort regime of the cod management plan (ICES, 2010). Although this management plan exists SSB of saithe is declining in recent years, recruitment is below average since 2006, and the mean weight-at-age is reduced (ICES, 2013a). Moreover, there is concern about a potential hyperstability (ICES, 2011), which is the process when catch rates decline much lower than the actual stock size does (Harley et al., 2001).

With respect to this situation the findings of this study suggest that SSB of saithe will further decline under the current management, because in its actual status it is unable to account for the spatio-temporal interactions between fleets and fish stocks. In particular, findings of Simons et al. (2014a), which did not consider the spatial dimension of the system, suggest that constraining the allowed annual change of the TAC by 15% is still sufficient in protecting SSB. In other words the current HCR was found to be successful in protecting SSB. Even under high natural variation of recruitment this HCR option was found to be successful and revealed an 80% probability of SSB being above its precautionary reference point in long-term. However, findings of Simons et al. (2014b), which considered the spatial dimension, suggest that SSB under the current management will further decline.
This is mainly due to the fact that by integrating the seasonal migrations of species and the contraction behaviour of saithe, the stock becomes more vulnerable to the fishery as fleet segments tend to follow fish to their feeding and spawning grounds. Thus, as spatial distribution of species has a profound effect on the spatio-temporal distribution of fishing effort and hence fishing mortality, it is suggested that the quota system is used in combination with a temporal area closure to protect SSB of saithe. In particular, in the study of WP6.4, the various area closures of different locations, sizes and duration were all successfully increasing SSB of saithe.

Moreover, findings of the study in WP6.4 suppose that the upcoming discard ban will be negative for the North Sea saithe stock, as fleet segments are predicted to increasingly catch young fish at the feeding grounds of saithe. Results of this study suggest that managers should provide incentives to fishermen rather than using banning rules. In particular, results suggest that a more flexible quota system in terms of inter-species quota exchange possibilities would be more effective in protecting both the North Sea cod and saithe stock. This inter-species quota exchange involves cost to the fisherman and in this way incentivizes fishermen to avoid cod-bycatch. However, it has shown to also provide fishermen the required opportunity to land the whole catch in cases where they had caught more cod than expected. The relevance of such an opportunity is supported by the interviewed German saithe fisherman, who has 32 years of experiences in that fishery, and stated: “Sometimes you already reach the 5% limit of cod within one haul...you then pile out of that area...there is always a risk...you can never be sure.”

Besides conservation issues, there is also the economic point of view when evaluating alternative management strategies. In particular, all tested management strategies involved short-term costs causing the exit of vessels. For instance, in Simons et al. (2014a) the tested HCRs caused a reduction in fleet size of up to 11%. In reality, the number of vessels of the considered fleet segments declined by around 5% in recent years (Anderson et al., 2012). Thus, predicted fleet size reductions might be overestimated. Moreover, fishermen may be quite resilient. For example, the interviewed German saithe fisherman explained that he has worked as an independent fisherman since he was 30 years old. He started with a quota for saithe of around 1800 tons, but after 10 years when his quota was ultimately reduced to 140 tons, he decided to work jointly with other fishermen for one company, but still staying in the same fishery. His chef stated that also most of the other German saithe fishermen have worked in that fishery for several years now. Finally, although in short-term there is a tension between conservation and economic objectives for most tested measures (the two HCRs, the southern and western area closure and the flexible quota system) fleet segments will benefit in the long-term.

CONCLUSION

This modelling approach is a step forward in the development of models that can be used for fisheries management evaluations, because it not only integrates essential biological and economic components equally, it also considers their interactions in time and space. The explicit and balanced representation of the biological and economic dynamics also means that the model can help clarify the implications of ecological changes not only for the fish stocks and fleet segments but also for effective forms of fisheries management, topics which are of growing concern for resource managers (Benoît and Swain, 2008; Brander, 2007). Thus, when designing a new management plan this model can help to understand how fishermen might respond to that plan and also to biological and (or) economic changes that can occur simultaneously. However, it is important to note that the model presented here is not an appropriate tool that should be used to dictate tactical management decisions, such as setting catch quotas or determining best location of closed areas. The model is simultaneously fit across multiple parameters and against multiple data sets. Given the uncertainty associated with these data sources, it is important to focus on accuracy rather than precision. In turn, this means that while the model is suitable for strategic direction setting, other models such as fishery stock assessment models (e.g.
Methot, 2009) or extended stock assessment models (Townsend et al., 2008) are much more appropriate for addressing specific tactical fisheries questions.

OUTLOOK

This modelling work stresses the importance of interdisciplinary and international collaborations between modellers, fisheries scientists, fishermen, stakeholder, economists, sociologists and biologists. Substantial effort was and will be devoted to the evolving model structure documentation through user manuals. Meetings of and for users and developers were and will be organized and attended to share experiences with the model, because they greatly contributed to its improvement. As fisheries managements' needs and demands evolve through time so will do this model. The future development will mirror many remaining contentions that plague effective implementation of the reformed CFP. A future objective is to establish a website that enhances sharing of experiences among users and to show others the model's potential. Moreover, significant time and effort will be put into making this model an easier handling tool to use, because scientific tools such as this model are only useful if the managers of the resource comprehend the information they provide (Lee, 1999).

