D9.2 Case Study 1 Report

Trade-offs in ecosystem-based fisheries management in the North Sea aimed at achieving Biodiversity Strategy targets

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List of abbreviations

BAU	Business as Usual
BD	Birds Directive
CFP	Common Fisheries Policy
CICES	Common International Classification of Ecosystem Services
CS	Case Study
DPSIR	Driver-Pressure-State-Impact-Response
EBM	Ecosystem Based Management
EEZ	Exclusive Economic Zone
EMFF	European Maritime and Fisheries Fund
ERA	Ecosystem Risk Assessment
ES	Ecosystem Services
ESI	European Structural and Investment funds
ESSS	Ecosystem Services Supply Score
EU	European Union
EUR	Euro
GES	Good Environmental Status
GVA	Gross Value Added
GW	Gigawatt
HD	Habitats Directive
IMP	Integrated Maritime Policy
IPCC	Intergovernmental Panel on Climate Change
IR	Impact Risk
MM	Management measures
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MSP	Maritime Spatial Planning
MSY	Maximum Sustainable Yield
NGO	Non-Governmental Organisation
NS	North Sea
OWF	Offshore Wind Farm
PoM	Programme of (management) Measures
SAC	Special Area of Conservation
SES	Socio-economic system
SRES	Special Report on Emissions Scenarios
WFD	Water Framework Directive
WWF	World Wildlife Fund

About AQUACROSS

Knowledge, Assessment, and Management for AQUAtic Biodiversity and Ecosystem Services aCROSS EU policies (AQUACROSS) aims to support EU efforts to protect aquatic biodiversity and ensure the provision of aquatic ecosystem services. Funded by Europe's Horizon 2020 research programme, AQUACROSS seeks to advance knowledge and application of ecosystem-based management (EBM) for aquatic ecosystems to support the timely achievement of the EU 2020 Biodiversity Strategy targets.

Aquatic ecosystems are rich in biodiversity and home to a diverse array of species and habitats, providing numerous economic and societal benefits to Europe. These valuable ecosystems are impacted by human activities and pressures, some at risk of irreversible damage, problems including pollution, contamination, invasive species, overfishing and climate change. These pressures threaten the sustainability of these ecosystems, their provision of ecosystem services and ultimately human well-being.

AQUACROSS responds to pressing societal and economic needs, tackling policy challenges from an integrated perspective and adding value to the use of available knowledge. Through advancing science and knowledge; connecting science, policy and business; and supporting the achievement of EU and international biodiversity targets, AQUACROSS aims to improve ecosystem-based management of aquatic ecosystems across Europe.

The project consortium is made up of sixteen partners from across Europe and led by the Ecologic Institute in Berlin, Germany.

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1 Introduction and background

The North Sea is one of the busiest seas with many (often growing or newly emerging) sectors laying claim to a limited amount of space. The main human activities include fishing, shipping, oil and gas extraction, and newly emerging activities such as the renewable energy sector. These combined human activities and their associated pressures on the environment have hindered the achievement of the ecological goals for the North Sea (Knights, 2011; OSPAR, 2010; EEA, 2015). In line with the European long-term Blue Growth strategy to support sustainable growth in the marine and maritime sectors, many of these activities, such as offshore wind farms (OWFs), are expected to increase and potentially further impact marine biodiversity and the ecosystem services it provides. Management of often multiple competing interests is complex and requires novel, more integrated approaches such as Maritime Spatial Planning (MSP) or Ecosystem-based Management (EBM), which come with additional requirements to the scientific knowledge base. This study aims at identifying the requirements of the North Sea scientific knowledge base to provide better guidance for such novel, integrated and more ecosystem-based management approaches.

1.1 Objective

The primary aim is to improve the knowledge base available to stakeholders to allow a more informed decision-making process toward the conservation of biodiversity and the ecosystem services it supplies. This is primarily aimed at the EU2020 Biodiversity Strategy but in practice includes several existing marine policy frameworks e.g. Habitats and Birds Directives (HD & BD), Marine Strategy Framework Directive (MSFD), Common Fisheries Policy (CFP) or Integrated Maritime Policy (IMP).

2 Establishing objectives

Societal goals may consist of ecological, social or economic objectives, often stated in (inter)national policy documents. Ecological objectives for the North Sea are stated in the EU Biodiversity Strategy (EC, 2011) or Marine Strategy Framework Directive (MSFD) (EC, 2008) and include a healthy marine ecosystem and the protection of biodiversity. These have resulted in the decision to create a network of N2000 Special Areas of Conservation (SACs) and other Marine Protected Areas (MPAs). At the same time, goals supported by sectoral EU policies apply to a large area of the North Sea, such as goals set by the Common Fisheries Policy (EC, 2009b; EC, 2013), which aims for a sustainable supply of seafood from fisheries, or the Renewable Energy Directive (EC, 2009a), which requires the EU to fulfil at least 20% of its total energy needs with renewables (including offshore wind farms OWF) by 2020. All three of these societal goals are known to take up considerable space in the North Sea and are thus among the main players in Maritime spatial Planning (MSP) (EC, 2014).

Due to the North Sea space limits, the aim to achieve these three goals simultaneously creates tension, and therefore trade-offs need to be considered. This CS starts from a consideration of the societal goals to determine the requirements of the North Sea scientific knowledge base to guide decision-making toward the (balanced) achievement of those societal goals whilst involving important societal actors, i.e. (national) government, fishing industry, offshore wind energy sector and Non-Governmental Organisations (NGOs).

2.1 Identifying policy objectives

As this study intends to provide an integrated perspective to EBM (including MSP), we identified different policy objectives, i.e. sustainable food supply, clean energy and a healthy marine ecosystem. Achievement of one (or more) goals may be at odds with that of another goal (Rouillard, 2016). For example, human activities such as wind energy and fishing, produce pressures of which the cumulative effects may impact biodiversity and compromise achieving a healthy marine ecosystem (EEA, 2015). For each of those goals, we present the current state of affairs in relation to existing relevant policy frameworks.

Sustainable food

Societal goal: The principal aim of fisheries management under the Common Fisheries Policy (CFP) is to ensure high long-term fishing yields for all stocks at the latest by 2020. This is referred to as Maximum Sustainable Yield (MSY) (EC, 2009b; EC, 2013).

Catches of (shell)fish in the North Sea have dropped from a peak level of 3-4 million tonnes taken per year starting in the late 1960s up to the mid-1990s, after which it declined to 1.4 million tonnes in 2012, with a slight increase since (ICES, 2017b). This decline has been attributed to overfishing and decreased productivity of important stocks such as cod and herring, but also to the successful reduction of fishing mortality to more sustainable levels after 2000 following policy measures (ICES, 2017b). There are two key policy instruments in Europe that regulate fisheries on commercial species. The first of these is the EU Common fisheries Policy (CFP), which is targeted on managing fisheries, while the MSFD is an environmental directive that aims to achieve good environmental status (GES). Regarding the impact of fishing of commercial species on the ecosystem, the CFP and MSFD are aligned. However, both policies differentiate in certain, conflicting elements. For example, the MSFD addresses the impacts of commercial fishing on the seafloor through Descriptor 6 for determining GES, while the CFP appeals to a general ecosystem-based approach to fisheries management to limit environmental impacts of fishing activities, without offering specifics on the dimensions of environmental impact. More importantly, the CFP is not only concerned with environmental goals such as the status of commercial (shell)fish species but also aims to ensure that fishing and aquaculture activities contribute to long-term economic and social sustainability. The CFP is directly funded by the European Maritime and Fisheries Fund (EMFF, 2014-2020), one of the five complementary European Structural and Investment (ESI) funds that aim to promote economic growth and job-based recovery within the EU. Clearly this aim for socio-economic sustainability may be at odds with the environmental goals. In contrast, the MSFD states that fishing for the current generation is not the only public interest, but that the regeneration and maintenance of marine biodiversity for use of current and future generations should be accounted for.

Clean energy

Societal goal: The Renewable Energy Directive establishes an overall policy for the production and promotion of energy from renewable sources in the EU. It requires the EU to fulfil at least 20% of its total energy needs with renewables by 2020 (EC, 2009a).

Currently, about a quarter of primary energy production in Europe comes from renewable sources, though its socio-economic importance varies greatly based on the type of energy produced. 10% of total wind energy in Europe is produced in offshore wind farms (OWFs), most of which are located in the North-East Atlantic (EEA, 2015). Off-shore wind employs 35000 people (full-time equivalent) and accounts for a Gross value added (GVA) of 2.4 billion EUR (EEA, 2015). Offshore wind is planned to provide a significant part of the EU's future renewable energy mix. However, the development and operation of OWFs impacts on other uses of the ocean and can (in)directly pose a threat to aquatic biodiversity (e.g. seabirds, bats, marine mammals, displacement of trawl fisheries that disturb previously non-fished seabed habitats).

Healthy marine ecosystem

The European Union Biodiversity Strategy, which translates the Aichi Targets[1] at the EU level, aims to "halt the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, restore them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss". The Biodiversity Strategy is aligned to several marine policy frameworks, e.g. Birds and Habitat Directive (BD & HD), the MSFD and the CFP.

The BD and HD aim to implement protected areas to effectively decrease species extraction and enhance the status of the environment and related biodiversity. The MSFD requires Member States to draw up a programme of measures (PoM) for each marine (sub-)region to achieve or maintain GES. This includes spatial protection measures contributing to coherent and representative networks of MPAs, adequately covering the diversity of the constituent ecosystems. The MSFD promotes the incorporation of MPAs in a country's PoM, including specific protective measures, as a means to achieve GES. The MSFD therefore does not necessarily demand MPAs if GES can be achieved with other measures. Thus, MPAs are not necessarily an addition to the Natura 2000 network, but Natura 2000 sites can rather be an element of the PoMs.

In addition to the implementation of N2000 SACs or other types of MPAs specifically aimed at achieving conservation goals there is the option to manage the OWFs, e.g. through a ban on specific activities such as trawl fisheries, so that these OWFs *de facto* become MPAs.

Integration of societal goals

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[1] https://www.cbd.int/sp/targets/

The EU Integrated Maritime Policy (EC, 2007) aims to provide a coherent policy approach with increased coordination between different policy areas, focussing on cross-sectoral and regionally cross-cutting maritime issues. The policy takes the interaction between different sectors into account and is therefore relevant for issues such as OWFs occupying historical fishing areas. The Maritime Spatial Planning Directive (EC, 2014) aims to ensure cooperation, harmonisation and coherent action across a range of policy areas, such as the BD, HD, MSFD, CFP and the Renewable Energy Directive. It does not set any environmental targets nor targets for economic activities. Instead, it provides a framework for setting targets and measures to e.g. maximise economic output (e.g. from fishing, wind parks) within boundaries of environmental requirements (e.g. MPAs).

