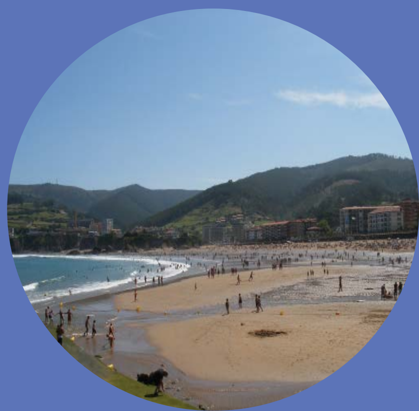
Options for Delivering Ecosystem-Based Marine Management

Assessing performance outcomes of management strategies for regional case studies



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Glossary

Word/Phrase	Acronym	Definition
BAU+	BAU+	A measure or suite of measures implemented in addition to Business-as-Usual that introduce a change or changes in the environmental, societal or economic landscape from its current state.
Business-as-Usual	BAU	Business-as-Usual is a description of the current management programmes in place (or in the process of being implemented but not yet operational) within a regional sea. BAU is used to describe the current state of the environmental, societal or economic landscape.
Driver	D	According to DPSIR, driver or 'driving force' is a need. Examples of primary driving forces for an individual are the need for shelter, food and water, while examples of secondary driving forces are the need for mobility, entertainment and culture. Here the driver is defined by the sector and activity.
Driving forces, Pressures, States, Impacts, Responses (DPSIR) framework	DPSIR	The causal framework for describing the interactions between society and the environment adopted by the European Environment Agency (definition taken from http://www.eea.europa.eu).
Ecosystem based management	EBM	The comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity (definition taken from OSPAR).
Good environmental status	GES	Environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations.
High level objectives	HLO	The overall objectives set by a particular policy or directive. For the Marine Strategy Framework Directive (MSFD) these are the eleven GES descriptors, whilst for the Habitat's Directive these are the criteria for Favourable Conservation Status.
Impact chain		Chain linking driver-pressure-state, that causes the specific impact.
Indicator		An indicator is a standard measure (metric) that allows change to be measured. Indicators may be abiotic (e.g. a chemical concentration) or biotic (a species or taxon). A reference value is used to indicate the expected state of an indicator.

Management measure		Specific controls applied to contribute to achieving the objectives. Several mechanisms may be applied to apply these controls, including technical, social or economic.
Management option		A management option consists of one or more measures adopted by the management authority in order to reach an operational objective, but not consisting of concrete management measures nor a specification of the actions required to fulfil the preconditions.
Management strategy		A management strategy consists of one or more measures adopted by the management authority in order to reach an operational objective. Unlike a management option, a strategy includes a specification (or at least consideration) of actions required to fulfil the preconditions for the implementation of the selected measures (e.g. monitoring and/or enforcement).
Pressure	P	The mechanism through which an activity has an effect on any part of the ecosystem. Pressures can be physical (e.g. abrasion), chemical (e.g. introduction of synthetic components) or biological (e.g. introduction of microbial pathogens). The pressures are based on the MSFD Annex III.
Sector		A business that exploits the same or related product or service provided by the marine ecosystem (e.g. shipping; coastal infrastructure).
State	S	According to the DPSIR framework, the 'state' of the environment is the quality of the various environmental compartments (air, water, soil, biota etc.) in relation to the functions that these compartments fulfil. The 'state of the environment' is thus the combination of the physical, chemical and biological characteristics (see MSFD Annex III).

1 Introduction

The Marine Strategy Framework Directive (MSFD) is a thematic strategy for the protection and conservation of the marine environment with the overall aim of promoting sustainable use of the seas and conserving marine ecosystems (EC, 2008). This should be achieved by applying an ecosystem-based approach to the management of human activities while enabling a sustainable use of marine goods and services. To that end, priority should be given to achieving or maintaining good environmental status (GES) in the Community's marine environment, to continuing its protection and preservation, and to preventing subsequent deterioration (EC, 2008).

The concept of GES is at the core of the MSFD and is described as the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable. GES shall be determined at the level of the marine region or subregion as referred to in Article 4, on the basis of eleven qualitative descriptors:

1. Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions.
2. Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems.
3. Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock.
4. All elements of the marine foodwebs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity
5. Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters
6. Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected
7. Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems
8. Concentrations of contaminants are at levels not giving rise to pollution effects
9. Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards
10. Properties and quantities of marine litter do not cause harm to the coastal and marine environment
11. Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment

Breen et al. (2012) considered these descriptors as the high level objectives (HLOs) of the MSFD (for more details see Knights et al. (2011)). These (sub)regional HLOs and the requirement to apply ecosystem based management (EBM) in order to achieve sustainable levels of exploitation, are at the basis of the principal aim of ODEMM to "develop a set of fully-costed ecosystem management options that would deliver objectives of the Marine Strategy Framework Directive, the Habitats Directive and other relevant guidelines and policies". This determined the work in this deliverable, where we identified in a number of regional case studies which descriptors are at high risk of not achieving GES (after Breen et al. (2012)). From those we selected two descriptors that would require the project to apply specific aspects of EBM in their management options to achieve the MSFD objectives. We chose Seafloor integrity (descriptor 6) because this involves multi-sector management options. Also, the foodweb descriptor (descriptor 4) was selected because the HLO was never considered before when developing management options and is therefore likely to require options involving different types of measures than existing conventional management.

In addition we wanted the same descriptor to be considered in different regions so that we could compare regional approaches to the same issue. The case study areas were based on the four European marine regions identified in the MSFD; the Northeast Atlantic, the Black Sea, the Baltic Sea and the Mediterranean Sea. These different regions require different and specific solutions to achieve and maintain GES because of their different natural environment and the different anthropogenic pressures and drivers that are present in these regions. Regions also differ in terms of governance structures and programs of measures that are currently applied. The differences between the case studies will allow testing of the ODEMM tools in terms of their general applicability.

For the different regional case studies the following objectives were chosen:

- North East Atlantic (NEA) – Sea floor integrity
- Mediterranean sea – Sea floor integrity
- NEA – Foodwebs
- Baltic sea– Foodwebs
- Black sea – Foodwebs

Within the case studies two different courses of action were considered; business as usual (BAU) and implementation of additional management strategies aimed to achieve GES for the specific descriptor (BAU+). In each case study we evaluated the different BAU and BAU+ measures to identify what should be considered the preferred options to achieve the policy goals.
In the case studies a qualitative/ semi-quantitative assessment was carried out in order to estimate the change of the ecological characteristics due to the implementation of BAU and BAU+ measures in the regional seas.

Our approach consists of the following steps:

1. A scoping exercise intended to identify those impact chains that contribute most to the risk of not achieving the selected HLOs. This is based on previous ODEMM work namely
    a. the development and identification of impact chains (Piet *et al.*, 2012) that link driver-pressure-state and that essentially link the ecosystem components relevant for the HLOs to the human activities that need to be managed.
    b. Followed by the risk assessment developed by Knights et al. (In prep) which identifies the high-risk impact chains for each (sub)region.
    c. A further selection of the most relevant high-risk impact chains which contain those ecosystem components on which the proposed MSFD indicators (see Piet et al. (2012)) for that HLO are based. These relevant high-risk impact chains determine which human activities (i.e. sectors and pressures) management should focus on.
2. The identification of existing (BAU) management measures as well as possible additional (BAU+) management measures intended to complement the existing measures and contribute to achieving GES.
3. Evaluation of the BAU and BAU+ management options using the most appropriate (and available) tools and sources of information (i.e. simulation models, empirical information and expert judgement).
4. Discussion of what can be considered (the most) appropriate management options to achieve the chosen (sub)regions HLOs.

In this synthesis report, we summarise all steps and outcomes from each case study. Full details of the analyses undertaken can be found in the full case study reports which are cited in each relevant chapter below.

2 Method

In the case studies the performance of different management measures, implemented to achieve GES for a descriptor, were evaluated. This was done using a specific method. First, a scoping exercise was conducted for each case study identifying the main threats that may prevent achieving GES as well as outlining the choice of foci taxa of that region. The choice of the foci taxa is based on the specific indicators proposed by the member states for the descriptor, in the region concerned and the operational status of the specific indicator (Piet *et al.*, 2012). Following the mapping of linkages between human uses and natural components of the ecosystem (Koss *et al.*, 2011), the application of the ODEMM pressure assessment (Robinson and Knights, 2011) and the DPSIR framework the main threats are presented using so-called impact chains which essentially consist of a driver-pressure-state linkage describing how a sector affects a specific ecosystem component through a pressure thereby causing an impact.
Second, potential management measures were identified through the application of a framework that matches measures to the (parts of) the impact chain (see Piet *et al*. (in prep)). Those measures matched to the high-threat impact chain that contained the foci taxa were the basis for this evaluation. Details of each step are given below.