ANNEX 6 REFERENCES


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ANNEX 7 - MODELLING FISHERMEN'S RESPONSE TO ALTERNATIVE AREA CLOSURES AND BYCATCH PREVENTION STRATEGIES: BIO-ECONOMIC IMPLICATIONS FOR THE NORTH SEA SAITHE FISHERY

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THE NORTH SEA SAITHE FISHERY

Saithe (Pollachius virens) is of major economic importance for North Sea fisheries, with annual landings values of around 15 million Euros (Anderson and Guillen, 2009). It is targeted by Norwegian, French, German, English, Danish, and to a small extend Swedish trawlers (ICES, 2012). There exists an EU-Norway long-term management plan for North Sea saithe. This plan involves a Harvest Control Rule (HCR) with annual Total Allowable Catches (TACs), and reference points. Blim is the reference point for SSB, below which there is a high probability that recruitment is impaired (ICES, 2010; Lassen and Medley, 2001). Bpa is the precautionary reference point for SSB, below which the stock would be regarded as potentially overfished (ICES, 2010; Lassen and Medley, 2001). F_tar is the average fishing mortality for age class 3-6 that is set as a target (ICES, 2010; Lassen and Medley, 2001). In the long-term management plan for North Sea saithe F_tar is set to 0.1 (F_(tar-low)), when SSB is estimated to be below the minimum level of 106 000 tons (Blim) (ICES, 2013b). Usually the fishing mortality is ~ 0.4, therefore a F_tar of 0.1 is a large reduction to allow SSB to recover. Where SSB is above 200 000 tons (Bpa), the parties agreed to restrict fishing on the basis of a TAC consistent with a target fishing mortality of 0.3 (F_(tar-up)) (ICES, 2013b). In the case if SSB is estimated to be between Bpa and Blim the target fishing mortality rate (F_(tar-mid)) is calculated as:

\[
F_{\text{tar-mid}} = F_{\text{tar-up}} - (F_{\text{tar-up}} - F_{\text{tar-low}}) \times \left( \frac{B_{\text{pa}} - SSB}{B_{\text{mn}} - SSB} \right)
\]

Although, there exists a long-term management plan, spawning stock biomass (SSB) of saithe has declined in the last few years and is currently close to Bpa (ICES, 2012). Besides the declining SSB values, recruitment of saithe has been below average since 2006 (ICES, 2012). Together with the lower growth rates (ICES, 2012), it indicates a decline in stock productivity. Moreover, there are raising concerns about a potential hyperstability (ICES, 2012), which describes the process when catch rates, which are used as a proxy of stock abundance in stock assessment, decline much slower than the actual stock abundance does (Harley et al, 2001). This questions the sustainability of the current HCR used in the management plan for North Sea saithe (ICES, 2012b).

Area closures

Area closures or Marine Protected Areas (MPAs) have received considerable attention as possible means of replacing or enhancing other management measures to control the utilisation of marine resources. An area closure could provide an insurance against management failures resulting from insufficient knowledge and understanding of the fishery system being managed (e.g. Ballentine 1994; Clark 1996; Lauck et al. 1998; Roberts and Polunin 1993; Sumalia 1998). However, it is important to consider how interactions of humans and biological systems influence the results of alternative area closures (Sanchirico and Wilen, 1999). Therefore, it is critical to incorporate integrated and explicitly spatial interactions of the biological and economic component in a fishery system to evaluate if a spatial management policy will work. In particular, it is necessary to understand how the economic response of fishermen in redistributing their fishing effort after closures will impact fish in other areas and the overall productivity of the fishery. In the present study both economic and biological consequences of imposing various area closures on top of an existing fisheries management system that limits catches by setting annual TACs were explored. As a part of this study it was investigated how interactions of fleet segments and fish stocks influence the results of alternative area closures. A bio-economic simulation and optimisation model is used to explore how area closures in combination with catch regulations might affect bycatches, net profits, and the spawning stock biomass. This is done in the light of a high
level of natural variation in recruitment. The simulations of area closures of different duration, size and location relative to major ports and its orientation relative to seasonal movement patterns of fish stocks were run and their effectiveness and the distribution of benefits across fleet segments from different ports analysed.

**Discards**

The present literature on discards has mainly been descriptive, with a focus on understanding discard rates of specific species (Welch et al., 2008), estimating the amount or proportion of total catch discarded from particular fisheries (Rochet et al., 2002; Stratoudakis et al., 1999), species and length compositions of discards (Catchpole and Gray, 2010), (Stratoudakis et al., 2001; Zeller and Pauly, 2005), as well as global discard estimates (Alverson et al., 1994; Kelleher, 2005). While these studies help to provide a better insight into the discarding problem there is a lack of quantitative studies regarding fishermen’s discarding behaviour. Thus the purpose of this study was to explore the fishermen’s incentives and responses to discard prevention strategies rather than to assess the actual level of discarding. Four fleet segments with saithe (*Pollachius virens*) as a target species and cod (*Gadus morhua*) as a bycatch species were included. In the model fishermen were assumed to strive for maximal profits with an optimal effort strategy, which in turn affected the two fish stocks. With the model both ecological (e.g. stock sizes, fishing mortality rates) and economic success (profits) were evaluated for the current management, a Discard Banning (DB) and an inter-species Quota Flexibility (QF) system where quota of saithe could be used to cover over-quota catch of cod at a ratio 1:5.

**MODEL DESCRIPTION**

The presented modelling approach is based on a bio-economic optimisation and simulation model called "FishRent" (Salz et al., 2011; Simons et al., 2014). It is a dynamic feedback model and is composed of several sub-modules (Figure A7.1). Different to previous models this model not only considers a possible effort re-distribution, it does account for the fact that economic conditions (e.g. revenues and fishing costs) will determine fishing effort and that management regulations itself will alter relative profitability and hence subsequent effort decisions by fleet segments, which in turn will impact the commercial fish stock.