2.2 Co-design

In order for the work in AQUACROSS to be relevant, stakeholders are consulted at various moments in the project. As this case study focuses on the North Sea, we involve stakeholders at the international level as well as the national level. Despite the international focus, to be relevant we have to zoom in to the processes taking place at the national level, as they feed us with ‘real cases’ to use for our modelling work and it is in these real settings that we can best ‘test’ if our methods and outputs are helpful to stakeholders. Following from the fact that marine spatial planning and the MSFD take place under the lead of member states, these cases can only be found at the national level. In order to be as relevant as possible we have also dovetailed our work closely to ongoing processes in two member states of the North Sea: the Netherlands and Belgium. And as stakeholders and policy makers are so busy, with stakeholder fatigue always lurking, we have not chosen for a ‘separate stakeholder process’ designed especially to our project. This choice means that we somewhat follow the ‘real’ ongoing processes, as much as possible. These processes guide the choices of the work we will be doing in the project. That implies that we use an adaptive strategy, making use of opportunities that arise.

Based on the stakeholder interactions we had, we made the choice to focus on food security (fisheries and aquaculture) and renewable energy (mainly wind) and their interactions, as well as with (planned) nature protection areas.

In **the Netherlands**, a process that started in 2017 was instigated by two national ministries: Agriculture, Nature and Food (formerly known as Economic Affairs) & Infrastructure and Water management (formerly known as Infrastructure and Environment), working together to develop a new long term strategy for the North Sea (in the Dutch EEZ) called the ‘North Sea 2030’ strategy. The 2017 elections brought a new government, bringing a third ministry to the table: Internal Affairs - responsible for marine spatial planning. With North Sea Strategy 2030, the government aims for a participatory process with stakeholders (users and Environmental NGO’s) and scientists participating. Three core topics have been recognised: energy (need for more wind energy), food provision (fisheries and new developments) and nature conservation (N2000, MSFD goals). The need for knowledge is an explicit part of this process, policy officers and stakeholders need to discuss goals, make choices, understand cumulative impacts, ecosystem services and understand trade-offs. The AQUACROSS project supports this process and participated when relevant. Therefore, time was invested in connecting to these ministries and their processes. Key events were the 'North sea days' yearly organised in October where many key actors gather to discuss these issues. In 2016 AQUACROSS introduced the project at the North Sea days, in 2017 AQUACROSS co-organised a session at the North Sea days and we aim to organise another session at the North Sea days 2018. In addition, the researchers linked with stakeholders such as with WWF directly seeking relevant options to cooperate. AQUACROSS has also linked to developments taking place at ICES. The WGMARS and WGINOSE projects have come together at the end of 2017 to make the IEA work of WGINOSE more salient by co-organising a stakeholder workshop with policy makers in the Netherlands. AQUACROSS took part in the preparation and implementation thereof. Core activity was a mental modelling exercise revealing the key policy objectives. This session was used to bring the AQUACROSS project to the fore and to continue linkages with ICES and policy for the modelling work undertaken in AQUACROSS. In addition, the main insight that was gained in this session was that food provision is not a focal point for the government. Although it is one of the three prime area's in the North Sea 2030 process (together with energy and nature protection) there are no *specific* national goals to fisheries (as there are for energy and nature protection).

In **Belgium**, the researchers consulted the stakeholders (mostly governance authorities) involved in managing fisheries activities in marine protected areas. Knowledge gaps were identified pertaining to the impact of potential fisheries management measures on defined nature conservation targets (MSFD, N2000). In addition, both the operators of the wind parks in Belgium (organised in the Belgian Offshore Platform) as well as the stakeholders involved in governance (organized in the existing working group 'Windparken') have been informed about the project and are willing to be involved in the stakeholder consultation. Whereas multi-use of wind parks in the Netherlands is focused on combining wind energy with recreation (navigation) and fisheries, in Belgium, aquaculture and wave energy are prioritised. In Belgium, these policy choices are regularly evaluated in the iterative process of marine spatial planning (6-year cycle).

3 Assessing the current state of the social-ecological system

In order to identify which policy goals have not been achieved and guide the management toward achieving those goals, we assessed the current state of the North Sea ecosystem using a risk-based approach. The basis of the approach was the AQUACROSS linkage framework, which follows the Driver-Pressure-State-Impact-Response (DPSIR) framework consisting of single so-called impact chains of causal links. This was recently expanded to include multiple chains while also explicitly considering human activities to represent human needs and their drivers (Borgwardt, 2018), as well as introducing human welfare into the DPSIR concept, thereby potentially covering the full social-ecological system (Teixeira, 2018). Risks to the ecosystem are linked to elements of the socio-economic system (SES) through the calculated impact risk (IR), which is the risk that ecosystem components are impacted such that biodiversity policy objectives are not achieved.

Typology of SES elements

The SES is based on a typology of human activities, pressures, ecosystem components and the ecosystem services they supply developed in the CS. Human activities impact the natural system (understood as pressures) and result in goods and services useful for society. A human activity may be the source of multiple pressures and any single pressure may be caused by more than one activity. We adapted the typologies of activities and pressures from previous classifications from the HD, WFD, and MSFD (EC 1992, 2000, 2008), as well as the statistical classification of economic activities (EC 2006) and previous typologies (White *et al*. 2013; Smith *et al*. 2016). The starting point of the typology of aquatic ecosystem components were the habitats defined by the European Nature Information System (EUNIS) habitat classification, as provided by the European Environment Agency (Davies *et al.* 2004). EUNIS represents a pan-European, hierarchical system that covers all types of habitats. These habitats were clustered in representative aquatic ecosystem types (e.g. Coastal, Shelf or Oceanic) and have associated sessile biota (living small animals that are not mobile). Additionally, three mobile biotic (animal) groups were defined: fish & cephalopods, birds and marine mammals. These were not assigned to specific habitats as they are mobile and can move between habitats. The typology of the Ecosystem Services and Abiotic Outputs of the system is approached from a supply-side perspective which includes everything that the habitats and/or biotic components have the capacity to supply (thus independent of whether they are used or not) and is consistent with the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2013) distinguishing between 1) Provisioning, 2) Regulating & Maintenance, and 3) Cultural ecosystem services.

For our purpose (determining the scientific knowledge base required for more informed decision-making) we distinguish between the “comprehensive SES” and the “focal SES”. The latter only including those elements, deemed relevant for the specific objectives identified in chapter 2 (i.e. human activities, pressures and ecosystem components (see table 1).

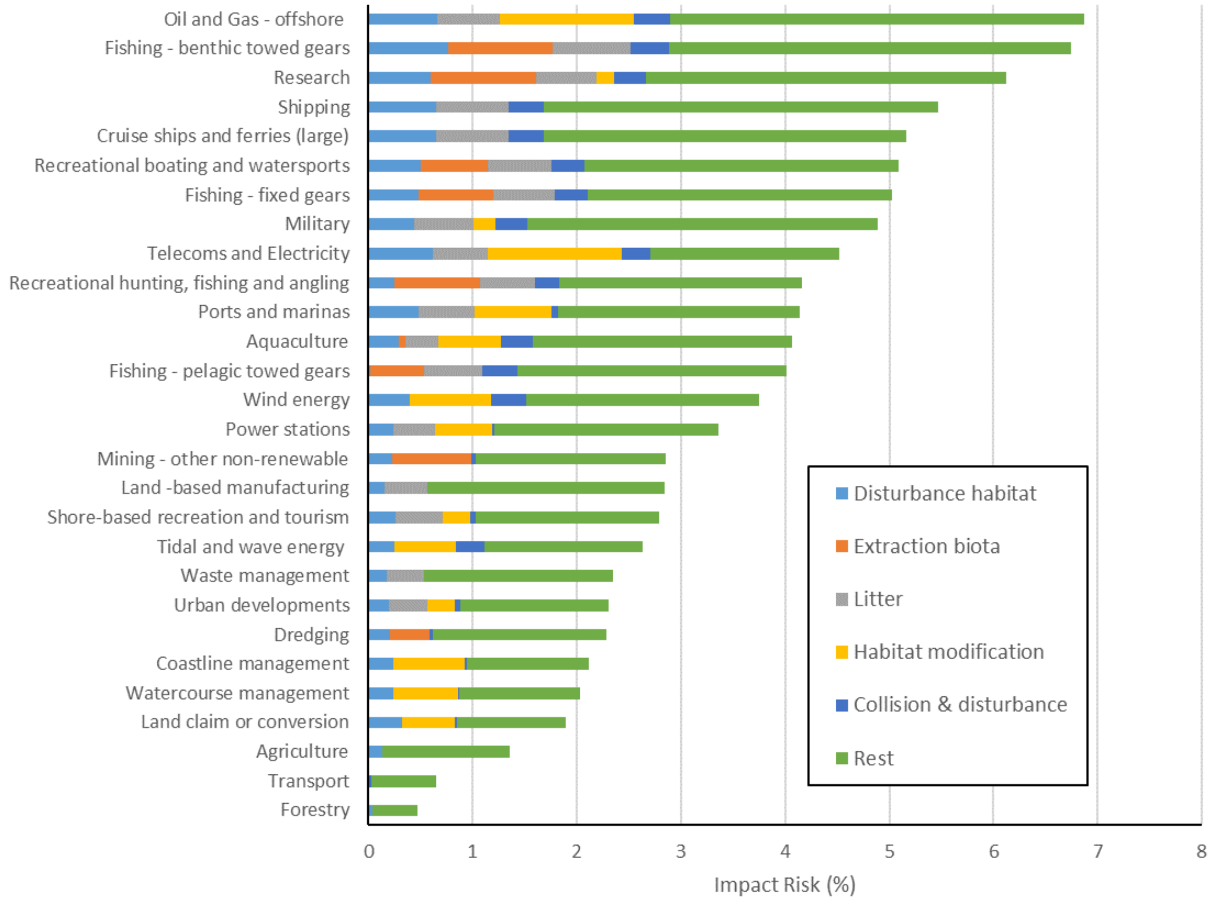
Table 1. The human activities, pressures and ecosystem components that make up the nodes of the North Sea "comprehensive SES" and the subset (in bold) that make up the "focal SES".