2.1 Step 1: Scoping exercise

The scoping exercise identifies those impact chains that contribute most to the risk of not achieving the selected HLOs. This is based on previous ODEMM work namely:

1.a. the development and identification of impact chains (Koss *et al.*, 2011; Robinson and Knights, 2011; Piet *et al.*, 2012) that link driver-pressure-state and that essentially link the ecosystem components relevant for the HLOs to the human activities that need to be managed.
1.b. Followed by the Pressure Assessment developed by Robinson and Knights (Robinson and Knights, 2011) which identifies the high-risk impact chains for each (sub)region.
1.c. A further selection is then made of the most relevant high-risk impact chains which contain those ecosystem components on which the proposed MSFD indicators (see (Piet *et al.*, 2012) for that HLO are based. These relevant high-risk impact chains determine which human activities (i.e. sectors and pressures) management should focus on.

2.1.1 Step 1.a: Development and identification of impact chains

The complete Pressure Assessment contains all sector-pressure- ecosystem component links. Detailed information about the development and use of this Pressure Assessment can be found in the Milestone report (Piet *et al.*, 2012) and the ODEMM Pressure Assessment Userguide (Robinson and Knights, 2011).

2.1.2 Step 1.b: Identification of high–risk impact chains

The Pressure Assessment was used to extract those sector/pressure combinations that pose the highest threat to a particular ecosystem characteristic. The following rules were used for all case studies to identify these so-called 'high-risk impact chains':

- extent = Widespread Patchy or Widespread Even, Degree Of Impact=Acute or Chronic and persistence=High or Continuous,
- extent = Widespread Patchy or Widespread Even, DOI=Acute and frequency=Occasional, Common or Persistent,
- extent = Widespread Patchy or Widespread Even, DOI=Chronic and frequency=Persistent or Common (Knights *et al.*, 2011) (Breen *et al.*, 2012).

The high-threat impact chains were narrowed down for the foodwebs descriptor by extracting only those high-threat impact chains that were linked to ecosystem components relevant for foodwebs (i.e. Plankton, Bottom fauna and flora, Fish (Benthic, Deep sea and Pelagic) Marine mammals and Reptiles and Seabirds (inshore and offshore)). For descriptor 6, sea floor integrity, the high-threat impact chains that were linked to the ecosystem component Habitats were extracted.
The results of these extractions identify the main Drivers (sector-activities), Pressures and Ecological characteristics that need to be considered for the management towards achievement of the objective of GES for descriptors in the different regions.

Per case study, the sector-pressure combinations resulting from the high-threat chains extractions were identified (see Table 2, Table 5, Table 11, Table 14 and Table 18) and used as the basis to determine which sector-pressure combinations to take forward based on the relevance of the combinations in the specific case study. These sector-pressure combinations were then considered in step 1.c using a second table (see Table 3, Table 6 and Table 12).

2.1.3 Step 1.c: Further selection of most relevant high-risk impact chains

The extractions of the high-threat impact chains and the list of indicators (see Table 1) were used together with expert judgement to further scope the case studies. For the foodwebs case studies, this was done using a second table format (see Table 3, Table 6 and Table 12). The sector-pressure combinations resulting from the table in step 1.b were considered in this second table and combined with foci taxa (i.e. relevant indicator species), further selecting the relevant taxa, sectors and pressures to consider in the case studies.
The choice of the relevant taxa on which to focus the information necessary to evaluate the management measures was guided by the proposed specific indicators in each of the MSFD (sub)regions as well as practical management considerations. The database of potential indicators was created based on datasets consisting of potential indicators that were submitted by regional experts (Piet *et al.*, 2012). The review of operational objectives (Breen *et al.*, 2011) provided a starting point for this database, narrowing down objectives and indicators.

After finalising step 1.c, the main threats in terms of sectors and pressures were identified and the foci taxa were defined for the case study. These were then taken forward to step 2, where identification of the BAU and BAU+ management measures aimed at these sectors, pressures and foci taxa took place.

Table 1. MSFD descriptors and corresponding attributes and indicators as phrased in the Commission Decision (EC, 2010) for Foodwebs and Sea-floor integrity

4. All elements of the marine foodwebs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity
4.1. Productivity (production per unit biomass) of key species or trophic groups 4.1.1. Performance key predator species using their production per unit biomass (productivity)
4.2. Proportion of selected species at the top of foodwebs 4.2.1. Large fish (by weight)
4.3. Abundance/distribution of key trophic groups/species 4.3.1. Abundance of functionally important selected groups/species
6. Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected
6.1. Physical damage, having regard to substrate characteristics 6.1.1. Type, abundance, biomass and areal extent of relevant biogenic substrate 6.1.2. Extent of the seabed significantly affected by human activities for the different substrate types
6.2. Condition of benthic community 6.2.1. Presence of particularly sensitive and/or tolerant species 6.2.2. Multi-metric indexes assessing benthic community condition and functionality, such as species diversity and richness, proportion of opportunistic to sensitive species 6.2.3. Proportion of biomass or number of individuals in the macrobenthos above some specified length/size 6.2.4. Parameters describing the characteristics (shape, slope and intercept) of the size spectrum of the benthic community

2.2 Step 2: Identification of BAU and BAU+ management measures

In this step, existing (BAU) management measures as well as additional (BAU+) management measures were identified. BAU and BAU+ were defined as follows:

- BAU: Business-as-Usual is a description of the current management programmes in place (or in the process of being implemented but not yet operational) within a regional sea. BAU is used to describe the current state of the operational environmental, societal or economic landscape.
- BAU+: A measure or suite of measures implemented in addition to Business-as-Usual that introduce a change or changes in the environmental, societal or economic landscape from its current state. These measures should complement the existing measures and should contribute to achieving GES.

The extraction of the high-risk impact chains linked to management measures served as a starting point/inspiration for identifying management measures. This extraction was the result of the merge of the Pressure Assessment database with the Management measures database (see also Piet et al. (2012)

for further background and information about these databases and the merge). The extraction of the high-threat impact chains for each descriptor resulted in a list of aims and mechanism linked to these chains. These were used as a starting point to scope the BAU and BAU+.
The inventory of potential BAU and BAU+ measures for the case studies was further defined, using a specific table format and existing documents and expert knowledge. Regional experts were asked to list measures that applied to the region. For each measure information was described such as the aim, mechanism, policy driver, references and whether data is already available on the effect of the measure. Also information was provided on whether the measure was included in the case study, and if so, whether it was considered BAU or BAU+. This inventory of measures was used to scope BAU and BAU+.

The BAU and BAU+ measures were grouped into management options. A management option consists of one or more measures implemented in order to reach an operational objective, but these do not necessarily consist of concrete management measures nor a specification of the actions required to fulfil the preconditions.

2.3 Step 3: Evaluation of BAU/BAU+ management options

Step 3 consisted of the evaluation of the BAU and BAU+ management options using the most appropriate (and available) tools and sources of information (i.e. simulation models, empirical information and expert judgement). Per case study different tools for evaluation were used, and evaluation tools were allowed to differ per foci taxa depending on the amount of information available.

2.4 Step 4: Discussion of management options

The final step consisted of a discussion of what can be considered (the most) appropriate management options to achieve the chosen (sub)regions HLOs. The outcome of the evaluation (step 3) was used to determine the preferred management option. We discussed whether the measures are able to steer towards the HLO.

3 North East Atlantic - Foodweb Case Study

Full details of this case study are given in Hintzen et al. (2013) with all steps and outcomes summarised below.

3.1 Step 1: Scoping

3.1.1 Step 1.a: Development and identification of impact chains

The results of the scoping steps 1a and 1b, the extraction of the high-threat impact chains for the North East Atlantic - foodweb case study, resulted in a selection of relevant sector-pressure combinations.

3.1.2 Step 1.b: Identification of high–risk impact chains

Each of the high-risk impact chain combinations were considered in the light of the case study (see Table 2) and decided whether the combinations were taken forward in the case study in scoping step 1c (Table 3).

The following sectors-pressure combinations came out of the table and were taken forward to step 1.c:

- Fisheries - Selective extraction of species
- Sea surface temperature/sea bottom temperature
- Large scale ocean circulations

Table 2. High threat sector-pressure combinations for the NEA foodweb case study (green cells) and the combinations that were taken forward in scoping exercise (blue cells). NA means the specific sector-pressure combination does not occur in the extraction of the high threat impact chains.