![Figure A7.1: Conceptual model design with arrows that explain the interaction between the sub-modules. The effort allocation pattern is changed until profit of all fleet segments is maximised. When profit is maximised the last effort allocation pattern is used in the Cobb-Douglas function to calculate catch, which in turn is used to calculate fishing mortality and SSB for the next step.](image_url)
Net profits

It is a model of a fishery system which focuses on the economic drivers, among which the profit earned by the fleet segments is the main driver (Figure A7.1). Profit generated from other non-explicitly modelled species or areas are taken into account in the model as a fixed proportion of the revenue. In the model profit depends on the amount of landed fish, prices for the landed fish and the costs of fishing. The latter was derived from Annual Economic Reports on the EU Fishing Fleet (Anderson and Carvalho, 2013) and included fuel costs (assuming a fuel price of 0.6 Euro per litre), variable costs, crew costs, capital costs (e.g. depreciation and interest payments) and fixed costs (e.g. administrative costs, insurance and maintenance costs). In the model profit, furthermore, depends on the interest rate for capital invested in the fleet. In particular, profit from two years ago determines the level of investment or disinvestment in the fleet (for details see Salz et al. (2011) and Simons et al. (2014)), involving changes in the number of vessels of a fleet segment.

Fishermen behaviour

It is presumed that fishermen seek to maximise profits by setting an optimal level and spatio-temporal distribution of fishing effort, which in turn impacts the fish stock. Each year, the applied CONOPT solver (for the detailed description of the CONOPT algorithm see (Drud, 1991)) uses various levels of fishing effort for each fleet segment, ICES rectangle and for each month within the historical minimum and maximum levels of each fleet segment. This effort level is used in the Cobb-Douglas production function (see Salz et al. (2011) and Simons et al. (2014)) and with regard to the cost, revenue and overall profit function (Figure A7.1). The solver then selects the effort level for each ICES rectangle, month and fleet segment that results in the maximum overall annual profit of all modelled fleet segments (Figure A7.1).

Population dynamics

The selected optimal effort level used in the Cobb-Douglas production function provides a catch estimate, which is then used in the Pope’s approximation (Pope, 1972) to calculate the number of individuals of ith age at time t:

\[(1) \quad N_{t,i,k} = N_{t-1,i,k} e^{-M_t} - \sum_j \left( \frac{C_{t-1,i-1,k,j}}{s_{i,j,k}} \right) e^{-\frac{M_t}{2}} \]

Where \(N_{t,i,k}\) is the number of fish of ith age in kth area at time t, \(C_{t,i,k,j}\) is the catch in numbers of ith age, in kth area and jth fleet segment at time t-1 and \(s_{i,j,k}\) is the catch share for ith age, in kth area and jth fleet segment (constant over time). The catch share serves to estimate the total catch of a species considering the catches of non-modelled fleet segments. \(M_i\) is the instantaneous natural mortality rate for ith age derived from ICES (2013b). In turn, the estimated number of individuals is then used in equation 3 to calculate the age-specific instantaneous fishing mortality

\[(2) \quad R_{t,i,k} = -\ln \left( \frac{N_{t,i,k}}{N_{t-1,i,k}} \right) - M_t \]

In the model individual fish grows according to the von Bertalanffy weight-at-age function (von Bertalanffy, 1938). For the case study the parameters used in this function were estimated directly from weight-at-age data of the North Sea saithe and cod stock (ICES, 2013b). Once a year, stochastic recruitment (the number of fish of age three (saithe) and age one (cod) at the beginning of the year) is calculated via a Beverton and Holt stock-recruitment function (Beverton and Holt, 1957).

\[(3) \quad R_t = \frac{a * SSB_t}{c + SSB_t} * e^{(D-CV-0.5*CV^2)} \]
With SSB as the overall SSB for a species at the peak of the spawning period. The parameters $a$ (190.9 for saithe and 97.4 for cod) and $c$ (76.4 for saithe and 14.6 for cod) are species-specific and were estimated via the non-linear least-squares approach with data of the North Sea saithe and cod stock (ICES, 2013b). $D$ is a standard normal deviate and $CV$ is the coefficient of variation ($CV = \frac{\text{standard deviation}}{\text{mean}}$), estimated based on historical stock sizes at age 3 for saithe and at age 1 for cod from 1967-2012 (ICES, 2013b). Each time the stochastic recruitment model is employed, 1,000 stochastic iterations are run. This means that for each time step/year, 1,000 random iterations from the probability distribution in the stock-recruitment function are run. For saithe the number of fish that recruit to each ICES rectangle within the defined feeding grounds (Figure A7.2a) is assumed to be an equal fraction of the entire number of recruits. For cod recruits are distributed equally among the ICES rectangles in which cod initially occurred (Figure A7.2b). At the end of each year, all fish of ith age are moved to the next age class. All fish older than the maximum age are accumulated in the last age class (plus group at age 10s).

Figure A7.2: The spatial layout for simulations of the North Sea saithe fishery. The North Sea is subdivided by the grid of ICES rectangles with a focus on four zones. Zone 2 is zoomed out and the individual ICES rectangles are numbered to explain individual area closures. Main home port for the Danish (Hirtshals), English (Grimsby), French (Boulogne) and German (Cuxhaven) fleet segment are shown. Feeding (grey) and spawning grounds (black) of North Sea saithe that were used to simulate seasonal migrations (a) and initial distribution of North Sea cod used to distribute modelled recruitment and to simulate dispersal of fish to adjacent ICES rectangles (b) are shown.

Seasonal movement simulations

Although simulations of species seasonal movements can only be a stylised representation of real movements, due to insufficient empirical information, there are reasons why they should be considered when evaluating alternative management scenarios. First, they are useful to demonstrate the impacts of directional movement of fish relative to the economic response of fleet segments. Second, species seasonal migration patterns influence the distance between the fishing grounds and ports of fleet segments, which through fuel use, investments and available time for fishing directly affect profits.