Human activities	Pressures		Ecosystem components			Ecosystem services	
Agriculture	Biological	**Extraction of flora and/or fauna**	**Fish & Cephalopods**			ES: Provisioning	**Raw Materials from Biomass**
Forestry		Introduction of genetically modified species	**Mammals**				**Nutrition from Biomass**
Aquaculture		Introduction of Microbial pathogens	Reptiles			Ecosystem Service: Regulation & Maintenance	**Maintaining Atmospheric Composition and Climate Regulation**
Coastline management		Introduction of non-indigenous species	**Birds**				**Lifecycle & Habitat Maintenance Gene Pool Protection**
Dredging		Translocations of species (native or non-native)	Habitats	**Habitats**			**Pest & Disease Control**
Land claim or conversion	Chemical	Changes in input of organic matter		Coastal-Terrestrial	Coastal dunes and sandy shores (B1)		**Soil Formation and Composition**
Watercourse management		Introduction of Non-synthetic compounds		Coastal-Terrestrial	Coastal shingle (B2)		**Maintaining Water Conditions**
Fishing - benthic towed gears		Introduction of Radionuclides		Coastal-Terrestrial	Rock cliffs, ledges and shores, including the supralittoral (B3)		**Mediation of Liquid Flows (Flood)**
Fishing - fixed gears		Introduction of Synthetic compounds		Inlets Transitional	Littoral rock and other hard substrata (A1)		**Mediation Mass Flows (Erosion)**
Fishing - pelagic towed gears		**Litter**		Inlets Transitional	Littoral sediment (A2)		**Mediation of Waste by Biota**
Land -based manufacturing		N&P Enrichment		Inlets Transitional	Infralittoral rock and other hard substrata (A3)		**Mediation of Waste by Ecosystems**
Mining - other non-renewable		pH changes		Inlets Transitional	Circalittoral rock and other hard substrata (A4)	Ecosystem Service: Cultural	**Intellectual Representative Interactions**
Oil and Gas - offshore		Salinity changes		Inlets Transitional	Sublittoral sediment (A5)		**Physical Experiential Interactions**
Power stations	Physical	**Abrasion/Damage**		Inlets Transitional	Pelagic water column (A7)		**Spiritual Emblematic**
Tidal and wave energy		**Artificialisation of habitat**		Inlets Transitional	Deep-sea bed (A6)		**Spiritual Symbolic Other**
Wind energy		Barrier to species movement		Coastal	Littoral rock and other hard substrata (A1)	Abiotic Output: Provisioning	**Raw Materials Non Metallic**
Research		Change of habitat structure/morphology		Coastal	Littoral sediment (A2)		Raw Materials Water
Ports and marinas		**Changes in Siltation**		Coastal	Infralittoral rock and other hard substrata (A3)		Renewable Abiotic Energy Sources
Urban developments		Changes in wave exposure		**Coastal**	**Circalittoral rock and other hard substrata (A4)**		Nutrition Mineral
Military		**Death or Injury by Collision**		**Coastal**	**Sublittoral sediment (A5)**		Nutrition Water
Shipping		**Disturbance (visual) of species**		Coastal	Pelagic water column (A7)	Abiotic Output: Regulation & Maintenance	**Maintaining conditions By Natural Chemical Physical Processes**
Telecoms and Electricity		Emergence Regime Changes		Coastal	Deep-sea bed (A6)		**Mediation of Flows By Solid Liquid Gaseous Flows**
Transport		**Selective Extraction of non-living resources: substrate e.g. gravel**		**Shelf**	**Circalittoral rock and other hard substrata (A4)**		**Mediation of Waste By Natural Chemical Physical Processes**
Cruise ships and ferries (large)		**Smothering**		**Shelf**	**Sublittoral sediment (A5)**	Abiotic Output: Cultural	**Intellectual Representative Interactions**
Recreational boating and water sports		**Total Habitat Loss**		Shelf	Pelagic water column (A7)		**Physical Experiential Interactions**
Recreational hunting, fishing and angling		Water abstraction		Oceanic	Deep-sea bed (A6)		**Spiritual Symbolic Other**
Shore-based recreation and tourism		Water flow rate changes		Oceanic	Pelagic water column (A7)		Spiritual Emblematic
Waste management	Energy	Electromagnetic changes					
		Input of light					
		Noise (Underwater and Other)					
		Thermal changes					

3.1 Assessment of current Drivers–Pressures–State

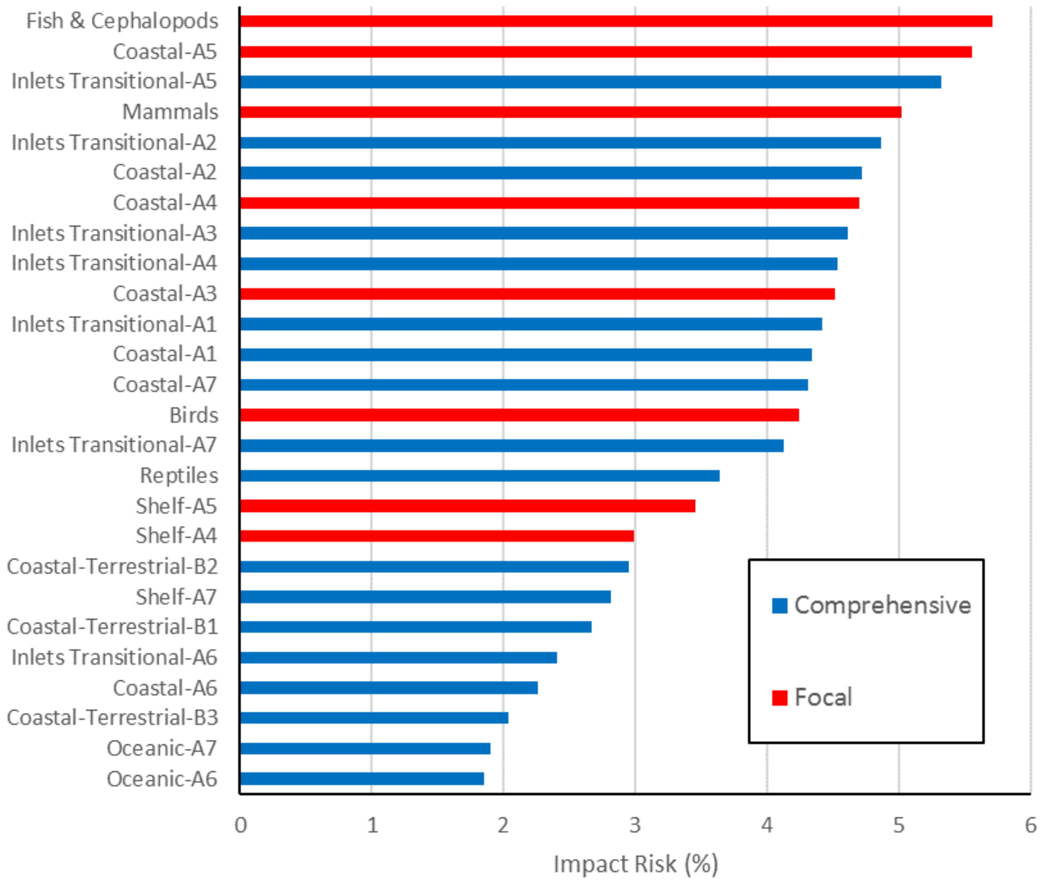
An assessment of the comprehensive SES in relation to the relevant biodiversity objectives (hence only including the Coastal and Shelf habitats – see table 1) shows the relative importance and contribution of human activities in the North Sea to the total risk that EU biodiversity policy objectives are not achieved (see Figure 1). The calculation of impact risk follows a standard approach to environmental risk assessment that considers risk as being composed of the exposure to human activity and their pressures, and the consequences of those activity-pressures as described in (Borgwardt, 2018). Fishing (as a whole) contributes most to this risk. With Offshore Oil and Gas being the single human activity that introduces the most impact risk (IR), directly followed by demersal fishing with towed gears. Both are contributing approximately 7% to the total IR, compared to for instance OWFs contributing almost 4% to the total IR. This risk assessment, however, is based on the recent status and therefore does not take into account the expected increase of OWFs, while, for example, offshore oil and gas is expected to decrease. The application of such future scenarios would change the relative importance of those activities, increasing the relative contribution of OWFs and decreasing that of oil and gas.

Figure 1. Relative importance of the human activities and some selected pressures in terms of their contribution to the total risk that biodiversity policy objectives are not achieved.



The risk-based assessment also shows the ecosystem components mostly at risk from the two selected human activities, i.e. trawl fisheries and OWFs. Figure 2 shows a ranking of all ecosystem components in the comprehensive SES based on their calculated IR. Figure 2 also shows the ecosystem components selected for the focal SES. In terms of IR covered by ecosystem components, the focal SES represents 32% of the total IR.

Figure 2. Relative importance of the ecosystem components in the comprehensive and focal SES in terms of the risk of the cumulative effects of the human activities and their pressures in figure 1.



3.2 Assessment of current Biodiversity-Ecosystem Functioning-Ecosystem Services

In order to provide the decision-makers an additional perspective to the impact on biodiversity described in the previous chapter we also assessed the impact on the supply of ecosystem services (Teixeira, 2018). This assessment is based on the calculation of an ecosystem services (ES) supply potential score (Culhane, 2018). The ES supply potential refers to the importance of an ecosystem component (habitat and associated communities) to contribute to an ES, and is assessed based on a qualitative valuation attributed by expert judgement. Links between ecosystem components and the ecosystem services they supply were given a weight of 0 (no supply), 1 (some supply) or 2 (important for supply). A total service supply potential score was then found for each ecosystem component based on the sum of the weighted scores across all services a component supplies. Figure 3 shows a ranking of all ecosystem components in the comprehensive SES based on their calculated service supply potential and the ecosystem components selected for the focal SES (red). In terms of service supply potential covered by ecosystem components, the focal SES represents 24% of the total service supply potential found. Figure 4 shows a ranking of the ecosystem services supplied by the focal ecosystem components based on the service supply score across all those components. This set of components is important in supplying regulation and maintenance services (e.g. waste treatment by benthic invertebrates) and cultural services (e.g. intellectual representations from birds). Moreover, it shows that several of those ecosystem services are impacted more than the ecosystem service that usually drives conventional marine (fisheries) management, i.e. nutrition from biomass (=catch of fish and shellfish).

Figure 3. Relative importance of the ecosystem components in the comprehensive and focal SES in terms of the potential to supply the ecosystem services listed in Table 1.