Sector / **Pressure**	**Agriculture**	**Aquaculture**	**Coastal Infrastructure (construction)**	**Fisheries**	**Landbased industries**	**Military**	**Non-renewable Energy (oil & gas constuction)**	**Research**	**Shipping**	**Telecommunications construction**	**Included in further scoping exercise?**	**Comment based on regional perspective and the case study context**
1. Smothering	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
2. Substrate Loss	NA	NA	Yes	Yes	NA	NA	Yes	NA	NA	Yes	No	Potential for local scale issues but considered unlikely to have population level impacts at NEA scale
3. Changes in siltation	NA	NA	NA	Yes	NA	NA	NA	NA	NA	NA	No	Little or no impact on foodweb ECs
4. Abrasion	NA	NA	NA	Yes	NA	NA	NA	NA	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at NEA scale
5. Selective Extraction of Non-living Resources	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
6. Underwater noise	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
7. Marine Litter	NA	NA	NA	Yes	NA	NA	NA	NA	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at NEA scale
8. Thermal regime changes	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
9. Salinity regime changes	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
10. Introduction of Synthetic compounds	NA	NA	NA	Yes	Yes	NA	Yes	NA	Yes	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at NEA scale
11. Introduction of Non-synthetic compounds	NA	NA	NA	Yes	Yes	NA	Yes	NA	Yes	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at NEA scale
12. Introduction of Radionuclides	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
13. Introduction of other substances	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
14. Nitrogen and Phosphorus enrichment	Yes	NA	NA	NA	NA	NA	NA	NA	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at NEA scale
15. Input of organic matter	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not applicable	Potential for local scale issues but considered unlikely to have population level impacts at NEA scale
16. Introduction of microbial	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not applicable	-

pathogens												
17. Introduction of non-indigenous spp. and translocations	NA	Yes	NA	Yes	NA	Yes	NA	Yes	Yes	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at NEA scale
18. Selective extraction of species	NA	NA	NA	Yes	NA	NA	NA	NA	NA	NA	Yes	MAIN FOCUS OF CASE STUDY, widespread and large scale removal of major fish species considered a major driver of changes in foodweb structure. Fishing is the key contributing sector of this pressure.
19. Death or injury by collision	NA	NA	NA	NA	NA	NA	NA	NA	Yes	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at NEA scale
20. Barrier to species movement	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
21. Emergence regime change	NA	NA	Yes	NA	NA	NA	NA	NA	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at NEA scale
22. Water flow rate changes	NA	NA	Yes	NA	NA	NA	Yes	NA	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at NEA scale
23. pH changes	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
24. Electromagnetic changes	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
25. Change in wave exposure	NA	NA	Yes	NA	NA	NA	NA	NA	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at NEA scale
26. Climate change												
26a SST/SBT changes											Yes	These are considered to be key potential drivers of EC population change. However, the main source of this, i.e. climate change is considered unmanageable in the time frame considered here and was therefore not included in the final case study work.
26b Sea level rise											No	NO - could be important for seabirds and seals (e.g. Haul out) but not considered likely to have an effect in the timeframe being considered
26c Precipitation (rainfall/freshwater/salinity changes)											No	NO - could be important for seabirds and seals (e.g. Haul out) but not considered likely to have an effect in the timeframe being considered
26d Intensity and frequency of storms (exposure)											No	NO - could be important for seabirds and seals (e.g. Haul out) but not considered likely to have an effect in the timeframe being considered
26e Ocean acidification (pH)											No	NO - Not considered likely to have an effect on ECs in the timeframe being considered.
26f Large scale ocean circulation (e.g. NAO)											Yes	See 26a

3.1.3 Step 1.c: Further selection of most relevant high-risk impact chains

The choice of the relevant taxa on which to focus the information necessary to evaluate the management measures can be guided by the proposed specific indicators in each of the MSFD (sub)regions as well as practical management considerations. Specific indicators focus only on the ecosystem components Fish (Benthic, Deep sea and Pelagic), Marine mammals and Reptiles and Seabirds (inshore and offshore). These relevant indicator species, i.e. foci taxa, were taken forward in the second table of the scoping exercise step 2.c (see Table 3). Similarly we excluded those impact chains involving pressures that were considered unmanageable in the time frame considered in this exercise, e.g. SST/SBT changes or sea level rise caused by climate change.

In order to characterize the fish community and incorporate existing species-specific (BAU) fisheries management measures, 12 species representing the most abundant (relevance for the foodweb functioning) and commercially most important (relevance fisheries management) species were selected for this case study. The species considered are: cod, dab, gurnard, haddock, herring, Norway pout, plaice, saithe, sandeel, sole, sprat and whiting, closely following the fish community setup by Speirs *et al.* (2010) and Blanchard *et al*. (in prep).

In order to identify the specific seabirds and marine mammals to consider in the evaluation of impact of the BAU and BAU+ scenarios on the North Sea foodweb, we used the species as mentioned in the proposed MSFD indicators for the Foodweb Descriptor in the North Sea.

In the second table of the scoping exercise (Table 3), we considered the three sector-pressure combinations resulting from the table in step 1.b, and the considerations of this step 1c (i.e. based on foci taxa and practical management considerations).

The exercise revealed that the relevant indicator taxa (i.e. fish, mammals and birds) were all direct or indirectly influenced by the sector-pressure combinations (see Table 3). It was chosen to take one sector-pressure combination forward in the case study, being:

- Fisheries - Selective extraction of species

Although the sea surface temperature, sea bottom temperature and the large scale ocean circulations have their impact on the foodweb, these drivers are not manageable and therefore were not further considered in this case study.

Table 3. Scoping exercise for the relevant sector-pressure combinations (see Table 2) and relevant ecological characteristics within the NEA foodweb case study

			Foci taxa by ECs																					Case Study?
EC			Mammals								Fish (demersal)										Fish (pelagic)		Birds	
Specific taxa			grey seal	harbour seal	bottlenose dolphin	harbour porpoise	white beaked dolphin	short beaked common dolphin	minke whale	long finned pilot whale	Cod	Dab	Gurnard	Haddock	Plaice	Saithe	Sandeel	Sole	Whiting	Norway pout	Herring	Sprat		
High-threat combinations (sector/pressure)	Fishing - Benthic trawling	Selective extraction of species	Yes, though indirect: overexploitation of prey species (for species that feed on benthic species e.g. grey seal and porpoise)								Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Yes, though indirect: • over-exploitation of prey species, • increased food provision through discarding	Yes
	Fishing - Pelagic trawling	Selective extraction of species	Yes, though indirect: overexploitation of prey species								N	N	N	N	N	N	N	N	N	Y	Y	Y		Yes

3.2 Step 2: Identification of BAU and BAU+ management measures

The scoping exercise resulted in one sector-pressure combination to take forward in the case study, being: Fisheries - Selective extraction of species. For the NEA case study involving the foodweb descriptor we focussed our Management Strategy Evaluation (MSE) exercise on fisheries management measures (i.e. driver: fisheries, sectors "fishing-benthic trawling" and "fishing-pelagic trawling") aimed at reducing the pressure "Selective extraction of species" and affecting the ecosystem state of the "Fish-benthic", "Fish-pelagic", "Seabirds" and "Marine mammals & Reptiles" components.
In fisheries management, different measures can be used, such as catch limitations (TAC), spatial and temporal restriction of fisheries, limit of mesh size and others. The most important management measure to keep stocks within biological limits or rebuilt the stocks are catch limitations (TAC). TACs are determined on an annual basis. While the current BAU measures should probably move ecosystem status in general and, more specifically, the foodweb towards GES, we explored an aspect of fisheries management not considered before, i.e. the manipulation of the size-selectivity, as this could be used to move ecosystem status further towards meeting the foodweb objectives while avoiding the possibility that the existing objectives for descriptor 3 (commercial fish) which determined the BAU measures, are compromised. Rationale behind this is that much of the foodweb functioning (and hence the main indicator, i.e. Large Fish Indicator LFI[1]) is related to size-structure.

Three different management options in addition to BAU were identified, all involving size selectivity: BAU+ knife edge selection, BAU+ protect old and BAU+ balanced fishing.
For the BAU scenario, the Yields, Fishing mortality (F) and spawning stock biomass (SSB) reference points were taken into account for all 12 fish species under the current management objectives. These objectives were derived from the ICES advice 2012, including a review of the advice given from 2004 onwards when available (first year ICES started to publish the advice sheets online). For each species, one or more F-targets and/or catch limits are applied.

For all BAU+ scenarios, it was assumed that levels of effort would be similar to BAU, where effort time series were fitted to historic observations. In addition different selectivities were considered based on current issues identified in the scientific literature for the BAU + scenarios from 2012 onwards (future period).

- The BAU+ knife edge selection scenario represents an alternative way of highly selective fishing. The selection is based on the von Bertanlanffy growth parameter (K) (Brunel and Piet, 2013).
- The BAU+ protect old scenario, also represents an alternative way of selective fishing. In this management strategy, the older ages are protected.
- In the BAU+ balanced fishing scenario, the fishing mortality is identical for all sizes in the size spectrum, i.e. a flat selection. The fishing occurs according to productivity selection on all weight/length groups. In general this can be compared to taking off a slice of the foodweb pyramid where top predators are least abundant and the small fish are most abundant.

Table 4. Overview of management options for the North East Atlantic case study

Management option	Description
BAU	For the BAU scenario, Fishing mortality for all 12 fish species under the current management objectives derived was set at MSY levels according to the ICES advice 2012.
BAU+ knife edge selection	Fishing mortality is at MSY but each species is harvested at or above the size at which a cohort reaches its maximal biomass.
BAU+ protect old scenario	Fishing mortality is at MSY but the older ages are protected.
BAU+ balanced fishing scenario	Fishing mortality is at MSY but the fishing mortality is based on productivity of the age-/size groups.

[1] The Large Fish Indicator was originally designed as an indicator for fishing pressure. Large-bodied species tend to be more vulnerable to fishing, which is why the LFI is sensitive (Greenstreet et al. 2011, ICES 2011) and specific (Houle et al. 2012) to fishing pressure on demersal species.

3.3 Step 3: Evaluation of BAU/BAU+ management options

Both the choice of appropriate models as well as the collection of empirical information was guided by the specific foodweb indicators proposed for the North Sea.