For saithe seasonal migrations to feeding and spawning grounds and dispersal to adjacent areas were simulated, while for cod only dispersal was simulated. In the model, at the end of each monthly time
step, fish movements occur and the number of individuals in each age group in each area is adjusted according to:

\[
N_{t,i,a} = N_{t-1,i,k} \left[ 1 - \sum_{k \neq l} (\text{dis}_{k,l} + \text{seas}_{k,l}) \right] + \sum_{k \neq l} N_{t-1,i,l} (\text{dis}_{l,k} + \text{seas}_{l,k})
\]

Where \( \text{dis}_{k,l} \) and \( \text{seas}_{k,l} \) are the dispersal rate and the seasonal migration rate from ICES rectangle \( k \) to contiguous ICES rectangle \( l \), respectively. Individuals can only move north, south, east or west. Dispersal of fish between contiguous ICES rectangles was equal for each species and each age group and was set to 0.1 indicating that 10% of the fish population in each ICES rectangle is moved north, south, east and west to each contiguous ICES rectangle each month. The seasonal migration rate allows a directional movement of fish in addition to the random component of movement modelled as dispersal. The migration parameter \( \text{seas}_{k,l} \) was set to 0.023 for saithe and to 0 for cod. This implies that for instance for saithe each month 2.3% of fish in ICES rectangle \( k \) is moved to one contiguous ICES rectangle \( l \) in addition to and independent of whatever movement occurs as a result of dispersal. The value for the movement parameter of saithe were set such that the density of the fish stock during the feeding and spawning period, respectively, approximates observed relative densities from scientific survey data of the International Bottom Trawl Survey (IBTS) for this stock during these times of the year (1st and 3rd quarter) (Figure A7.3).

In the model, from November to January it is assumed that saithe that is three years or older migrate from the feeding grounds to their spawning grounds given to a predefined moving matrix (Figure A7.3). In February the spawning event is assumed to happen for both species and saithe stays on its spawning ground (Figure A7.3). From March to May modelled individuals are assumed to migrate from the spawning ground to the feeding grounds (Figure A7.3). Individuals stay at their feeding grounds from June to October, before they anew migrate to the spawning ground between November and January (Figure A7.3).
Figure A7.3: For quarter 1 and 3, the initial biomass distribution in tons of North Sea saithe derived from IBTS survey data is shown indicating the distribution during spawning and feeding, respectively. For quarter 2 and 4, no survey data exists and maps show regions that indicate target feeding and spawning grounds, respectively. Arrows indicate the preferred movement of individuals.
**SCENARIOS**

**Area closures**

Various area closures were tested in combination with a quota system to protect SSB of saithe. For each closure scenario the effects on profit and SSB were compared with the values achieved without a closure (baseline scenario). Area closures were introduced exclusively in zone 2 (Figure A7.1), because zone 2 is the primary zone where the saithe stock is believed to aggregate for spawning and is hence especially vulnerable to fishing (Jones and Jonson, 1971; Olsen et al., 2010). Area closures were imposed at the beginning of the modelling period and were kept closed from fishing for either two months (January to February), covering the spawning peak of North Sea saithe (peak), or for the whole year (whole)(Table A7.1). To explore the effect of the size and spatial orientation of closures relative to fishing ports and seasonal migrations of fish, simulations of area closures differed in sizes with a 25% or 50% closure of zone 2 and location with a northern, southern, western or eastern closure of zone 2 (Table A7.1). For instance, a northern closure of 25% included the ICES rectangles 1-4 of zone 2 (Figure A7.1, Table A7.1) and a northern closure of 50% included ICES rectangles 1-8 of zone 2 (Figure A7.1, Table A7.1).

Table A7.1: Description of the different area closures. In zone 2 the northern, western, eastern or southern part is closed for 25% or 50% during the spawning peak of 2 months (peak) or the whole year (whole) considering a dispersal rate of species to adjacent areas of 0.1 or 1. Numbers in parenthesis represent the ICES rectangles of zone 2 that are closed.

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<thead>
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<th>Location</th>
<th>Size</th>
<th>Duration</th>
<th>Dispersal rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>25% (1-4) 50% (1-8)</td>
<td>peak</td>
<td>d=0.1</td>
</tr>
<tr>
<td>South</td>
<td>25% (13-16) 50% (9-16)</td>
<td>peak</td>
<td>d=0.1</td>
</tr>
<tr>
<td>West</td>
<td>25% (1,5,9,13) 50% (1-2,5-6,9-10,13-14)</td>
<td>peak</td>
<td>d=0.1</td>
</tr>
<tr>
<td>East</td>
<td>25% (4,8,12,16) 50% (3-4,7-8,11-12,15-16)</td>
<td>peak</td>
<td>d=0.1</td>
</tr>
</tbody>
</table>

**Discard prevention strategies**

Two discard prevention strategies were contrasted to a scenario of the current management (Table A7.2). For all scenarios changing conditions of two factors were tested. The first factor was the catch rate which was either deterministic or stochastic. Latter one was modelled by adding a stochastic term \(e^{(D+CV-0.5+CV^2)}\) to the Cobb-Douglas production function using catch, effort and stock biomass data from 2002-2010 to determine the parameter values. Stochastic catch rates represent the case where fishermen are not able to predict exact catch rates of species, applicable to young, unexperienced fishermen or when testing a new fishing ground. Deterministic catch rates represent the best case situation where fishermen perfectly know about the potential catch rates in areas. Such a case may be applicable to experienced fishermen who know their fishing grounds very well.