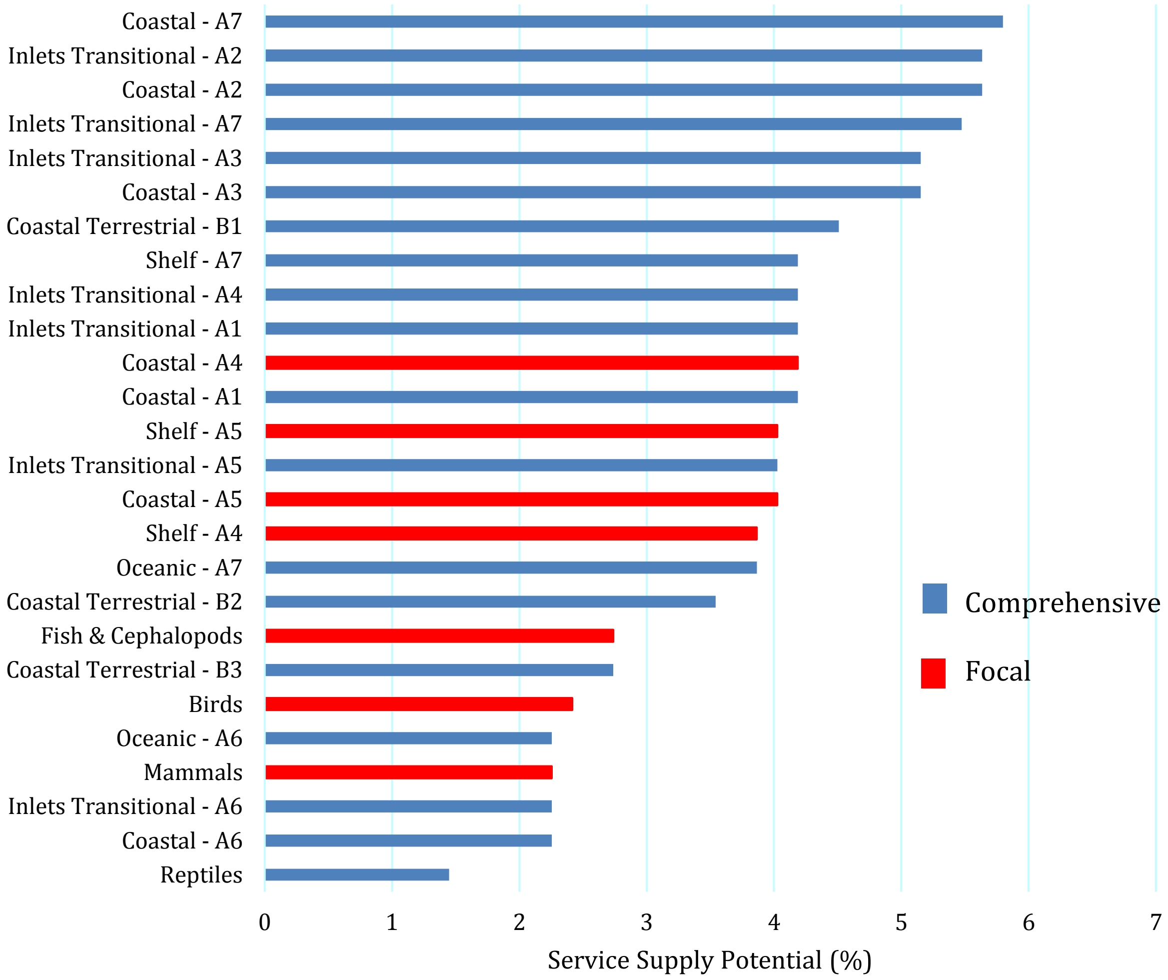
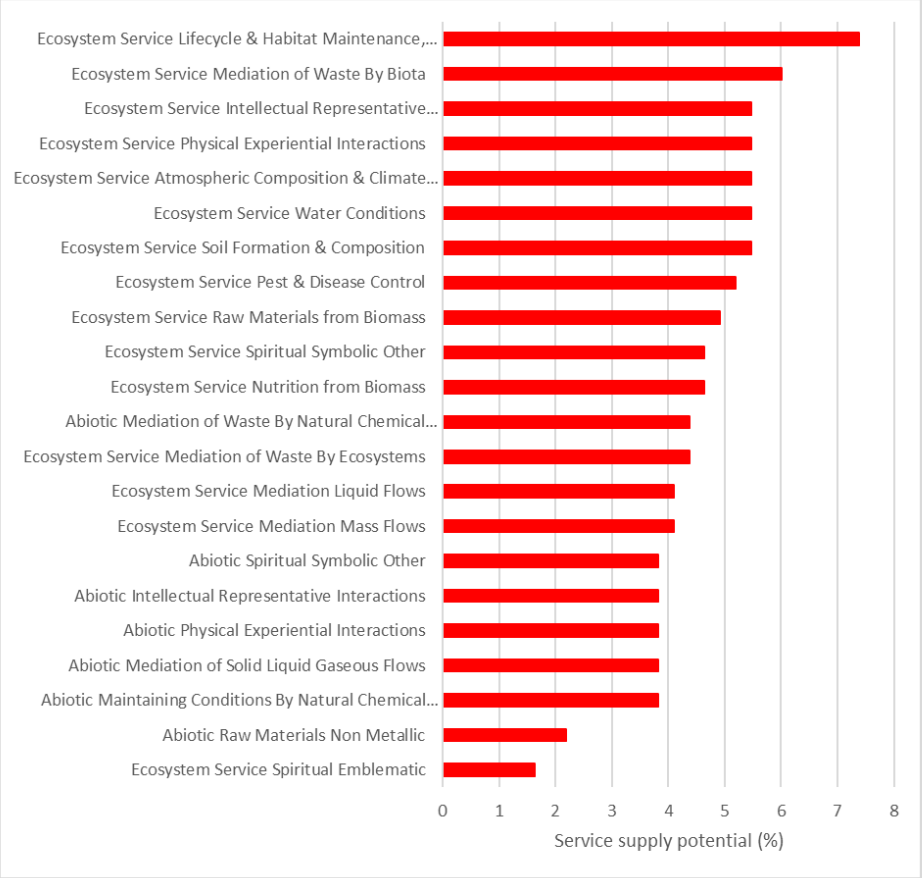


Figure 4. Relative importance of the ecosystem services in the focal SES in terms of the potential to supply the ecosystem services by the set of focal ecosystem components shown in Figure 3.

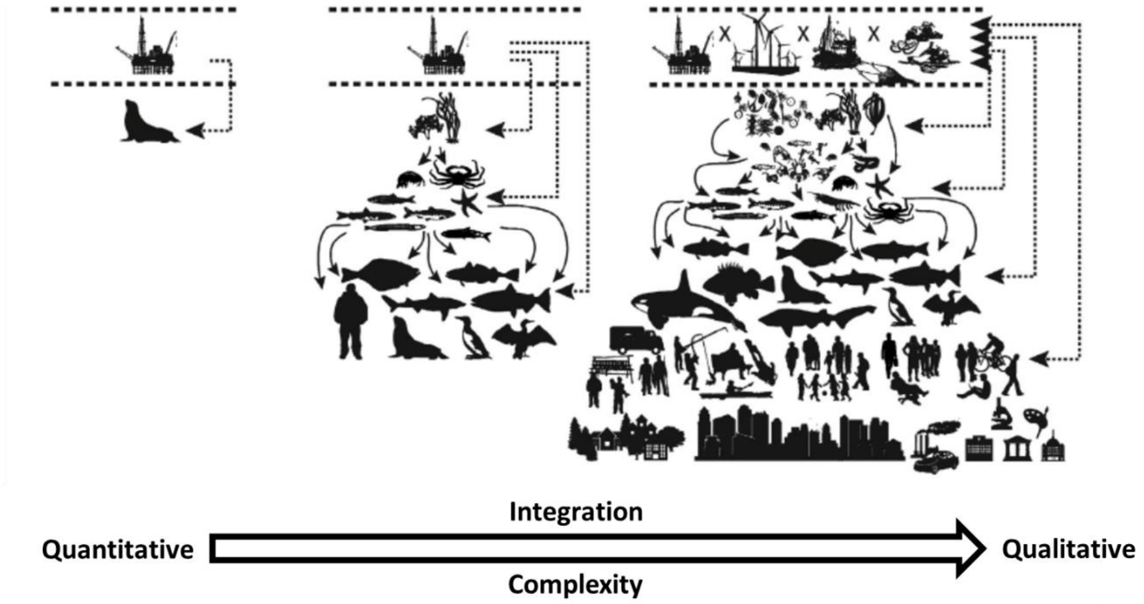


3.3 Assessing the knowledge base of the ecological system

Our assessment of the knowledge base of the North Sea ecological system follows the conceptual framework for ecosystem risk assessment (ERA) (Holsman, 2017). It distinguishes different levels of risk analyses and classes of system complexity, varying from qualitative to semi-quantitative approaches that cover extensive SESs with high complexity to quantitative approaches that cover only a small subset of the SES (see figure 5). We illustrate this by considering two extremes:

- A single impact chain involving the main fishing-induced pressure affecting the seabed habitats, i.e. Fishing with benthic towed gears-physical disturbance-sublittoral sediment and how this is affected by management decisions involving the two sectors, i.e. fisheries and OWFs. The knowledge base allows a fully quantitative assessment.
- An (more) integrated approach involving several pressures affecting biodiversity in a wider sense, i.e. including seabed habitats but also fish, seabirds and marine mammals. The knowledge base allows a qualitative (or semi-quantitative) assessment.

Figure 5. Example of ecosystem risk assessments of increasingly complex ecological systems and for which the knowledge base allows more qualitative risk assessments (adopted from Holsman 2017).



Quantitative information

Here we focus on two human activities: fisheries and OWFs; linked to the societal goals identified in chapter 2.

Fisheries

Probably the best source of information on fishing in the North Sea comes from the recent ICES fisheries overview (ICES, 2017b), showing some general information on the food supply, i.e. landings, and the fishing effort involved. In this overview, we find that around 6600 fishing vessels are active in the Greater North Sea, i.e. fishing capacity. Total fishing effort has declined substantially since 2003. Total landings peaked in the 1970s at 4 million tonnes and have since declined to about 2 million tonnes.

This CS focusses on fisheries with active gears that by fishing, impact the seabed, i.e. otter trawl, seine and beam trawl. These fisheries accounts for most of the fishing effort and capacity but is less important than the pelagic fishery in terms of volume of landings.

Figure 6. Greater North Sea fishing effort (thousand kW days at sea) in 2003–2015, by gear type (LL = longlines) (From ICES, 2017b).