The MSE focussing on the "Fish-benthic" and "Fish-pelagic" components was based on a size spectrum foodweb model while the MSE on the "Seabirds" and "Marine mammals & Reptiles" components was based on empirical information allowing inferences of how the changes in the fish community in turn affected these components. These two approaches are described in separate sections.

3.3.1 Fisheries assessment

The effect of the measures on benthic and pelagic fish was quantified by means of a size spectrum foodweb model. For the simulations by the size spectrum foodweb model, the twelve most abundant and/or commercially most important species were selected. For these species, the life-history characteristics, such as growth, reproduction and mortality, are included in the foodweb model. Their feeding behaviour is incorporated as follows; the smallest fish feed only on the resource, while the larger fish also predate on those smaller fish species with which there is a spatial and temporal overlap. The dynamics and interactions of the twelve selected species are described by a number of differential equations and incorporated in the size spectrum foodweb model (SBM) (Blanchard *et al.*, in prep).

The four different management options were simulated by the SBM; i.e. BAU, BAU+ knife edge selection, BAU+ protect old and BAU+ balanced fishing. Each scenario was evaluated twice, i.e. after a 10 and a 50 year period.

3.3.2 Seabirds and marine mammals assessment

The second part of the evaluation looks at the effects of the management strategy scenarios on seabirds and marine mammals. It was not possible to calculate the effects, but inferences were made on the basis of how the changes in the fish community calculated by the model affected these species, using literature and expert knowledge on predator-prey relationships and prey consumption.

3.4 Step 4: Discussion of management options

3.4.1 Results fisheries assessment

Table 5. Change in SSB (%) per species in 2020 of various BAU+ scenarios compared to BAU scenario. The no effort scenario is used to provide a "pristine" reference situation: a scenario without fisheries

	Knife edge	Protect old	No effort	Balanced fishing
Cod	164	406	656	-60
Dab	13	113	29	192
Haddock	-75	-78	-98	-33
Herring	-61	-81	-96	401
N.pout	171	225	149	217
Plaice	-72	-67	-94	-43
Saithe	-62	124	76	-84
Sandeel	-39	330	377	312
Sole	-81	-70	-92	-23
Sprat	-35	18	314	163
Whiting	-65	-67	-90	-24
Mean	-31	92	117	216

Table 6. Change in indicator value (%) in 2020 of various BAU+ scenarios compared to BAU scenario

	Knife edge	Protect old	No effort	Balanced fishing
LFI[2]	30	69	103	-79

Table 7. Change in SSB (%) per species in 2060 of various BAU+ scenarios compared to BAU scenario

	Knife edge	Protect old	No effort	Balanced fishing
Sprat	-11	-6	159	85
Sandeel	71	286	301	262
N.pout	26	204	186	143
Herring	-76	-10	-3	-1
Dab	46	271	142	136
Whiting	-47	1	1	-12
Sole	-52	-5	28	32
Plaice	-5	-3	18	1
Haddock	-53	-31	-36	-24
Cod	67	332	480	456
Saithe	132	83	60	-91

Table 8. Change in indicator value (%) in 2060 of various BAU+ scenarios compared to BAU scenario

	Knife edge	Protect old	No effort	Balanced fishing
LFI	65	4	19	5

BAU base level: The targets set under the BAU scenario for SSB, fishing mortality F or catch, are relatively well met for nearly all fisheries. Only saithe is under-exploited for most of the time. Nearly all stocks show very little fluctuations in their development in SSB. The Large Fish Indicator shows an increase, which is due to an increase in cod. The natural mortality is highest for the smallest fish. The feeding level (i.e. the amount of food that is encountered by an individual as a fraction of what it can maximally eat), also one of the results of the model, is subject to moderate disturbances under the BAU scenario.

Under the **BAU+ knife edge scenario**, the system initially seems to be in a perturbed state with the SSB of almost all species declining, except for cod and Norway pout. Towards 2020 all species abundances seem to become more stable and most populations start to recover from the decline in biomass. Under those conditions, catches start to recover as well. Beyond 2020 and toward 2060, also other species like saithe, sandeel and dab, show a positive effect compared to the BAU situation. Under this scenario, the large fish indicator (LFI) is higher than under BAU conditions suggesting a clear positive effect on what can be considered the main foodweb indicator. When looking at the SSB of individual fish species, however, the knife edge scenario is least favourable of all scenarios.

For the **BAU+ protect old scenario**, the system is not in a steady state in 2020. Nearly all larger fish show a declining trend over time. Expecting a lower reproductive capacity for these larger species, this could be explained by the increased fishing mortality on younger fish, resulting in a lower SSB for these species. Only the top predators such as cod, pout, dab and saithe benefit from an increase in sprat and sandeel. The feeding level is less consistent, than under the BAU scenario. There is a clear indication that cod and saithe have more than enough food available.
The share of large fish (LFI) is increasing, because of an increase in cod and saithe and a reduction in herring.

Under the BAU+ balanced fishing scenario, the natural mortality curve only shows moderate perturbation. The SBB increases for many species, and for the species that show a decrease, the species

[2] In this analysis LFI has been interpreted as a total fish community indicator. LFI was therefore calculated including all fish species, not only demersal species.

become more stable in their abundances, already early in the time series, before 2020. Catches remain relatively stable for most species up to 2020.

The fish community indicator LFI decreases considerably, this can be attributed to the sharp increase in small pelagic species. When the development of the LFI is followed over a longer period until 2060, the value starts to increase.

3.4.2 Results assessment seabirds and marine mammals

Furness found a relationship between sandeel densities and the breeding success of kittiwakes, arctic terns, arctic skuas and great skuas (Furness, 2007). However, there were no indications that fisheries reduce the availability of sandeels.
On the basis of expert knowledge, the fish predation of mammals in the North Sea was roughly estimated at 750,000 tonnes, which is about one third of the total fisheries catch. For the North Sea, there is no evidence of food limitation for marine mammals.
Every three years, the ICES working group on Multi Species Assessments (WGSAM), estimates the predation mortalities for several fish species, with a Multi-species Stochastic Stock Assessment model.
The model results show that the predation by seabirds has a negligible effect on prey fish species. The model outcome shows a significant effect for the predation of porpoises on whiting. However this effect is moderate in comparison with the effects of predation of cod and whiting on prey fishes.
In terms of the food availability for seabirds and marine mammals, the BAU+ balanced fishing scenario seems most promising. Under this scenario there is a large increase in fish biomass. The increase is mainly due to an increase in smaller fish. Therefore it is expected that the seabirds will benefit more, than the mammals.

Research by i.a. Camphuysen et al. (1995; 2008), showed that discards from fisheries are a very important addition to the diet of many gulls. Changes in discarding practices as may result from our BAU and BAU+ measures, may affect both the amount as well as the composition of the discards. This may well have knock-on effects on these seabird species.

3.4.3 Conclusion

Given that the LFI is our chosen indicator for the foodweb situation, the preferred management strategy should have a positive effect on this indicator.
The knife edge and protect old scenario both result in a higher LFI value than under BAU conditions. The BAU+ protect old scenario seems the most promising on the short term until 2020. Concerning the change in SSB, the BAU+ balanced fishing scenario is also preferable on the short term until 2020. Many species will profit from these circumstances, and also the total biomass is highest under these conditions.

On the long term, the knife edge scenario seems to be the most promising based on the % change in indicator value (LFI). From the perspective of the SSB of individual fish species, however, the knife edge scenario seems to be the least beneficial of all scenarios for most of the fish species. The balance fishing and protect old scenario's result in higher SSB's for most species.
When other ecosystem components like the seabirds are also taken into consideration, the knife edge scenario also seems less favourable, because of the poor results for herring and sandeel.

4 Baltic Sea - foodweb case study

Full details of this case study are given in the Baltic Sea Case Study report (Baltic Sea Case Study, 2013) with all steps and outcomes summarised below.

4.1 Step 1: Scoping

4.1.1 Step 1.a: Development and identification of impact chains

The extraction of the high-threat impact chains for the Baltic Sea - foodweb case study rendered several sector-pressure combinations.

4.1.2 Step 1.b: Identification of high–risk impact chains

Each of the high-risk impact chain combinations were considered in the light of the case study focus which determined whether the combinations were taken forward (see Table 5).

For this case study it was decided to take the following sector-pressure combinations forward to step 1.c:

- Nitrogen and Phosphorus enrichment - Agriculture
- Nitrogen and Phosphorus enrichment – Land-based industry
- Input of organic matter – Agriculture
- Input of organic matter – Waste Water Treatment
- Input of organic matter - Fisheries
- Introduction of NIS – mostly Shipping (with Fisheries and Military as less important sources)
- Selective extraction of species - Fisheries
- SST/SBT changes
- Precipitation (rainfall/ freshwater/ salinity changes)

Table 5. High threat sector-pressure combinations for the Baltic Sea foodweb case study (green cells) and the combinations that were taken forward in scoping exercise (blue cells). NA means the specific sector-pressure combination does not occur in the extraction of the high threat impact chains.