Table A7.2: Characteristics of the scenarios. Status-Quo (SQ), Quota Flexibility (QF) and Discard Banning (DB) scenario with deterministic or stochastic catch rates and stable or shifted species distributions. Stable distributions involved a 60% and shifted distributions an 85% spatial overlap of the North Sea cod and saithe stock.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Catch rates</th>
<th>Species overlap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status-quo (SQ)</td>
<td>deterministic</td>
<td>stochastic</td>
</tr>
<tr>
<td>Quota Flexibility (QF)</td>
<td>deterministic</td>
<td>stochastic</td>
</tr>
<tr>
<td>Discard Banning (DB)</td>
<td>deterministic</td>
<td>stochastic</td>
</tr>
</tbody>
</table>
The second factor was the species spatial overlap, which was either at 60% or at 85% (Table A7.2, Figure A7.4). Given the evidential northward distribution shift of cod (e.g. Engelhard et al., 2013) these different degrees of spatial overlap of target and bycatch species were simulated to analyse their impact on the success of the two management scenarios. In the North Sea saithe fishery, the degree of the overlap of North Sea cod and saithe plays an important role for fishermen as they may try to avoid cod bycatch. The spatial overlap of 60% was determined via the Schoener’s D index (Rödder and Engler, 2011; Schoener, 1968) and based on species distributions in 2013. In order to define a realistic range for a species distribution shift, the study of Engelhard et al. (2013) were used as a reference. According to that study a realistic range for a distribution shift of cod is one degree of latitude, resulting in an 85% spatial overlap.

![Figure A7.4: Spatial overlap of North Sea cod and saithe in zones 1-4 (z1-z4) with a 60% overlap a) and 84% overlap b).](image)

**Status-quo scenario**

In the Status-Quo scenario (SQ scenario), the two species, cod and saithe, were managed independently by single-species landings quotas. It was assumed that the fleet segments primarily target saithe, and that fishing continues until the saithe quota is fully taken, irrespective of the cod quota. For this scenario over-quota catch of cod could not be landed and discarding was allowed to occur. This scenario is thought to approximately reflect the current management situation.

**Discard banning scenario**

In the Discard Banning (DB scenario), the fishery was regulated by single-species catch quotas and the fleet segments had to stop fishing when the quota of one species was reached. In other words discards were banned. For this scenario estimated amounts of discards were added to existing landings quotas to generate a catch quota. Discard estimates were derived from the ICES InterCatch database (InterCatch, 2014). To make the data for FishRent compatible with the InterCatch output the following adjustment was made

\[ d = \frac{(D \times l_j)}{L} \]

Where d is the revised discard value for the fleet segments used by FishRent, l is the weight of landings for the fleet segments used by FishRent and L and D are the weight of landings and discards entered for the (vessel length aggregated) metier in InterCatch. It was assumed that quotas were not transferable. This scenario mimics the future situation when the discard ban as a part of the reformed CFP will be imposed.

**Quota Flexibility scenario**

For the inter-species Quota Flexibility (QF scenario), management is based on single-species landings quotas, but cross-species exchanges where quota of saithe can be used to cover over-quota catches of cod at a ratio 1:5 were allowed and could be conducted on a monthly basis. Thus, fishermen had the
opportunity to land their over-quota catch but were in general incentivised to avoid over-quota bycatch as an exchanged involved cost in terms of reduced quota of their target species. For instance, if a fisherman has 200 kg over-quota catch of cod he is allowed to land it and earns 400 Euro, assuming an average fish price for cod of 2 Euros per kilogram. However, in turn he loses 1000 kg of his saithe quota, which involves a loss of 500 Euro, assuming an average fish price for saithe of 0.90 Euro per kilogram. Hence, this management scenario allows fishermen to be more flexible in their decision making while providing a clear incentive to avoid bycatches, which in turn may increase marketable catches and fishing income. In the model fleet segments that are assumed to seek for maximising profit try to avoid the costly cod bycatches by changing their effort strategy.

RESULTS

Area Closures

Impacts on net profits and SSB

A “bestcase” condition included an annual area closure of 50% of zone 2 with a dispersal rate of species of 10%, whereas a “worstcase” condition comprised a two months closure of 25% of zone 2 and a dispersal rate of 100%. For closures with “bestcase” conditions net profits for the overall fleet were up to 8% higher than the baseline net profit (Figure A7.5). For closures with “worstcase” conditions net profits for the overall fleet were decreased by up to 7% (Figure A7.5). However, the impact of the orientation of an area closure relative to home ports on net profits differed considerably between fleet segments (Figure A7.5).
Combining a catch regulation with area closures showed that even for “worstcase” conditions the probability of SSB being above Bpa was 13% increased for the northern, 19% for the southern, 15% for the western and 5% for the eastern closure (Figure A7.6).

The northern, southern and western closure with “bestcase” conditions revealed 22%, 31% and 29% increased average SSB values, respectively (Figure A7.6). However, the eastern closure with “bestcase” conditions resulted in only 8% increased SSB values (Figure A7.6). Similarly, the eastern closure had little effect on SSB for all other tested conditions (25% and 50% closure, peak and whole, high and low diffusion rate) (Figure A7.6).
Figure A7.6: Change (%) of median SSB values for the different types of area closures relative to the baseline values. Results are shown for the closures of 25% (a) and 50% (b) of the northern (black), southern (light grey), western (dark grey) and eastern (grey) part of zone 2 during the spawning peak (peak) and the whole year (whole) with a dispersal rate of either $d=0.1$ or $d=1$. The marked part of a) represents the “worstcase” and the marked part of b) shows results for the “bestcase” condition.