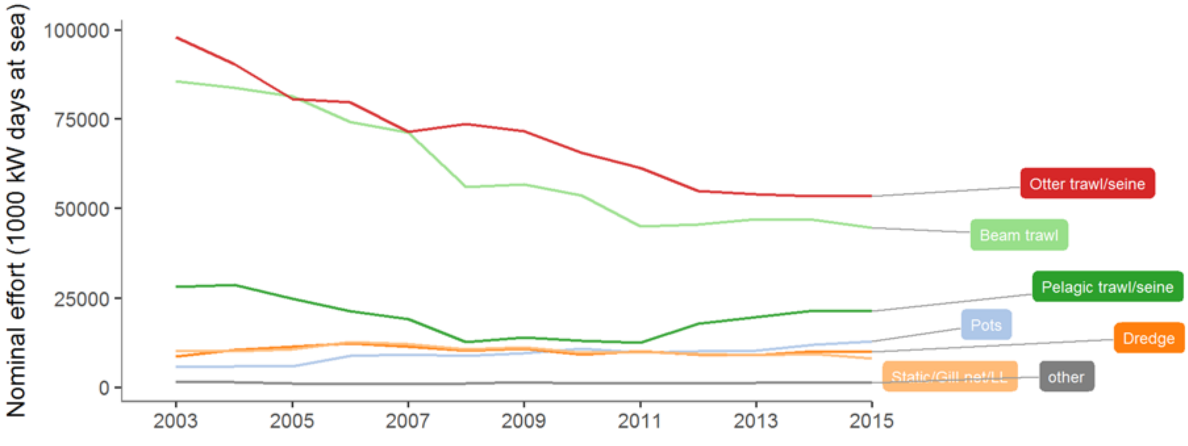
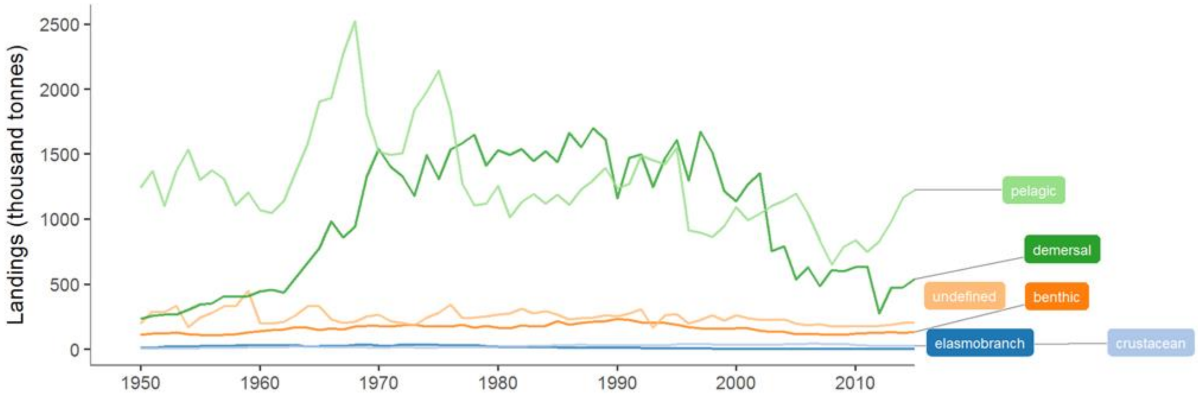


Figure 7. Landings (thousand tonnes) from the Greater North Sea in 1950–2015, by fish category. (From ICES, 2017b).



Fisheries in the Greater North Sea catch a large diversity of species. These have been categorised into species that are pelagic, demersal, benthic, crustaceans, and elasmobranchs. Because of its focus on bottom fisheries, this CS only considers the landings of demersal (e.g. roundfish such as cod, haddock and saithe), benthic (e.g. flatfish such as plaice and sole) and elasmobranch species (i.e. sharks and rays).

Landings can be seen as a provisioning ecosystem service (food provision), but fishing also impacts the ecosystem. The two main ecosystem effects of fishing, next to landings, are discards[2] (catch not retained on board as it cannot be landed and has no market value) and the physical disturbance of the seabed. ICES (ICES, 2017a) provides an overview of the indicators

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[2] With the introduction of the landing obligation in 2015, discards (gradually) need to be landed and cannot be thrown overboard anymore.

of the pressure and impact of bottom-contacting fishing gear on the seabed. These indicators are selected based on their ability to describe impacts on a continuous scale that can be used in the evaluation of the trade-off between the fisheries landings and their impacts on the seabed. We adopted two of those indicators:

- Average fishing intensity. Average number of times the area is swept by bottom-contacting fishing gears. Estimated as the sum of the swept area (depending on gear width, vessel speed, and fishing effort) for all vessels using bottom-contacting gears divided by the total North Sea area.
- Proportion of area fished. The sum of swept area across all grid cells (c-squares, 0.05o × 0.05o grid) in a considered area, where the swept area in a specific grid cell cannot be greater than the area of that grid cell, divided by the total area of all grid cells.

In general, fishing pressure is highly aggregated. The proportion of grid cells at depths of less than 200 m (which constitutes the main part of the North sea) that were fished in 2015 was 80% for the North Sea, while the proportion of the area fished was 54%. 90% of the fishing pressure in 2015 was aggregated into 36% of the grid cells[3].

OWFs

With a total net installed capacity (both onshore and offshore) of 169 GW, wind energy remains the second largest form of power generation capacity in Europe, closely approaching gas installations. In 2017, wind energy covered 11.6% of the EU's electricity demand (WindEurope, 2018). The first offshore wind farm (Vindeby) was installed in Denmark in 1991. Since then over 4000 offshore wind turbines have been installed in Europe amounting to 16 GW in 2017 (Figure 8). By 2020, offshore wind is projected to grow to a total installed capacity of at least 25 GW (WindEurope, 2018). Installations in the North Sea account for 71% of all installed offshore wind capacity in Europe, with most wind farms located in the shallow southern North Sea. By 2030 almost 48 GW of installed capacity is anticipated in the North Sea, taking up large parts of the maritime zones of Germany, the Netherlands, Denmark and Belgium. How this development will impact seafloor integrity will depend on both technical choices and management regimes i.e. if and how fisheries are allowed in wind farm areas.

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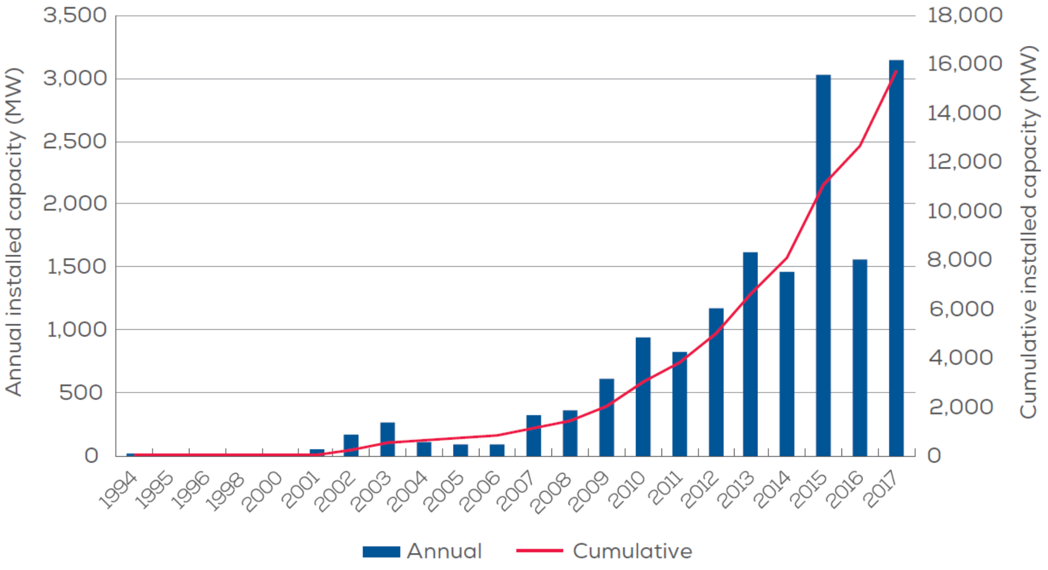
[3] These percentages are scale dependent and depend on the current spatial resolution; should this resolution change, these percentages would change also.

Figure 8. Cumulative and annual offshore wind capacity (WindEurope, 2018).



Source: WindEurope

Qualitative information

In addition to the information describing the focal human activities in the North Sea, we carried out a qualitative assessment of the impacts of those activities and their pressures on the ecosystem components in the North Sea. We identified the links between all of the activities, pressures and ecosystem components (see Table 1), where each activity-pressure-component is one impact chain and one interaction. We weighted each interaction according to five risk criteria: the spatial extent i.e. how much an activity-pressure overlaps with an ecosystem component; the dispersal potential of the pressure; the frequency of the interaction; the persistence of the pressure once the activity stops; and the severity of the interaction on the ecosystem component. This allowed us to explore, for example, how many widespread activity-pressures occur in the system; how many continuous vs. occasional activities are occurring; and how many chronic vs. severe activities there are. These descriptive weightings were further assigned a numerical value to obtain an overall impact risk score (IR) (Borgwardt, 2018) and the summary of the results can be seen in Figure 1 above.

4 The baseline and future scenarios

4.1 Identifying gaps between baseline and objectives

Several different assessments have revealed that environmental policy objectives have not been achieved for the North Sea. The two most recent and comprehensive are (OSPAR, 2010) and (EEA, 2015).

OSPAR (2010) states that the decline in biodiversity is a long way from being halted with many threatened and/or declining species and human activities, specifically fisheries, threatening the extent and condition of several seabed habitats. Offshore renewable energy is mentioned as one of several emerging human activities making increasing demands on marine space and resources.

(ICES, 2017a) provides a first and tentative estimate based on fishing effort data over the period 2012-2015 that fishing depleted on average 24% of the biomass of the benthic invertebrate community in the North sea (excluding >200m depth).

The EEA (2015) assessment tentatively concludes that our seas cannot be currently considered 'healthy'. There are no seabed habitats that meet a favourable conservation status in the North East Atlantic. In the North Sea approximately at least one-third and up to three quarters (depending on the criteria applied) of the commercial fish species are not in “Good Environmental Status” while most of the seabird species are below target levels.

4.2 Scenario development

The likelihood of implementation and the subsequent consequences of the EBM strategies (see next chapter) occurs in a context shaped by broad-scale natural or anthropogenic processes. Anthropogenic scenarios are basically pictures or representations intended to describe such potential future contexts; they provide a general overview of possible future states of the world based on social and economic developments in the coming decades. We have based our North Sea scenarios on two major studies which both follow the four-quadrant approach, whereby the future ‘possibility space’ is divided, based on two axes or dimensions identifying the two driving forces with the greatest importance and the highest uncertainty.