Pressure / Sector	Fisheries	Agriculture	Coastal Infrastructure (construction)	Land-based industry	Military	Waste Water Treatment	Shipping	Included further scoping exercise?	Comment based on regional perspective and the case study context
1. Smothering	NA	NA	Yes	NA	NA	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Baltic Sea scale
2. Substrate Loss	NA	NA	Yes	NA	NA	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Baltic Sea scale
3. Changes in siltation	NA	Yes	NA	NA	NA	Yes	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Baltic Sea scale
4. Abrasion	NA	NA	NA	NA	NA	NA	Yes	No	Potential for local scale issues but considered unlikely to have population level impacts at Baltic Sea scale
5. Selective Extraction of Non-living Resources	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
6. Underwater noise	NA	NA	NA	NA	Yes	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Baltic Sea scale
7. Marine Litter	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	There is not enough information about the effects of marine litter in the Baltic Sea foodwebs. According to the present knowledge, most of marine litter is of land-based origin.
8. Thermal regime changes	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
9. Salinity regime changes	NA	NA	NA	NA	NA	Yes	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Baltic Sea scale
10. Introduction of Synthetic compounds	Yes	Yes	NA	NA	Yes	Yes	Yes	No	Introduced substances may accumulate along a trophic foodweb, not a lot of information available. We decided not include this in the Baltic Sea case study as it is extremely difficult to consider in such analysis.
11. Introduction of Non-synthetic compounds	Yes	Yes	NA	NA	Yes	Yes	Yes	No	Introduced substances may accumulate along a trophic foodweb, not a lot of information available. We decided not to include this in the Baltic Sea case study as it is extremely difficult to consider in such analysis.
12. Introduction of Radionuclides	NA	NA	NA	NA	Yes	NA	NA	No	Normally radionuclides should not be introduced, so this is relevant under some extraordinary event only
13. Introduction of other substances	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
14. Nitrogen and Phosphorus enrichment	NA	Yes	NA	Yes	NA	NA	NA	Yes	Nutrient enrichments control the foodwebs by bottom up regulation. Primary issue in the Baltic Sea area
15. Input of organic matter	Yes	Yes	NA	NA	NA	Yes	NA	Yes	Input of organic matter enhances bacterial production and can drive the foodweb dynamics towards heterotrophy. Gives also a

									window of opportunity for harmful phytoplankton species that are able to take up organic substrates
16. Introduction of microbial pathogens	NA	NA	NA	NA	NA	Yes	Yes	No	Potential for local scale issues but considered unlikely to have population level impacts at Baltic Sea scale
17. Introduction of non-indigenous spp. and translocations	Yes	NA	NA	NA	Yes	NA	Yes	Yes	Introduction of NIS can change the dynamics within a foodweb and at worst case, outcompete native species
18. Selective extraction of species	Yes	NA	NA	NA	NA	NA	NA	Yes	Selective extraction of species (here meaning the removal of certain fish species that are sitting on the top of the foodweb) alters the routes of material and energy in the foodwebs
19. Death or injury by collision	NA	NA	NA	NA	Yes	NA	Yes	No	Potential for local scale issues but considered unlikely to have population level impacts at Baltic Sea scale
20. Barrier to species movement	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
21. Emergence regime change	NA	NA	Yes	NA	NA	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Baltic Sea scale
22. Water flow rate changes	NA	NA	Yes	NA	NA	Yes	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Baltic Sea scale
23. pH changes	NA	NA	NA	NA	NA	Yes	NA	No	Could be relevant in some coastal areas, but information of this is probably very scarce?
24. Electromagnetic changes	NA	NA	NA	NA	NA	NA	NA	Not applicable	-
25. Change in wave exposure	NA	NA	Yes	NA	NA	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Baltic Sea scale
26. Climate change								No	-
26a SST/SBT changes								Yes	The increase in water temperature may increase bacterial activity, which can affect nutrient recycling and mineralization in surface waters. These changes can have an influence on phytoplankton species composition and primary production, which are of great importance for the Baltic ecosystem. For example, warming will inhibit cold-water species (such as some diatoms) but may stimulate warm water species, such as the bloom-forming toxic cyanobacteria. Reduced ice cover and earlier stabilization of the water column in spring will also cause the spring bloom to begin earlier. Changes in the timing of the blooms and in the species composition will also disturb the existing foodwebs, provoking changes at the higher trophic levels.
26b Sea level rise								No	Not relevant
26c Precipitation (rainfall/freshwater/salinity changes)								Yes	Salinity and temperature have been observed to be key drivers to phyto- and zooplankton communities
26d Intensity and frequency of storms (exposure)								No	Not relevant
26e Ocean acidification (pH)								No	decalcification
26f Large scale ocean circulation (e.g. NAO)								No	Not relevant
26g Changes in temperature and ice period								No	Considered in 26a

4.1.3 Step 1.c: Further selection of most relevant high-risk impact chains

In this step of the scoping exercise we considered the sector-pressure combinations resulting from step 1.b and whether these pathways had an influence on the relevant taxa. Relevant taxa were taken from the indicators database and included plankton, bottom flora and fauna, fish, marine mammals and seabirds.

In order to characterize the fish community, three species representing the commercially most important species were selected for this case study. The species considered are cod, herring and sprat.

The exercise revealed that one or more of the relevant indicator taxa (i.e. plankton, bottom flora and fauna, fish, mammals and birds) were directly or indirectly influenced by one or more the sector-pressure combinations (see Table 6). It was chosen to take four sector-pressure combinations forward, being:

- Agriculture - Input of organic matter
- Agriculture - Nitrogen and Phosphorus enrichment
- Fishing benthic trawling – Selective extraction of species
- Fishing pelagic trawling – Selective extraction of species

We excluded those impact chains involving pressures that were considered unmanageable in the time frame considered in this exercise, e.g. SST/SBT changes or sea level rise caused by climate change.

Table 6. Scoping exercise for the relevant sector-pressure combinations (see Table 5) and relevant ecological characteristics within the Baltic Sea foodweb case study

			Foci taxa by Ecs																													Case Study?
EC			Plankton							Fish									Mammals			Birds		Benthic flora and fauna								
Specific taxa			diatoms	dinoflagellates	Chlorophyll a as a proxy of the PP	cyanobacteria	*A. ostenfeldii* abundance during late summer	*Pseudocalanus* spp.	Mean zooplankton size	Cod	Herring	Sprat	flatfish	Salmon	Sea trout	Perch	Zander	Roach	Baltic ringed seal	Grey seal	Baltic harbour seal	Great cormorant	Eider	*Fucus* spp.	*Furcellaria lumbricalis*	*Zostera marina*	*Chara tomentosa*	*Cladophora glomerata*	*Mytilus* spp.	*Marenzelleria* spp. Abundance and distribution	Zoobenthos diversity, coastal and open sea	
High-threat combinations (sector/pressure)	Agriculture	Input of organic matter	Y	Y	Y	Y	Y																	Y	Y	Y	Y	Y	Y	Y	Y	Yes
	Agriculture	Nitrogen and Phosphorus enrichment	Y	Y	Y	Y	Y																	Y	Y	Y	Y	Y		Y	Y	Yes
	Fishing – Benthic trawling	Input of organic matter	Y	Y	Y	Y																										No
	Fishing –Pelagic trawling	Input of organic matter	Y	Y	Y	Y																										No
	Fishing - Benthic trawling	Introduction of non-indigenous species	Y	Y						Y			Y																		Y	No
	Fishing - Pelagic trawling	Introduction of non-indigenous species	Y	Y							Y	Y		Y	Y																Y	No
	Fishing - Benthic trawling	Selective extraction of species								Y			Y																			Yes
	Fishing - Pelagic	Selective									Y	Y																				Yes

	trawling	extraction of species																														
	Land-based industry	Nitrogen and Phosphorus enrichment	Y	Y	Y	Y	Y																									No
	Military	Introduction of non-indigenous species	Y	Y	Y				Y	Y	Y	Y	Y	Y	Y																	No
	Shipping	Introduction of non-indigenous species	Y	Y	Y				Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y											No
	Waste water treatment	Input of organic matter	Y	Y	Y	Y																										No

4.2 Step 2: Identification of BAU and BAU+ management measures

As shown in the scoping exercise, this case study is focussing on fisheries and agriculture – in terms of their impacts on Baltic Sea foodwebs.

4.2.1 Fisheries assessment

Fisheries management measures (i.e. sectors "fishing-benthic trawling" and "fishing-pelagic trawling") are aimed at reducing the pressure "Selective extraction of species" and affecting the ecosystem state of the "Fish-benthic", "Fish-pelagic", "Bottom flora and fauna" and "Marine mammals" components.
The most important management measure to keep stocks within biological limits or rebuild the stocks are catch limitations (TAC). Other measures to regulate selectivity, such as gear and mesh size regulations, are imposed as well. In the Baltic, catch limits are set on the basis of fishing mortality levels.

Two different management options were simulated; For the business as usual scenario, the *status quo* fishing mortality (Fsq) was the management objective. For the BAU+ , the Fmsy for all stocks and years was the management objective.

Within the Fsq and the Fmsy scenarios, simulations were carried out with different selectivity options for both the BAU and the BAU+ scenario. For these simulations the gear selectivity was changed from a L50% of 38 cm to a L50% of 40 cm (lengths at which respectively 50% of the fish are retained in the codend).