Impacts on cod catches

For the German and Danish fleet segment a southern closure was predicted to cause 10% to 13% (“worstcase”) and 14% to 17% (“bestcase”) increased cod catches (Figure A7.7). This is due to the induced shift of fishing effort from zone 1 and 2 (low risk of cod catches) to zone 3 and 4 (high risk cod catches) (Figure A7.4). For the French fleet segment, the southern closure triggered an increase in effort concentration in zone 1 and 2, resulting in 2% (“worstcase”) to 8% (“bestcase”) decreased cod catches (Figure A7.7). For the western closure an increase of cod catches was predicted for all modelled fleet segments (Figure A7.7). This increase was differing between fleet segments, ranging from 2% to 12% (Figure A7.7). The northern closure with “worstcase” conditions revealed 3% decreased cod catches for the whole fleet (Figure A7.7). However, for “bestcase” conditions with low dispersal of species and a closure of 50% lasting the whole year, cod catches for the whole fleet were increased by 9% (Figure A7.7), as fleet segments shifted their effort to zone 3 and 4 (higher risk of cod catches).
Figure A7.7: Change (%) of cod catches for the whole fleet, the German, English and Danish fleet segment relative to the average values of historical cod catches. a) shows results of the “worstcase” condition where 25% of the northern (black), southern (light grey), western (dark grey) and eastern (grey) part of zone 2 are closed during the spawning peak with a dispersal rate of $d=1$. b) shows results for the “bestcase” scenario with a 50% closure of the northern (black), southern (light grey), western (dark grey) and eastern (grey) part of zone 2 for the whole year considering a dispersal rate of $d=0.1$. 
Discard Prevention Strategies

Discard Banning

From the perspective of a fisherman deterministic catch rates and low spatial overlap of species represented the best case condition, because potential catch rates were perfectly known and less effort was needed to avoid cod bycatch (Table A7.2). For this best case condition of the DB scenario English and French fleet segments shifted around 12% of their effort from zone 2 to zone 1 to avoid cod bycatch (Figure A7.8). German and Danish fleet segments shifted 36% to 39% of their effort, respectively, from zone 2 in the first quarter to zone 4 in the third quarter (Figure A7.8).

The increased effort concentration in zone 4 resulted in a higher fishing pressure on young saithe of age 3 (Figure A7.2a, A7.9b). In the fourth quarter fleet segments returned to zone 2 to spend the rest of their effort in this zone, because there the saithe stock started to aggregate for spawning. For the DB scenario with the best case condition the fleet segments continued to fish in zone 2 in quarter 4 until their cod quota was reached and they had to stop fishing. On average over the modelling period, zone 1 accounted for 5% of the landings weights, zone 2 for 20%, zone 3 for 60% and zone 4 for 15%. In

Figure A7.8: Change (%) for the French, English, German and Danish fleet segment as well as for the overall fleet in effort (days) for the Discard Banning (DB) scenario with a) the best case condition (deterministic catch rates and low overlap of stocks) and b) the worst case condition (stochastic catch rates and high overlap of stocks), relative to the Status-Quo (SQ) scenario in 2020.
contrast, zone 1 accounted for 10%, zone 2 for 60%, zone 3 for 10% and zone 4 for 20% of the landings weights in the SQ scenario.

As the cod quota was lower than the saithe quota, fleet segments could on average fish only 79% of the saithe quota, catching mostly young saithe of age 3 in zone 4 and old saithe of age 8 in zone 2 (Figure A7.10). As a result SSB declined, especially when young saithe of age 3 reached older age classes in subsequent years. SSB of saithe did not recover until 2020 (Figure A7.11b). Catch per unit of effort (CPUE) of saithe in zones where effort was displaced decreased, resulting in reduced profits for the modelled fleet segments in 2020 (Figure A7.11a). Especially, the fishing effort of the Danish fleet segment had been initially concentrated in zone 4, and under a discard ban, even more of its effort was concentrated there (Figure A7.8). As a consequence of the increased fishing pressure and thus decreasing CPUE, net profits for the Danish fleet segment were reduced most when compared to the other fleet segments (Figure A7.11a).
An 85% spatial overlap of both stocks and stochastic catch rates for scenario B, represented from the fishermen perspective the worst case condition. For this worst case condition of the DB scenario effort was shifted to zone 4 in quarter 3 and returned to zone 2 in quarter 4 (Figure A7.8). When compared to the best case condition of the DB scenario the worst case condition caused even more reduced profits for all fleet segments in 2020 (Figure A7.11a).
Figure A7.11: Change (%) for the whole fleet and the French, English, German and Danish fleet segments in net profit for a) the Discard Banning (DB) scenario and b) the Quota Flexibility (QF) scenario with the best case condition (deterministic catch rates and 32% overlap of stocks) and the worst case condition (stochastic catch rates and 85% overlap of stocks), relative to the Status-Quo (SQ) scenario in 2020.

Quota Flexibility

In the QF scenario fleet segments could land their over-quota catch of cod by losing saithe quota at a ratio 1:5. Thus there was an incentive to avoid bycatch of cod. Until 2018, modelled fleet segments shifted their effort increasingly from zones 1 and 2 in quarter 1 to zone 4 (Figure A7.12).
Figure A7.12: Average days-at-sea per vessel among the years. From 2013-2018 effort of the modelled fleet segments were shifted to zone 4 to avoid discards of North Sea cod and to allow an increase of days-at-sea per vessel. From 2018 onwards the TAC of North Sea cod increased and some of the effort was returning to zones 1 and 2. Results are shown for the Quota Flexibility (QF) scenario with deterministic catch rates and 32% overlap of the stocks.

In turn, discards of North Sea cod were declining during these years (Figure A7.13). However, with declining cod discards effort in terms of days at sea increased and reached a maximum of 195 days per vessel in 2018 (Figure A7.12). This extra effort was used to fish mainly in zone 4 during the rest of the year rather than following saithe to the spawning ground which included a high risk of cod bycatch. As the CPUE of saithe in zone 4 was lower than the one in zone 2 the extra effort was needed by fleet segments to fish their saithe quota, but did also involve increased fishing costs. Due to increased effort levels in zone 4, which covered the feeding ground of North Sea saithe, SSB of saithe declined until 2018 (Figure A7.9d). Consequently, the TAC for saithe was reduced and effort decreased to 186 days per vessel until 2020 (Figure A7.12). In 2018, the cod quota started to increase, because the cod stock recovered (Figure A7.9c).