IPCC-SRES

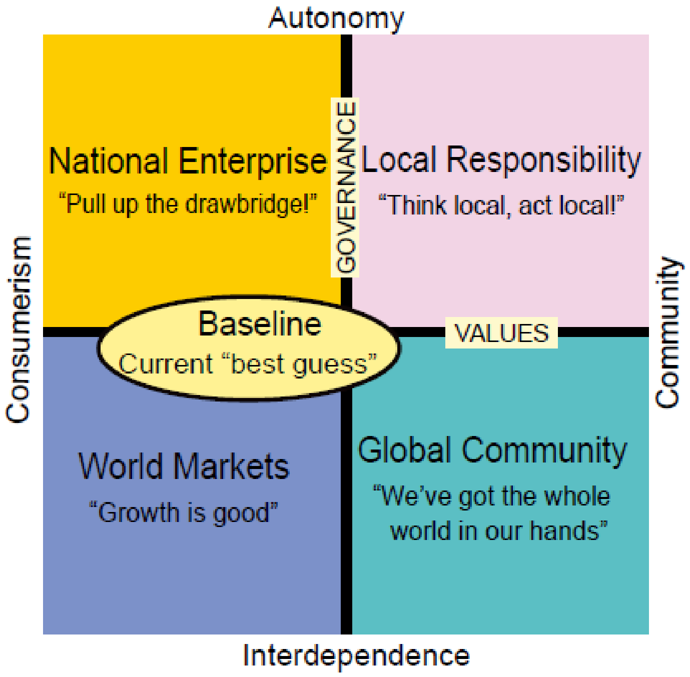
The Special Report on Emissions Scenarios (SRES) is a report by the Intergovernmental Panel on Climate Change (IPCC) that was published in 2000 and we used the SRES AR4 storylines to inspire our scenarios. Figure 9 is based on two major axes:

- The horizontal axis distinguishes between consumerism where people aspire to material wealth and community where people aspire to high levels of welfare and a healthy environment. Sustainable developments are assumed to increase towards the right.
- The vertical axis distinguishes between an emphasis on local/national perspectives versus one on global/international perspectives.

Distinguishing four potential anthropogenic future scenarios:

- World markets: Technology and markets fail to deliver sustainable solutions
- National Enterprise: National identity gets in the way of global sustainability
- Global Community: International co-operation towards global sustainability
- Local Responsibility: Tailored solutions for local problems

Figure 9. Potential anthropogenic scenarios according to Special Report on Emissions Scenarios (SRES) AR4 storylines



PBL Netherlands Environmental Assessment Agency

(Matthijsen, 2018) is a recent study based on extensive consultation of Dutch stakeholders on future (2030 and 2050) scenarios and focussing specifically on the three major societal goals on which this CS is based, i.e. sustainable food supply, clean energy and a healthy marine ecosystem. The study reveals similar (but tilted) axes as the IPCC study and where the scenario IV in the upper right represents the most ambitious environmental scenario (Figure 10).

Figure 10. Potential anthropogenic scenarios based on a study by the Netherlands Environmental Assessment Agency

This scenario study is specifically interesting because it provides concrete scenarios for one of the societal goals, clean energy, albeit only for the Dutch EEZ (Table 2). Note that only the most ambitious scenario IV should manage to achieve the Paris Agreement to keep the global temperature rise this century well below 2 degrees Celsius above pre-industrial levels. It appears that decisions pertaining to the transition to clean energy are likely to have the biggest consequences both economically as well as (indirectly, e.g. as the consequence of decreases in fishing) ecologically.

Table 2. Predicted capacity (in GW) of OWFs in the Dutch EEZ

Future scenario	I	II	III	IV
2030	4.5	7.5	11.5	15
2050	12	22	32	60

5 Evaluation

Current management has failed to achieve several of the environmental goals (see chapter 4.1). At the same time new activities are emerging to meet energy goals. Here we consider a suite of management measures aimed at decreasing the deficit between the current situation and the societal goals identified in our discussion of the policy objectives.

5.1 Detailed specification of relevant EBM solutions

For our EBM solutions we only consider the Programme of Measures (PoM) consisting of different management measures that interact directly with the ecological system. A consideration of a comprehensive EBM plan including also an implementation plan consisting of different policy instruments would have required a truly coupled social-ecological system as opposed to only the ecological system, which is beyond the scope of this study. Table 3 presents the management measures in the EBM plan in relation to the identified societal goals.

Table 3. Specific aim of the management measures (MM) in the EBM plan and the societal goals and human activities they are related to.

Societal goals	MM#	Specific aim of the management measure (MM)	Human activities
Sustainable food supply	1.1	Extension of regular fisheries management to achieve MSY through a reduction in fishing effort or capacity	Fisheries with benthic trawls
	1.2	More precautionary fisheries management that results in bigger reduction of fishing effort or capacity than 1.1 and results in less than the maximum sustainable food supply.	
	1.3	Using incentives to change fishers' behaviour in order to reduce physical disturbance of the seabed habitats.	
	1.4	Applying new technology, i.e. gear substitution of conventional beam trawl to pulse trawl, to reduce the impact of fishing on the ecosystem.	
Healthy marine ecosystem	2.1	A ban on all extractive human activities in existing MPAs.	All extractive human activities, i.e. fisheries, dredging and mining
Clean energy	3.1	Using turbines that reduce bird mortality in OWFs	OWFs and fisheries with benthic trawls
	3.2	Erecting the OWFs in locations where bird mortality is lower	
	3.3	Banning fishing with benthic trawls in the OWFs	
	3.4	Building OWFs such that their additional hard substrate enhances marine biodiversity	

5.2 Evaluation

We evaluate the effectiveness of the EBM measures to contribute to the conservation of biodiversity, i.e. achievement of the “healthy marine ecosystem” societal goal, while also considering potential management initiatives toward achieving the other societal goals, i.e. a “sustainable food supply” and “clean energy”. For example, increasing the (degree of) implementation of the fisheries management measures (1.1-1.4) should improve the biodiversity status but at the risk of failing to achieve a sustainable food supply. Or similarly, the extension of OWFs required to meet our clean energy goals are likely to increase the OWF-related pressures on the ecosystem and hence compromise biodiversity. The degree to which biodiversity is compromised can be mitigated though measures 3.1 and 3.2 while (part of) these impacts may be compensated by the direct benefits from measure 3.3 or potential indirect effects from the fishing ban in the OWFs. We expect that the anthropogenic scenarios (chapter 4.2) determine the likelihood that certain measures are implemented (or not) and, if implemented, the degree to which they mitigate the targeted anthropogenic pressures, e.g. reduction amount of fishing effort, contaminants or marine litter, spatial extent MPA or OWF.

For this evaluation we apply the two types of assessment mentioned in our description of the knowledge base (chapter 3.4). First we conduct an integrated (but semi-quantitative) risk-based approach involving several pressures affecting biodiversity, which then guides a more in-depth quantitative indicator-based approach that only considers a single impact chain.

Integrated risk-based approach

This risk-based approach is conducted on what is considered the focal SES. For the evaluation of the management measures this only involves the ecological system, and only a specific (focal) subset of the activities, pressures and ecosystem components, deemed most relevant for this evaluation. The evaluation of the performance of the management measures is based on their potential contribution to reduce total impact risk (IR). The proportion of total aggregated IR reduced by a specific management measure compared to the baseline scenario (or business as usual) is used as the indicator of effectiveness. We assume the baseline situation for any management measure is represented by the risk scores of the selected (suite of) impact chain(s) without any other management measures that are being considered. For example, the effects of management measures involving OWFs or MPAs assume that in the baseline situation the risk of fishing impact was estimated without any consideration of the OWFs or MPAs already in place preventing fishing in those areas. A management measure that eliminates fishing from 10% of the North Sea is therefore expected to reduce 10% of the impact risk caused by fishing without any consideration of the extent by which fishing is already affected by other (spatial) management measures.

Below we will describe the application of the risk assessment to evaluate three broad categories of management measures each aimed at a specific societal goal (see table 3 and Annex I), i.e. (1) Sustainable food supply, (2) Healthy marine ecosystems and (3) Clean energy.

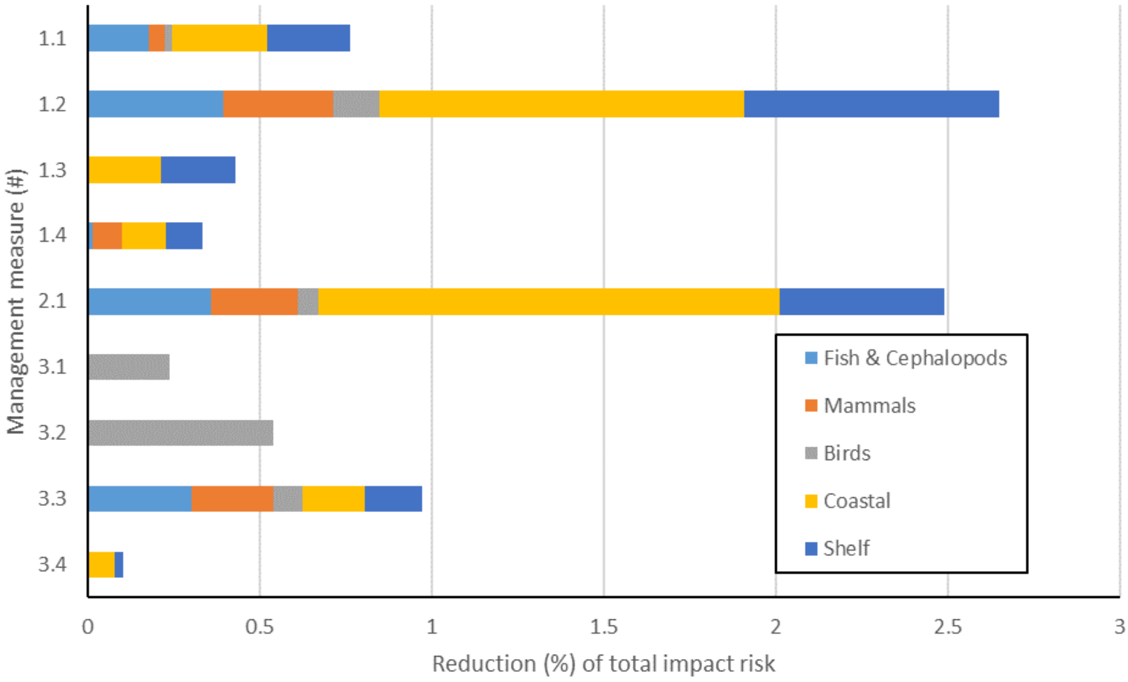
The effectiveness of the management measures is calculated as the aggregated risk across all impact chains affected by the management measure (defined by the human activities in table 3 and the pressures and ecosystem components in Annex I) multiplied by the estimated degree to which IR of those specific impact chains is reduced (Annex I). Effectiveness reflects the potential degree to which the implementation of the measure contributes to biodiversity conservation compared to the baseline situation and is calculated as the cumulative reduction (%) of impact risk on the combined biodiversity components in the focal SES.