Table 7. Overview of management options for the Baltic Sea case study - fisheries

Management option	**Description**
Fisheries BAU: F *status quo,* L50%=38cm	For the business as usual scenario, the *status quo* fishing mortality was the management objective.
Fisheries BAU+: F *status quo*, L50%=40cm	For this scenario, the status quo fishing mortality was combined with a change in gear selectivity.
Fisheries BAU+: F *Fmsy*, L50%=38cm	In these scenarios the objective was Fmsy or ICES transition to Fmsy for all stocks and years, combined with different gear selectivities.
Fisheries BAU+: F *Fmsy*, L50%=40cm	

4.2.2 Eutrophication assessment

The increased anthropogenic input of Phosphorus and Nitrogen leads to eutrophication in the Baltic Sea. Eutrophication may lead to changes in the phytoplankton community structure and biomass, including blooms of harmful algal species (HABs) and nuisance macroalgae. In areas where there is a nitrogen limitation, an excess amount of phosphorus will accumulate, and cyanobacterial blooms can occur.
Agricultural management measures (i.e. sector "agriculture") are aimed at reducing the pressure "Input of organic matter" and "Nitrogen and Phosphorus enrichment", affecting the ecosystem state of the "Fish-benthic", "Fish-pelagic", "Bottom flora and fauna" and "Plankton" components. In this case study two management options affecting the input of N and P were considered: The BAU scenario describes a situation equal to the current management situation. The BAU+ scenario assumes a reduction in nutrient as required by the Baltic Sea action Plan (BSAP). Both scenarios take the expected climate change into account by including climate projections for 1961-2099 (Meier *et al.*, 2012).

Table 8. Overview of management options for the Baltic Sea case study - eutrophication

Management option	**Description**
Eutrophication: BAU	The BAU scenario describes a situation equal to the current management situation.
Eutrophication: BAU+	The BAU+ scenario assumes a reduction in nutrients as required by the Baltic Sea action Plan (BSAP).

4.3 Step 3: Evaluation of BAU/BAU+ management options

The management strategy evaluation consisted of three parts: A quantitative multispecies fisheries assessment, a quantitative assessment of two management strategies for decreasing the effects of eutrophication and a consideration of the other foodweb components (i.e. mammals and birds) in the Baltic and their main threats.

4.3.1 Fisheries assessment

For the multispecies fisheries assessment, cod, herring and sprat were selected. These 3 species contribute to over 90% of the catches in weight for the Baltic area. The species interaction is incorporated as follows; adult cod (3 yr and older) eats herring and sprat of all ages, young cod (1-2 yr) eats young herring and sprat (0-1yr) and adult sprat (2 yr and older). The fishery acts as a top-predator catching the adult cod, herring and sprat.

For the quantitative fisheries assessment, 2 different models were used; A multispecies stock-production model (Horbowy, 1996, 2005) was applied to simulate the stock dynamics and the trophic interactions of cod, herring and sprat stocks in the central and eastern Baltic in the period 1982-2011. The estimates of the stock sizes for the beginning of 2012 were used as the starting values for the simulation with the stochastic multispecies stock production prediction. This second model was used to predict the development in biomass and catches for the analysis period.

Per scenario, time series were carried out for a period of almost 40 years (2012- 2050), but for the current analysis the 2022 results are looked at.

4.3.2 Eutrophication assessment

Anthropogenic nutrient input in the Baltic Sea, has led to changes in the phytoplankton composition and to blooms of planktonic algae species and macroalgae. Meier et al. performed eutrophication simulations for the Baltic Sea (Meier *et al.*, 2012). The same approach of was used to simulate the dynamics of eutrophication-related components under the two different scenarios. For these simulations, three coupled physical-biogeochemical models were used. In the model runs, the development of winter DIN (dissolved inorganic nitrogen) and DIP (dissolved inorganic phosphorus), summer chlorophyll a concentrations, summer cyanobacteria and other phytoplankton biomasses were simulated. The results of these simulations were used in this case study, to assess the effects of different management scenarios.

Time series were carried out for the period from 1961 until 2091/2093.

Eutrophication may enhance production of certain fish species by increasing the productivity of the whole ecosystem, but it might also have negative consequences for fish stocks because of an increase of areas under hypoxic or anoxic conditions. These changes in productivity were not considered in the multispecies fisheries assessment for this case study.

4.3.3 Seabirds and marine mammals assessment

For the assessment of the other foodweb components, no model simulations were used, but a literature review was carried out. Inferences were made based on this literature.

4.4 Step 4: Discussion of management options

4.4.1 Results fisheries assessment

Change in SSB(%) in 2050 per species for various BAU+ scenarios compared to the BAU scenario.

Species	Fmsy
cod	-10*
herring	28
sprat	-10

where BAU scenario means F=Fsq for each species

	Fsq, L50%=40	Fmsy, L50%=38	Fmsy, L50%=40
cod	5	-8*	-2

where BAU scenario (for cod) means F=Fsq, L50%=38

* Difference in assessed values is caused by application of different models described in the Baltic Sea Case Study report (Baltic Sea Case Study, 2013).

Table 9. Average (2046-2050) SSB and catches (10^3 tons) of cod for two selectivity (L50%=38 and L50%=40 cm) and fishing mortality options (F= Fsq and F=Fmsy) and % of change compared to present selectivity (L50%=38 cm)

	Average		% change in	
option	**SSB**	**catch**	**SSB**	**catch**
present selectivity, L50%=38 cm, $F=F_{msy}$	311	51.8		
L50%=40 cm, $F=F_{msy}$	330	49.0	1.06	0.95
present selectivity, L50%=38 cm, $F=F_{sq}$	337	51.7		
L50%=40 cm, $F=F_{sq}$	355	48.9	1.05	0.95

For the evaluation period until 2030, there is a high probability (74%-95%) that the biomass of cod and sprat will be higher than the observed average levels (1982-2011) under the **BAU Fsq scenario**. For herring is the probability that the biomass will be above the average level rather low, with 34%.

Under the **BAU+ Fmsy scenario** there is a high probability (69%-95%) that the biomass of cod, herring and sprat will be higher than the observed average levels (1982-2011). In respect of the BAU scenario, an improvement can be seen for the biomass results for herring. This can be deduced to the fact that the Fmsy for herring is much lower than the Fsq. For cod and sprat both mortality numbers are relatively close.

For the evaluation period 2030-2050, there is a high probability (73%-95%) that the biomass of cod and sprat will be higher than the observed average levels (1982-2011) under the BAU Fsq scenario. For herring is the probability that the biomass will be above the average level, much lower with 45%.

Under the **BAU+ Fmsy scenario** there is a high probability (78%-95%) that the biomass of cod, herring and sprat will be higher than the observed average levels (1982-2011). In respect of the BAU scenario, an improvement can be seen for the biomass results for herring.

The increase in selectivity from a **L50% of 38 cm** to a **L50% of 40 cm**, has the same effect on the BAU and BAU+ scenario. For both scenarios the higher selectivity results in a 5 % increase in the spawning stock biomass.

4.4.2 Results eutrophication assessment

Table 10. Scenarios for the Baltic Proper and Gulf of Finland. Winter DIN (µM) and DIP (µM) concentrations as well as summer cyanobacteria (in carbon, µg/L), other phytoplankton (in carbon, µg /L) and chlorophyll a (Chl-a, µg/L) concentration at the surface in 2012, 2032 and 2052 under BAU and BAU+ scenarios according to Meier et al. (2012). As in the HELCOM assessment for eutrophication, the levels are presented as five-year averages, in order to even out natural variation (in other words, i.e. 2012 is represented by 2010-2014).

Baltic Proper	**BAU**			**BAU+**		
	2012	2032	2052	2012	2032	2052
DIN	4.1	5.1	6.4	3.8	3.5	3.7
DIP	0.6	0.8	1.0	0.6	0.7	0.6
Cyano bm	41	55	52	43	50	37
Phytopl. bm	48	80	86	50	62	44
Chl *a*	1.6	2.7	2.9	1.7	2.1	1.5

Gulf of Finland	**BAU**			**BAU+**		
	2012	2032	2052	2012	2032	2052
DIN	7.7	9.7	11.0	7.1	5.8	6.2
DIP	1.0	1.1	1.4	1.0	0.8	0.9
Cyano bm	86	88	65	88	72	43
Phytopl. bm	119	129	128	118	105	86
Chl *a*	4.0	4.3	4.3	3.9	3.5	2.9

Under the BAU scenario the DIN, DIP and chlorophyll a concentrations continue to increase for the coming decades. Also the cyanobacteria and other phytoplankton biomass are predicted to increase for the next 1-4 decades, but this increase will level out before the 2030's (however, some sub-basin variability is expected).

Under the BAU+ scenario the DIN, DIP and chlorophyll a concentrations will decrease within the coming decades but this will take some time. The cyanobacteria and phytoplankton biomasses also show a decrease towards the end of the time series.

4.4.3 Results assessment seabirds and marine mammals

For zooplankton in the Baltic Sea, it is extremely difficult to distinguish between the effects caused by climatic and anthropogenic factors. Fisheries management may have a knock-on effect on zooplankton biomasses. An increase in sprat and herring as can be seen in the BAU+ -scenario, which will cause a higher predatory pressure on certain zooplankton species, like for example copepods.
For the fish-feeding birds, e.g. cormorants and white tailed eagle, there are no indications that the observed trends in the occurrence of these species were induced by fisheries or eutrophication. A change in management strategy for fisheries or eutrophication will probably have no effect on the occurrence of these species.