Figure A7.13: Over-quota catch (tons) of North Sea cod from the modelled fleet segments among years. Results are shown for the Quota Flexibility (QF) scenario with deterministic catch rates and 32% overlap of the stocks.
However, fleet segments did reallocate only 5% of their fishing effort back to zone 2 in 2018 (Figure A7.14). This allowed the cod stock to recover to a higher level than that for the DB scenario in 2020 (Figure A7.14). In 2020 fishing effort was then spread more evenly throughout the year and areas.

Also SSB of saithe was higher than that for the DB scenario (Figure A7.14), because in the QF scenario fleet segments stopped fishing completely in zones 1 and 2 until 2018. Profits of all modelled fleet segments were higher for the QF scenario than those of the DB scenario in 2020 (Figure A7.11).

Figure A7.14: Change (%) in SSB for cod (dark grey) and saithe (light grey) for a) the Discard Banning (DB) scenario and b) the Quota Flexibility (QF) scenario, relative to the Status-Quo (SQ) scenario. Results are shown for deterministic (det) and stochastic (sto) catch rates and for a species spatial overlap (o) of 32% and 85%.
DISCUSSION

Area Closures

Stock protection

Using area closures as an alternative (additional) management measure is controversial. Critics argue that most commercial species are too mobile to benefit, and that area closures are only appropriate in very specific cases (usually small-scale tropical fisheries) (Gell and Roberts, 2003). The present study tested various area closures of different sizes, durations and locations relative to species seasonal movements. These movements included species seasonal migrations, which were modelled as a fixed pattern among years, whereas in reality there is evidence that mature saithe skip spawning in certain years and do not migrate (Jorgensen et al. 2006). However, these simulations were helpful to clarify that when fish exhibit seasonal migrations and tend to aggregate at different areas (spawning and feeding grounds) at different times of year, the location, duration and size of the area closure has profound effects on how it impact the success in protecting the fish stock. For instance, the southern and northern area closures that were parallel to the migration route between spawning and feeding grounds allowed fish to stay inside the closure during spawning and its migration to feeding grounds. Thus these closures provided protection almost throughout the year (except during feeding), reduced fishing mortality and hence led to great increases in SSB. Especially, the southern closure of 25% and 50% of zone 2 reduced the efficiency of fishing effort by displacing fleet segments to areas with lower fish densities. This effect was stronger, if the closure lasted the whole year. The western closure lasting the whole year provided partial protection throughout the migratory range of the stock with less effect on the overall fishing mortality in the short-term, but considerably reduced fishing mortalities once the stock had built up inside the boundaries of the area closure.

Results demonstrated that the size of an area closure should be matched to the scales of movement of the species that they are designed to protect. For example, closures of 50% revealed higher increases in SSB than closures of 25%. Thus, when aiming to protect a highly migratory species area closures need to be larger in size than when aiming to protect a sedentary species with a low spill-over from the closed areas. In the latter case, a few smaller area closures might be more effective than one large one.

Although, modelled dispersal of species limited the effectiveness of any particular pattern of area closure size, duration and location, each of the various area closures that had been tested in combination with a quota system demonstrated that it is able to successfully protect the spawning stock of North Sea saithe.

Ultimately, the results demonstrate that if an area closure is well set taking into account its size, duration and location relative to species seasonal movements and major ports, it can be suitable for mobile species such as saithe. This outcome is supported by examples from reality where closures were successful in protecting a highly migratory species. For instance, many lobster species exhibit seasonal movements on large scales suggesting protection in reserves as unlikely. However, there is evidence from the Mediterranean (Goñi et al., 2001), New Zealand (Kelly et al., 2000), Australia (Edgar and Barrett, 1999), the Bahamas (Lipcius et al., 2001), and Canada (Rowe, 2001) that lobster stocks do build up in area closures. Moreover, Norse (2003) states that even highly migratory species, such as sharks, tuna and billfish, can benefit from area closures targeted to places where they are highly vulnerable, such as nursery grounds, spawning grounds or aggregation sites such as sea mounts.

Economic costs and benefits

Although simulations demonstrate that the various area closures in combination with quotas will be successful in protecting the stock they have heterogeneous impacts on individual fleet segments from different nations and home ports. Even when the area closure did result in little change in overall net profits, there were winners and losers, and the distribution of gains and losses may not be intuitively
obvious. The location of the area closure obviously determines where effort is displaced to. Moreover, the location of an area closure relative to the home port of fleet segments decides if steaming costs increase and catches decrease.

For instance, the southern closure caused that the German and Danish fleet segments reduced steaming costs by shifting their effort to areas that were closer to their home ports. However, these areas had low cpues and hence the fleet segments did suffer reduced net profits. This in turn did lead to declines in fleet sizes of these fleet segments. On the contrary, the English and French fleet segment tended to benefit from a southern closure, as they could continue to fish in zone 2 (high cpue) and were often taking advantage from the higher distance between fishing grounds and ports of the German and Danish fleet segment. The southern closure showed even for the “bestcase” condition less promise for increasing the net profits of the German and Danish fleet segments. Thus, for these fleet segments, this area closure initially resulted in catch declines that, in net profit, weighted more heavily than net profit increases that occurred in mid- and long-term. Contrary, results for the western closure illustrated the potential benefits of combining closures with quotas in protecting long-term economic yields for all modelled fleet segments by reducing the risk of a further stock decline for North Sea saithe. With the western area closure the conservation effects won out over the short-term losses. This holds against the two levels of species dispersal rates, although with increasing dispersal the effect of the western closures on economic outcomes became smaller.

Sanchirico and Wilen (1999), who used a conceptual analysis, found that under open access most area closures produced a biological benefit but that there were few combinations of biological and economic parameters that gave rise to both a harvest increase and a biological benefit. Even the presented results suggest that for the North Sea saithe fishery area closures may increase the productivity of the fish stock and may reduce the probability of a further decline of SSB, but they may not lead in all cases to economically efficient use of the resource.