This evaluation shows that the precautionary fisheries management measure (1.2, Table 3) is most effective to conserve overall biodiversity (Figure 11). This is because the way the measure is defined in the risk assessment, where we assume that all fishing stops once these estimated lower catch quotas are achieved. This essentially implies a 50% (or for some fisheries even 73%) reduction in fishing effort (or capacity), which would compromise the viability of the fishing fleet and economic sustainability as well as the societal goal of sustainable (maximum) food supply. More sophisticated quantitative models would be required to explore the trade-offs between food supply and conservation goals. What this evaluation did show, and what is not considered in the existing quantitative models, is that several other pressures, notably physical disturbance affecting the seabed habitats and marine litter affecting all ecosystem components, are also potentially affected by such measures and contribute even more to the cumulative effects on biodiversity than the one ecosystem component, fish, that these models do include.

The second best management measure (2.1) in terms of effectiveness performs well because it includes several sectors, i.e. all types of fishing, dredging and mining, and assumes all their activities are banned equivalent to the current extent of all MPAs. In practice, not all MPAs require a total ban of all these activities and often the siting of MPAs is such that economically important areas, e.g. with high fisheries catch per unit of effort, are avoided. A more detailed evaluation of the current and future MPA network would require detailed spatial maps of both the MPAs and all relevant human activities. At least in case of fishing it is known that fishing patterns may change over time and that any extrapolations of future reductions in catch opportunities based on maps of past exploitation patterns are at best only indicative of what can be expected.

Pertaining to the measures involving OWFs, the most effective measure, again, involves a ban of all fishing with benthic trawls within the OWF area. This implied assumption is that these fishing activities then disappear so that it essentially implies a significant reduction in fishing effort. This is not realistic for the economic reasons given before and in reality will result in the fishing activities reallocating to other areas outside the OWF area, which may even result in a net negative impact. Also, the estimated reduction in fishing-induced impact risk is based on an assumed 25% decrease for which considerable uncertainty applies as it depends, similar to the evaluation of the MPAs, on an assumed overlap between future fishing activities and the future position of the OWF, both of which are not considered in this exercise and currently unknown. The next best performing measures involving OWFs suggests a considerable potential reduction in impact risk on only one component, i.e. birds, depending on the design of the wind turbines (3.2) or their location (3.1). This, again, illustrates that more detailed information is required but that this can considerably reduce the impact risk on a component which could, at least in the Netherlands, prevent the development of any further anthropogenic impacts such as OWFs that cause additional mortality.

Figure 11. The effectiveness per management measure (see table 3) expressed as the potential reduction (%) of total impact risk in the focal SES, compared to the baseline situation.

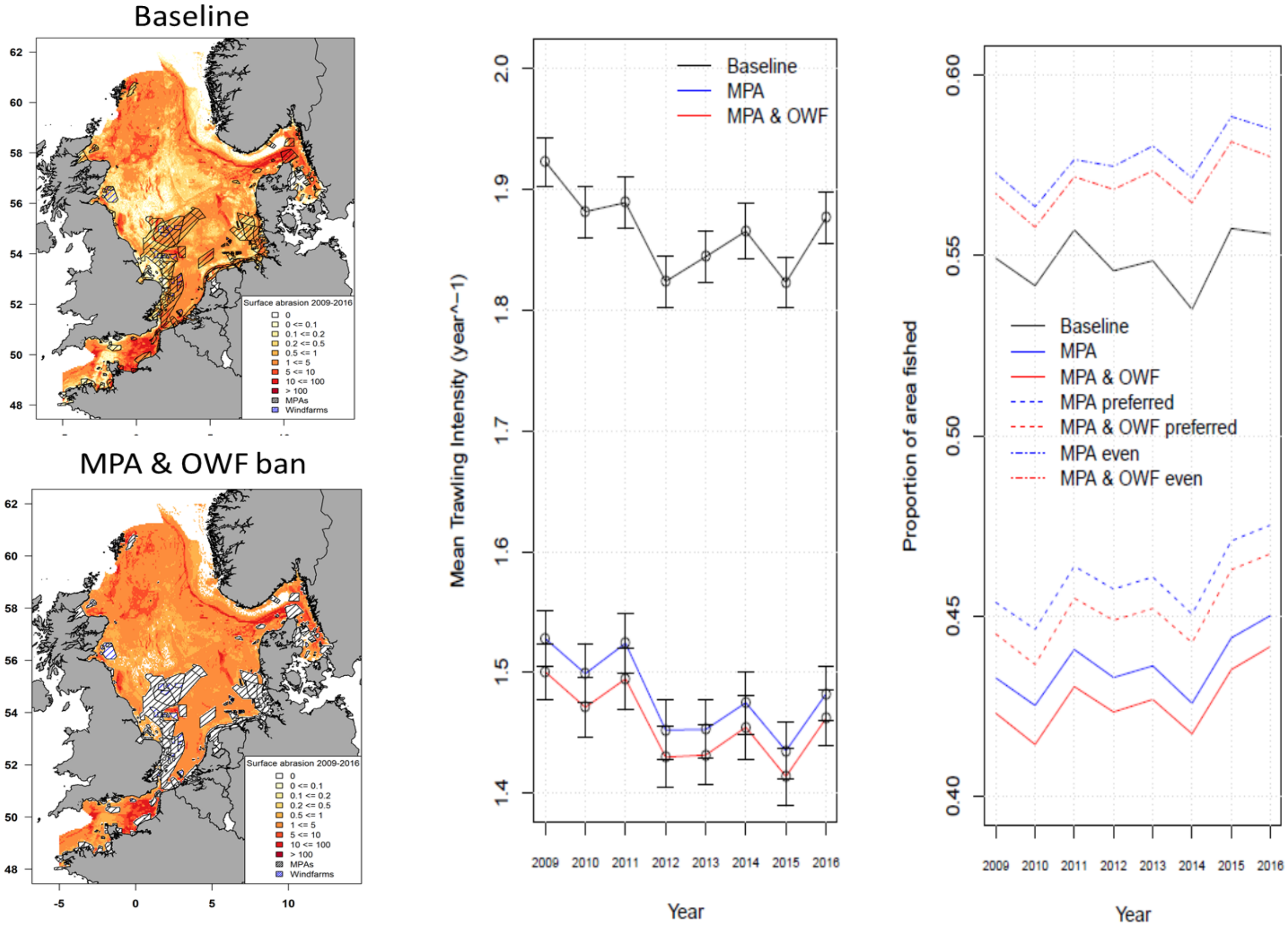


Quantitative indicator-based approach

Guided by the outcome of the integrated approach we focussed on a single impact chain, i.e. Fishing with benthic towed gears-physical disturbance-sublittoral sediment, to evaluate two management measures, i.e. 2.1 and 3.3. These involve a ban on fishing in respectively MPAs and/or OWFs. They are evaluated in terms of their effect on the two indicators that are used to assess the effects of physical disturbance on the seabed habitats (3.4.1): Average fishing intensity and Proportion of area fished (Figure 12). Lower indicator values reflect a decrease in fishing pressure and should hence result in an improved conservation status of seabed habitats.

Figure 12 compares the baseline situation to a scenario where fishing is banned from the (already planned) MPA and OWF areas. For the evaluation we use information of international fishing pressure (period 2009-2016) and assume that (a) all effort in the areas disappears versus (b) reallocates to other fished areas or (c) any area, implying no prior knowledge on fishing grounds. This results in a decrease in both indicators by over 20% (if only the MPAs are closed and slightly more if also the OWFs are closed for fishing) in case of scenario a. Comparing this with the more realistic scenarios b and c then shows that assumptions on how

Figure 12. Results for the evaluation of the effectiveness of a fishing ban in planned MPAs (From OSPAR http://carto.mpa.ospar.org/1/ospar.map) and OWFs (From EMODnet http://www.emodnet-humanactivities.eu/view-data.php). The two maps show a baseline situation based on information of international fishing pressure (From ICES/OSPAR, period 2009-2016, http://ices.dk/sites/pub/Publication%20Reports/Advice/2017/Special_requests/OSPAR.2017.17.pdf) and a situation where all effort within the MPAs and OWFs is reallocated across the North Sea without any prior knowledge of fishing grounds (=scenario c). The left graph shows for the mean trawling intensity the difference between the baseline and scenario a, the right graph right the proportion of the North Sea area that is fished for the baseline scenario and the scenarios b (preferred) and c (even).



fishing effort is redistributed makes a significant difference to how the management decision affects the fishing pressure on the seabed habitats. Scenario b causes a decrease of the proportion of the North Sea area fish from approximately 55% to 45% whereas scenario c results in a slight increase from 55% to approximately 57% (Figure 12).

Impact Assessment

In this section, we discuss the potential financial effects of the proposed measures.

Reducing fishing effort in the North Sea (measures 1.1, 1.2 and 1.3)

Any proposed measures that imply a reduction in fishing effort or capacity will have an impact in the overall profitability of the fleet. Commercial fisheries in the North Sea (as reported by OSPAR) account for €4.1 bn turnover, €558 m GVA and 75,000 employment; with around €2 bn turnover in the Channel and North Sea area alone (OSPAR, 2013).

The impact from the reduction in fishing effort from the implementation of measures 1.1, 1.2 and 3.3 is assumed to result in a reduction of value of landings for certain segments and the associated reduction in total income. For the purposes of the analysis, we assume a direct relationship between decreased fishing effort, landings and their value (e.g. 10% reduction in fishing efforts equals a 10% reduction in value landings). Please note that other factors that may come into play relevant for this analysis have not been considered, for example the impact of changes on volume on landings on market prices and income.

We apply Doring et al., 2010 results (based on AER, 2010 data) to estimate changes in fish landings and income. Their methodological approach allows for a degree of fleet segmentation. The authors developed detailed economic indicators for the ten most important fleets in terms of revenues from the exploitation of North Sea stocks. Out of a total of 83 European fleets active in the North Sea in 2010, the value of the selected 10 fleet segments used in this study accounts for a total income of 1024 million Euro, which is around 60% of total landings value by EU registered fleets in the area in 2008 (Doring et al., 2010). The selected fleet segments included from Doring et al., 2010 that are relevant for this analysis are: DNK Pela-Trawl 24-40, DNK Pela-Trawl 40XX, GBR PotsTraps 00-10 and NDL PelaTrawl 40XX).

Table 4. Estimated loss in volume of landings and income

Measure	Expected impact reduction in fishing effort (%)	Loss in Volume of landings (1000 tons/year)	Loss in Income (million Euros/year)
1.1	7.5 %	65.5	28.3
1.2	50 %	436.5	188.6
3.3	25 %	218.3	94.3

As for measure 3.3, banning fishing with benthic trawls in the OWFs, the results need to be treated with caution. In reality, fishers will probably re-locate to other areas, so there may not actually be a reduction in effort.