For eiders, the food quality is crucial. For the quality of food, the bivalve flesh mass is a decisive factor. Studies by (Zwarts, 1991; Beukema *et al.*, 1993; Zwarts and Wanink, 1993) showed that this flesh mass depends on winter temperatures and is highly variable between years. The observed decrease for this species is probably not induced by fisheries or eutrophication. A change in management strategy concerning fisheries or eutrophication will probably have no direct and fast effect on this species.

For wintering ducks like the velvet scoter and long-tailed duck, the reasons of decline are largely unknown. Multiple causes can be indicated, like climate change, oil pollution and by-catch. Eutrophication may also play a role in the decline. Reductions in nitrogen and phosphorous loads, may induce a decline in benthic invertebrates and small pelagic fish, the prey species of these wintering ducks.

Eutrophication and fisheries are not a direct threat for the ringed or grey seal. Climate change (winter time temperatures) and "old" contaminants, already present in the system, are the major threats for the ringed seal. Contaminants, effects of shipping, hunting and lost fishing gear are direct dangers for the grey seal. However, indirect effects of eutrophication through the foodweb cannot be excluded. A change in management strategy concerning nutrient input, might have an effect on the ringed and grey seal populations.

There are no indications that eutrophication or fishery induced a decline of the common seal population. Major threats for this species are viral infections, hunting and habitat loss. A change in management strategy concerning nutrient input or TAC's, will probably have no impact on this species.

Major threats for porpoises are by-catch, pollution and underwater-noise. A change in management strategy concerning nutrient input or TAC's, will probably have no impact on this species.

4.4.4 Conclusion

Comparison between the different management scenarios shows that under BAU+ conditions for fisheries an improvement can be seen in herring biomass. For the other fish species in the assessment, an improvement with regard to the BAU situation is less clear, but those stocks are already exploited in a way which is securing the GES achievement.

Besides TAC's also a change in selectivity is assessed for both the BAU and BAU+ scenario. The increase in selectivity results in 5% spawning stock biomass increase and similar decline of catches for both fishing mortality options (F=Fsq and F=Fmsy).

The HELCOM nutrient targets will not be reached in either of the two scenarios (BAU and BAU+) for eutrophication in the 21st century, but it shows a stronger reaction to the BAU+ scenario, which will lead to values closer to the target value. Chlorophyll a targets will not be reached under the BAU scenario. Under the BAU+ scenario the targets for chlorophyll will be reached, although this will take some time.
Other phytoplankton and cyanobacteria biomass also respond more strongly to BAU+, than under BAU conditions.

Although the negative side-effects of eutrophication will be less under the BAU+ scenario for eutrophication, the consequences of the decreased food availability on fish production and thus yields due to the eutrophication measures may need to be considered.

It is hard to say what the effect of the different nutrient input- and TAC-scenarios will be on the top-predators. For cormorants, eiders and white tailed eagle, porpoises and common seals, there are no indications that the observed trends in the occurrence of these species where induced by fisheries or eutrophication. For the wintering ducks, it is not yet clear if there is an effect of eutrophication on these species. For ringed and grey seals indirect effects of eutrophication through the foodweb can also not be excluded. A change in management involving nutrient input, might have an effect on these species.

5 Black Sea - foodweb case study

Full details of this case study are given in Akoglu et al. (Akoglu *et al.*, 2013) with all steps and outcomes summarised below.

5.1 Step 1: Scoping

5.1.1 Step 1.a: Development and identification of impact chains

The extraction of the high-threat impact chains for the Black Sea - foodweb case study resulted in a number of sector-pressures combinations.

5.1.2 Step 1.b: Identification of high–risk impact chains

Each of the high-risk impact chain combinations were considered in the light of the case study and decided whether the combinations were taken forward in the case study (see Table 11).

For this case study it was decided to take forward sectors-pressure combinations to step 1.c:

- Fisheries - Selective extraction of species
- Fisheries – Introduction of non-synthetic compounds
- Shipping – Introduction of non-synthetic compounds
- Shipping – Introduction of non-indigenous species
- Agriculture – Input of organic matter
- Agriculture - Nitrogen and Phosphorus enrichment
- Sea surface temperature/sea bottom temperature
- Large scale ocean circulation (e.g. NAO)

Table 11. High threat sector-pressure combinations for the Black sea foodweb case study (green cells) and the combinations that were taken forward in scoping exercise (blue cells). NA means the specific sector-pressure combination does not occur in the extraction of the high threat impact chains.

Pressure / Sector	Fisheries	Shipping	Agriculture	Coastal Infrastructure (construction)	Tourism/Recreation	Waste Water Treatment	Included in further scoping exercise?	Comment based on regional perspective and the case study context
1. Smothering	Yes	NA	NA	Yes	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Black Sea scale
2. Substrate Loss	Yes	NA	NA	Yes	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Black Sea scale
3. Changes in siltation	NA	NA	Yes	NA	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Black Sea scale
4. Abrasion	Yes	NA	NA	NA	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Black Sea scale
5. Selective Extraction of Non-living Resources	NA	NA	NA	NA	NA	NA	Not applicable	-
6. Underwater noise	NA	NA	NA	NA	NA	NA	Not applicable	-
7. Marine Litter	Yes	NA	NA	NA	Yes	NA	No	Not included in the case study due to relatively small impact
8. Thermal regime changes	NA	NA	NA	NA	NA	NA	Not applicable	It is included in the climate change in the context it will be considered
9. Salinity regime changes	NA	NA	NA	NA	NA	NA	Not applicable	-
10. Introduction of Synthetic compounds	Yes	Yes	Yes	NA	NA	NA	No	It might be, the small plastics, but there is no specific investigations and information - not included in the case study
11. Introduction of Non-synthetic compounds	Yes	Yes	NA	NA	NA	NA	No	Not included in the case study due to relatively small impact (no evidence of strong impact on foodwebs)
12. Introduction of Radionuclides	NA	NA	NA	NA	NA	NA	Not applicable	-
13. Introduction of other substances	NA	NA	NA	NA	NA	NA	Not applicable	-
14. Nitrogen and Phosphorus enrichment	NA	NA	Yes	NA	NA	NA	Yes	N and P enrichment could effect on phytoplankton abundance and taxonomic structure. But based on modelling of Daskalov, eutrophication is not key driver of Foodwebs change (Daskalov *et al.*, 2007)
15. Input of organic matter	NA	NA	Yes	NA	NA	NA	Yes	Driver of bottom-up ecosystem change through system's vigour

16. Introduction of microbial pathogens	NA	NA	NA	NA	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Black Sea scale
17. Introduction of non-indigenous spp. and translocations	NA	Yes	NA	NA	NA	NA	Yes	In this CS, key drivers related to fishery are considered, which includes NIS
18. Selective extraction of species	Yes	NA	NA	NA	NA	NA	Yes	Driver of food-web structure change.
19. Death or injury by collision	NA	Yes	NA	NA	NA	NA	No	It is related to mammals. We have decided not to include EC-mammals in case study , because there is not enough data about effect of this pressure on mammals abundance
20. Barrier to species movement	NA	NA	NA	NA	NA	NA	Not applicable	-
21. Emergence regime change	NA	NA	NA	NA	NA	NA	Not applicable	-
22. Water flow rate changes	NA	NA	NA	Yes	NA	Yes	No	Potential for local scale issues but considered unlikely to have population level impacts at Black Sea scale
23. pH changes	NA	NA	NA	NA	NA	NA	Not applicable	-
24. Electromagnetic changes	NA	NA	NA	NA	NA	NA	Not applicable	-
25. Change in wave exposure	NA	NA	NA	Yes	NA	NA	No	Potential for local scale issues but considered unlikely to have population level impacts at Black Sea scale
26. Climate change							Yes	
26a SST/SBT changes							Yes	There is evidence of correlation between SST and plankton biomass /productivity, NIS introduction. However, climate change is considered unmanageable in the time frame considered here and was therefore not included in the case study work.
26b Sea level rise							No	No evidence of strong impact
26c Precipitation (rainfall/freshwater/salinity changes)							No	Nutrients could come with precipitation, but it could not consider as key driver
26d Intensity and frequency of storms (exposure)							No	No evidence of strong impact
26e Ocean acidification (pH)							No	No evidence of strong impact
26f Large scale ocean circulation (e.g. NAO)							Yes	There is evidence of correlation between NOA and plankton biomass/productivity. However, climate change is considered unmanageable in the time frame considered here and was therefore not included in the case study work.

5.1.3 Step 1.c: Further selection of most relevant high-risk impact chains

In this step of the scoping exercise the sector-pressure combinations resulting from step 1.b were considered, and whether these pathways had an influence on the relevant taxa (see Table 12). Relevant foci taxa were taken from the indicators database and included plankton, bottom flora and fauna, fish, marine mammals and sea birds.