Side effects

The spatial re-allocation of effort that occurs when areas are closed can have detrimental impact on target species, non-target species and habitat in the areas that remain open. However, in many cases such consequences remained un-analysed, especially, as most modelling of area closures ignores fishermen behaviour (Rijnsdorp et al., 2001). The model presented here accounts for this behaviour such that fleet segments can change their spatio-temporal effort distribution, their level of fishing effort as well as their number of vessels participating in that particular fishery. Results demonstrate that increases in SSB for North Sea saithe that received protection from the area closures were offset by increases in bycatches of North Sea cod that absorbed the displaced effort. Especially, the German and Danish fleet segment revealed increased cod bycatches exceeding the 5% mark in some years due to their effort shift that was caused by the southern closure. In the model the allowed effort in terms of days at sea was not reduced for a fleet segment when it exceeded the 5% mark. However, in reality a vessel that catches cod by more than 5% of its total catch will be considered to belong to the cod fishery and hence will suffer decreased sea days from the effort regime of the cod management plan. As fishing grounds of saithe are far from home ports for most of the modelled fleet segments, such a reduction in sea days might have a profound impact on their ability to catch their saithe quota completely. Thus, area closures trying to protect the spawning stock of saithe may have a negative impact on the cod stock through higher cod bycatches, which then are likely to involve economic costs for involved fleet segments due to stronger effort limitations.

Moreover, modelled catch was limited by the quota and over-quota catch was not allowed to be landed, reflecting the current situation in the North Sea saithe fishery. As a result, increased cod catches led to discards as fleet segments had no incentive to alter their catch composition to match their joint species to the quota, as if doing so decreases their profit (Poos et al., 2010). Thus, fleet segments tended to discard the unproductive species in this case cod (when its catch has reached its quota), while
continuing to harvest the productive species, saithe, until its quota was taken. Obviously, the increased discarding of cod limits the ability of the stock to recover. Thus, whether the new level and distribution of fishing effort leads to an increase or a decrease in overall benefits derived from all directly or indirectly affected fleet segments will depend on the size, the shape, the time and the location of the area closure and the characteristics of the species it protects. Moreover, also physical, biological, socioeconomic and regulatory characteristics of the fisheries surrounding it may play an important role (Allison et al. 1998; Apostolaki et al. 2002; Baskett et al. 2006). Therefore, considerable research on the behaviour of both fish and fleet segments in the North Sea fisheries will be required before an area closure could be designed in a cost-effective way for the North Sea saithe fishery.

**Discard Prevention Strategies**

**Discard Banning**

A discard ban was successful in protecting the cod stock and resulted even in a continuous increase in cod stock size among modelling years. This is remarkable, because only catches of included fleet segments were modelled explicitly while catch rates of cod from other fisheries were modelled as a fixed proportion. Thus, the decrease of cod bycatch in the modelled North Sea saithe fishery, where cod bycatch is in general very low when compared to other North Sea fisheries (Catchpole et al., 2005; Garthe et al., 1996; ICES, 2013a), seemed to be enough to lead already to an increase of the cod stock.

Although a discard ban may be beneficial for one species it may cause a decline of other species. For instance, in the DB scenario catches of the unproductive stock (cod) were limited by the discard ban, catches for the productive stock (saithe) were constrained, but SSB for cod was increasing while SSB for saithe was declining. This was mainly due to the effort shift of modelled fleet segments to avoid cod bycatch and the fact that effort was then directed towards young saithe prior to spawning. Thus, although fleet segments caught less saithe in the DB scenario than in the SQ scenario, they were catching mainly young saithe prior to spawning which affected SSB in the long-term. When catch rates were perfectly known (deterministic) the negative impact on the saithe stock was highest, because fleet segments returned to zone 2 in quarter 4 which was the zone where saithe then started to aggregate for spawning. This behaviour has increased the pressure on the saithe stock and has led to a lower spawning stock of saithe, lower catches and hence lower profits in the long-term.

The risk of a discard ban being negative for one species while being beneficial for another species was also stated by Hall and Mainprize (2005). In their study they named several examples (e.g. the Northern blue fin tuna) where a discard ban encouraged the greater utilization of bycatch species leading to overexploitation of these species. Moreover, the model predictions of seasonality in spatial effort allocation, and the southward shift of fishing effort are confirmed by real observations of the fleet segments. In particular, a southward shift is observed since EU fleets targeting saithe have fallen under the effort regime of the cod management plan in 2009 (ICES, 2010).

**Quota Flexibility**

Simulation results suggest that the QF approach will sustain both stocks in the long-term. More importantly, the QF scenario provided evidence that it can be beneficial both biologically for the stocks and economically for the fleet segments in that fishery in the long-term. In this scenario fleet segments could retain marketable fish (cod) that would previously have been discarded. In the model, fleet segments were able to reduce over-quota discarding of cod by reallocating fishing effort and by increasingly targeting saithe. Avoidance of the unproductive stock (cod) required more days at sea as fleet segments shifted their effort to zones with low cod bycatch but with low CPUEs for saithe. As a consequence fuel costs were increased. However, the avoidance behaviour of fleet segments led to a higher SSB level of saithe and cod in the long-term, which in turn resulted in higher catches and hence increased profits. Thus, although catch and revenue of saithe were lowered in the short-term, the drop
in revenues was more than made up for by a reduction in costs in the long-term as with increasing stock size costs per unit of catch declined. Therefore, simulation results suggest a long-term economic benefit as fishing mortality was reduced helping stocks to build up and allowing larger quotas in the future.

**ANNEX 7 REFERENCES**


Zeller, D., and Pauly, D. 2005. Good news, bad news: global fisheries discards are declining, but so are total catches. Fish and Fisheries, 6: 156-159.)