Habitat banking (measure 1.3)

Habitat credits have the potential to minimise the benthic impacts of bottom trawl fisheries at a minimal loss of landings and revenue. According to Batsleer et al., 2018, "*vessels can reallocate their effort to less vulnerable fishing grounds, while allowing the fishery to catch their catch quota and maintain their revenue*".

This economic instrument provides incentives for fishers to target healthy stocks, in addition, it can include provisions for using and developing more selective fishing gear. Depending on the design of the instrument, extra credits can be gained through applying best practices and new technology including the use of environmentally sensitive, selective fishing gear or through respecting voluntary closures[4]. Another potential financial benefit is the possibility to transfer or "sell quota" to other fishermen based on established rules.

In relation with its impact to the sector, the increased financial costs to the fishermen would be related to scoping new catching areas and the potential increase in fuel consumption to get to these locations. The relative cost of the credits would need to be carefully assessed as it may have potential implications on top of the costs of existing fishing licenses. This can be designed in terms of annual landings, uptake of habitat credits, quota, and available credits.

As with any other economic instruments, an increase in transaction costs can be expected. Transaction costs are the costs associated with designing, setting up and maintaining the scheme (staffing and training, costs for bureaucracy and users groups; investment in property, infrastructure and equipment; time and money related to measurement, reporting, enforcement and further evaluation for example). Additional implementation, monitoring and enforcement costs to the regulated management body are likely to be transferred to the sector through modifications to the legislative setting. Ultimately, the existence, magnitude and distribution of TC may explain the success or failure of the instrument (Delacámara et al., 2013)

Technology substitution: pulse trawl (measure 1.4)

This measure involves gear substitution of conventional beam trawl to pulse trawl, to reduce the impact of fishing on the seafloor. The technology consists mainly of electrodes attached to the bottom of the nets that send electrical pulses through the surrounding area. Switching to electric pulse gear can cost around €300,000 to fit on a vessel[5].

A recent study has reviewed the economics of gear transition from traditional beam trawl to pulse trawl (Hamon et al., 2016). The authors conclude that pulse trawl increases profits when targeting sole stocks, as the technique reduces fuel consumption considerably. Returns on investment of around 24% were estimated for the Dutch fleet and around 6 % for the Belgium fleet in the assessed examples. However, the study fails to include in the analysis the length of time for the investment, which is necessary to assess the true rate of return. Noteworthy, shorter returns on investment can be expected when fuel prices are higher.

Despite the potential advantages over conventional beam trawl, government support through subsidies is still needed to ensure uptake of pulse trawling technology in the Netherlands (Hamon et al., 2016), proving that the sector without public support is reluctant to invest in technological innovation. Other relevant uptake factors to consider are research, information

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[4] https://ec.europa.eu/fisheries/sites/fisheries/files/docs/body/clientearth_mcs_en.pdf

[5] https://www.theguardian.com/environment/2018/jan/15/european-parliament-to-decide-future-of-pulse-fishing

and awareness campaigns, all of which remain at this moment heavily subsidised (Hamon et al., 2016).

Banning extractive activities in Marine Protected Areas (Measure 2.1)

This measure would apply to the 18% of EU waters area in the North Sea within 200nm that have been designated as MPAs. To offer an illustration of the scale of the potential impact of the ban and because of a lack of spatial information, we assume a direct link between area exploited and turnover for different extractive human activities in the North Sea. This follows the same assumption used for the decrease of the risk that is equal to the surface area of the North Sea covered by MPAs. We apply OSPAR (2013) turnover figures as reported for OSPAR region II countries for all extractive activities. Turnover has been used to express the cost of the measure, as many OSPAR countries fail to report GVA figures.

Table 5. Turnover OSPAR region II (M€) and cost of measurement 2.1 (m€) per activity and total.

Activities	Turnover OSPAR region II (M €)	Cost of the measure(m €)
Commercial Fisheries	2000	360
Oil and Gas	170000	30600
Aggregate Extraction	1000	180
TOTAL		31140

Off-shore wind farms: reducing bird mortality (measures 3.1 and 3.2)

The generation of renewable energy in the North Sea accounts for around €83 bn turnover, €4.6 bn GVA and14,200 employment (OSPAR 2013). Wind turbines are installed for 20-25 years before decommissioning (Bouty et al., 2017).

Measure 3.1 proposes that fewer and larger turbines are installed, as these have a higher clearance. At their lowest point the wings are 25-30 meter above sea-level and most seabirds fly at lower altitudes. This reduces the number of collisions in two ways: less collisions per turbine and fewer turbines per windfarm. This measure is currently enforced in The Netherlands and it is in addition preferred by the industry, as it is more cost-effective than the installation of many smaller wind turbines for the same amount of energy produced[6].

Under measure 3.2, OWF are located in places where bird mortality is lower. In practice, this measure means moving installations further offshore. This is currently an ongoing industry trend as governments are scoping/licensing areas further offshore for the development of new OWFs.

Off-shore wind farms: promoting biodiversity (measure 3.4)

Measure 3.4 proposes to build OWFs in such a way that their additional hard substrate enhances marine biodiversity. The extra costs of building an artificial reef are minimal compared to the costs of the cable/turbines/installation. A safe assumption (likely overestimated) would be that they add 0.1-0.5% to the total project cost.

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[6] https://www.renewableenergyworld.com/articles/print/volume-21/issue-1/features/wind/bigger-turbines-better-economics-more-digitization-on-deck-for-2018-wind-power-market.html

5.3 Pre-conditions for successful implementation of EBM

Despite EBM being mentioned in every major marine policy framework the successful implementation of EBM in the North Sea mostly depends on the institutional set-up and its governance processes, which should allow or (even better) require integrated ecosystem-based scientific advice to guide decision-making. This study, however, did not focus on the governance aspects that determine the demand for and uptake of EBM advice but instead focussed on the knowledge base on which this scientific advice is based.

Thus, in this study we interpreted these pre-conditions as the requirements of the scientific knowledge base of the socio-ecological system to guide (more) integrated ecosystem-based decision-making. This study aimed to advance scientific advice by adopting a more integrated perspective, thereby allowing consideration of different societal goals that targeting multiple sectors and impact different components of the ecosystem. This implies that we focussed on three of the principles for marine EBM identified by Long et al. (Long et al., 2015) and further developed in Piet et al. (submitted):

- It considers ecological integrity and biodiversity. With its focus on many different ecosystem components, including both species and habitats, this is a clear improvement to conventional management focussing on a single species or component.
- It considers ecosystem connections. This integrated perspective also requires a full consideration of all potential ecosystem connections. Even though our focal SES covers only a subset of the comprehensive SES, it is a major improvement, as it includes many more ecosystem connections than existing single-sector or single-species approaches. For example, typical fisheries management consists of only a single impact chain in this linkage framework, e.g. Fishing (benthic towed gears) – Extraction of flora and/or fauna – Fish & Cephalopods (see table 1).
- It considers cumulative impacts. This approach applies an integrated perspective in that it explicitly considers different societal goals and how their achievement is potentially compromised by several human activities and their pressures. Current management in the North Sea is usually focussed on a single sector (e.g. fisheries management).

In this study we interpreted integration as the consideration of different ecosystem components and human activities, thereby restricting ourselves to the ecological system. Further integration would involve the application of a coupled SES where the performance of the EBM plan is assessed both in relation to the ecological system as well as the social system.

The results of this study show that integrated ecosystem-based scientific advice can provide a new perspective to the conventional science advice confined within the institutional silos and, as such, should be considered complementary to this. The results also show that the current knowledge base needs considerable development before it can fulfil this role. The risk-based approaches appear promising for integrated assessments of cumulative effects, although they need to advance from qualitative expert-judgement-based approaches to more quantitative approaches based on the best available information.

6 Discussion and Conclusions

The operational EBM approach applied in this CS is built on previous (ecosystem-based) management statements that EBM should be considered an incremental piecemeal process where each EBM cycle advances the process to provide salient and credible advice to the decision-makers and other actors (Rockmann et al., 2015). Compared to prior cycles of (ecosystem-based) management advice this EBM cycle is novel in that it presents a first attempt to provide a more integrated, ecosystem-based approach which considers diverse societal goals, includes several sectors, and considers their impacts on the entire ecological system (but not the social system). This is also a first attempt to apply a risk assessment in order to assess the effectiveness of a suite of management measures that are part of an EBM plan. Even though only the application of a semi-quantitative risk assessment framework (see (Holsman, 2017)), is presented in this paper, it indicates the main threats to a healthy marine ecosystem and the most effective management measures to mitigate those threats. As such, this provides the basis for more quantitative modelling tools that only cover a small part of the focal SES but can forecast specific scenarios in the detail required by decision-makers. The outcome of this semi-quantitative risk assessment should guide the selection and, if needed, further development of those quantitative modelling tools that cover the main threats (represented by specific impact chains) and/or most promising management measures.

This first attempt to apply a semi-quantitative risk assessment in order to assess the effectiveness of a suite of management measures showed that this approach is a useful first step in identifying the critical activities, pressures and ecosystem components that need to be targeted by management measures. As we have shown, the advantage of the risk assessment approach is the ability to define the focal SES in the context of the full SES.

This initial evaluation of all the management measures is based on a semi-quantitative risk assessment framework. This does allow an integrated perspective covering the full breadth of all the relevant human activities, their pressures and how their cumulative effects impact all the different components in the ecosystem but often lacks the accuracy to provide the detail that decision-makers probably require at the scale considered here. It does succeed, however, in providing guidance to the next step in developing the knowledge base, i.e. the selection and further elaboration of quantitative models. As a final point, it is clear that in order to evaluate specific management measures, the risk assessment also needs to be based on the actual spatial distributions of the human activities, their pressures, the ecosystem components, the ecosystem services they provide and an accurate understanding on behavioural responses to proposed measures. A knowledge base suitable to guide EBM therefore needs to acquire sufficiently detailed spatial maps of the distribution of all these elements of the SES.

This exercise aimed at providing guidance for (more) integrated EBM has shown how risk-based frameworks can be used to provide guidance for identifying suitable management measures. This revealed their use in providing a more integrated perspective including several human activities and their pressures impacting all the main components in the marine ecosystem but also their limitations in terms of the required accuracy and detail required by decision-makers. Our findings provide direction to the (further) improvement of the North Sea knowledge base and the type of risk assessments it can support, while acknowledging the trade-offs between being comprehensive but qualitative versus quantitative but limited in terms of the part of the SES that can be covered. This will apply even more if the next step in integration is to be made, i.e. the consideration of a coupled social-ecological system allowing the application of interdisciplinary science.

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Annex

All annexes are available on the AQUACROSS website Case Study 1 page.

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