To characterize the Black sea foodweb, 12 state variables were included in the foodweb model; detritus, phytoplankton (unspecified), zooplankton (unspecified), the heterotrophic dinoflagellate (*Noctiluca scintillans)*, three jellyfishes (*Mnemiopsis leidyi*, *Aurelia aurita* and *Beroe ovata*), the four main commercial fish species (Black Sea sprat, Black Sea anchovy, turbot and the Black Sea whiting) and one variable to represent the piscivorous fishes and marine mammals predation pressure on fish species in the Black Sea ecosystem. This last variable was used as a closure term in the model.

Sea birds were not included in the foodweb model. However, sea birds (cormorants) were included in the case study, to assess impact of the BAU and BAU+ scenarios on their abundance.

The exercise revealed that one or more of the relevant indicator taxa (i.e. plankton, bottom flora and fauna, fish, mammals and birds) were direct or indirectly influenced by 1 or more sector-pressure combinations (see Table 12). It was chosen to take 3 sector-pressure combinations forward, being:

- Fishing benthic trawling – Selective extraction of species
- Fishing pelagic trawling – Selective extraction of species
- Shipping – Introduction of non-indigenous species

We excluded those impact chains involving pressures that were considered unmanageable in the time frame considered in this exercise, e.g. SST/SBT changes or Large scale ocean circulation caused by climate change.

Table 12. Scoping exercise for the relevant sector-pressure combinations (see Table 11) and relevant ecological characteristics within the Black sea foodweb case study

			Foci taxa by Ecs																	Case Study?
EC			**Plankton**						**Fish (demersal)**			**Fish (pelagic)**			**Bottom flora and fauna**			**Mammals**	**Birds**	
Specific taxa			Phytoplankton	Edible zooplankton	Copepoda species: *Acartia clausi, Calanus euxinus, Pseudocalanus elongatus*	*Mnemiopsis leidyi*	*Aurelia aurita*	*Noctiluca scintillans*	Whiting (*Merlangius merlangus*)	Turbot (*Psetta maxima*)	Anadromous fishes	Black Sea Anchovy (*Engraulis encrasicolus ponticus*)	Black Sea Sprat (*Sprattus sprattus phalaericus*)	Horse mackerel (*Trachurus mediterraneus*)	*Mytilus galloprovincialis*	Rapana harvesting	*Phyllophora sp.*			
High-threat combinations (sector/pressure)	Fishing - Benthic trawling	Selective extraction of species							Y	Y	Y				Y	Y	Y			Yes
	Fishing - Pelagic trawling	Selective extraction of species							Y		Y	Y	Y	Y				Y		Yes
	Agriculture	Input of organic matter	Y												Y		Y			No[1]
	Agriculture	Nitrogen and Phosphorus enrichment	Y														Y			No[2]

[1 2] - Local sources of organic matter through agriculture are not more than 10% of riverine load by Danube. However, the agricultural contribution through Danube is included in our calculations.

5.2 Step 2: Identification of BAU and BAU+ management measures

In the Black Sea multiple events have taken place that have influenced functioning of the ecosystem, such as eutrophication, extension of hypoxia areas, declining benthic habitat, fish stock collapse and outburst of invasive species (most importantly ctenophore *Mnemiopsis leidyi*). These were initially thought to be the result of eutrophication, however, recently it became clear that this may have come from cascade effects sometimes caused by overfishing.

As became clear in the scoping exercise, this case study is focussing on fisheries management measures (i.e. driver: fisheries, sectors "fishing-benthic trawling" and "fishing-pelagic trawling") aimed at reducing the pressure "Selective extraction of species" and affecting the ecosystem state of the "Fish-benthic", "Fish-pelagic", "Bottom flora and fauna" and "Marine mammals" components.
In fisheries management, different measures can be used, such as catch limitations (TAC), spatial and temporal restriction of fisheries during reproduction periods, optimal mesh size and others. Catch limitations are the most important management measures to keep stock within safe biological limits and are determined on annual basis. In the Black sea, the values of actual fishing mortality (F) are different from Fmsy required for sustainable fisheries.

Four different management scenarios were simulated; BAU, BAU+ v1, BAU+ v2 and BAU+ v3. Per scenario, time series were carried out for a fifty year period.
For the BAU scenario the current fishing mortality and primary production levels are used and kept constant till 2050. Primary production level of 2010 was kept constant till the end of the simulation.
In the BAU+ v1 scenario the current primary production is presumed, and fishing mortalities, are assumed equal to Fmsy starting from 2010 onwards.
In the BAU+ v2 scenario, fishing mortalities are assumed equal to Fmsy from 2010 onwards. For eutrophication, a 50% decrease in primary production level is used and applied continuously.
For the BAU+ v3 scenario, fishing mortalities are assumed equal to Fmsy from 2010 onwards while a primary production level, 1,5 times as high as the current value, is used and applied continuously throughout the simulation period.

Table 13. Overview of management options for the Black Sea case study

Management option	Description
BAU	For BAU, the current fishing mortality and primary productions levels are used.
BAU+ v1	In this option the current primary production is maintained, but for the fishing mortalities, Fmsy is applied.
BAU+ v2	Fmsy is applied for the fishing mortalities and for eutrophication, a 50% decrease in primary production level is used.
BAU+ v3	Fmsy is applied for the fishing mortalities and a primary production level, 50% above the current value, is used.

5.3 Step 3: Evaluation of BAU/BAU+ management options

5.3.1 Fisheries and eutrophication assessment

A management strategy evaluation was carried out for the North-Western part of the Black Sea. The ecosystem in this area is threatened by a large fishing effort. The area is also subject to anoxic events as a result of eutrophication. The MSE focussing on the "Fish-benthic" and "Fish-pelagic" components was based on a foodweb model while the MSE on the "Seabirds" and "Marine mammals & Reptiles" components was based on empirical information allowing inferences of how the changes in the fish community in turn affected these components.

To study the effects of fisheries management measures on the ecosystem state of "Fish-benthic" and "Fish-pelagic", four main commercial fish species were analysed in this case study; pelagic species sprat and anchovy, demersal species turbot and whiting. These species were chosen because anchovy contributes to over 80% of the total catch, turbot because this species is critically overfished and whiting because this is an important foodweb component (predating on sprat and anchovy and prey for turbot). All these species are currently being overfished. The four species all have important spawning and feeding habitats in the North West part of the Black sea. The case study therefore focussed on this area. This area is also most affected by eutrophication.

The effect of the measures on benthic and pelagic fish was assessed using the models Ecopath and Ecosim. In the Ecopath module, species, functional groups and trophic interactions between these

species and groups are incorporated. The following prey-predator interactions were considered: sprat and anchovy are both prey for whiting and turbot, and whiting is a prey for turbot.
The ecosystem state is represented by key parameters and input data per group/species. The input data consist of biomass per unit area, production rate, consumption rate, composition of the diet and fishing mortalities.

Besides data for the four fish species also data for phytoplankton, zooplankton and top predators are included in the ecosystem model (marine mammals are used as a closure term in the model). To estimate the effect of eutrophication, primary production was taken as input variable in the model, which was accomplished as forcing on the phytoplankton group. The phytoplankton data consist of annual averages. This means that the effect of seasonal algal blooms cannot be represented by the model.
The top predators (bonito, bluefish and Atlantic mackerel) are incorporated in the model as one functional group of piscivorous fish.
After the mass-balance model was established in the Ecopath module, the Ecosim module was used to simulate a dynamic situation of the ecosystem. Per management option, time series were carried out for a fifty year period.

5.3.2 Assessment top predators

The top predators (bonito, bluefish and Atlantic mackerel) were not included as specific groups in the model but as one group. It was therefore not possible to calculate the effects per species or species-group.

5.4 Step 4: Discussion of management options

5.4.1 Results fisheries and eutrophication assessment

Table 11. Relative change in Biomass of four fish sp. (Anchovy, Sprat, Turbot and Whiting) in three management scenarios with respect to the BAU scenario for the year 2020, when the model reaches steady-state.

	BAU+ v1	BAU+ v2	BAU+ v3
Anchovy	1.3%	-85%	66%
Sprat	4.8%	-86%	73%
Turbot	32%	-85%	135%
Whiting	26%	-83%	110%

Table 12. Relative change in foodweb indicators in three management scenarios with respect to the BAU scenario for the year 2020, when the model reaches steady-state.

	BAU+ v1	BAU+ v2	BAU+ v3
Proportion of large fish by weight	+	-	+
Ratio fodder zooplankton/ total zooplankton	NA	+	-

Legend:
(+) Positive effect compared to the BAU level
(-) Negative effect compared to the BAU level
(++) very positive effect compared to the BAU level

Under the **BAU+v1 scenario**, there is only a slight increase in total fish biomass compared to the BAU situation. However, both the biomasses of turbot and whiting show significant increases under this scenario with respect to BAU. This is probably due to the fact that the Fmsy for whiting and turbot is much lower than the current fishing mortalities. For sprat and anchovy this Fmsy value is close to the current fishing mortality.

Under the **BAU+ v2 scenario**, the total fish biomass shows a sharp decline compared to BAU. This can be attributed to a decreased primary production level. This effect is amplified by a higher grazing pressure, because of lower fishing mortality.

Under the **BAU+ v3 scenario**, with an increased primary production level, the total biomass of fish increased significantly. It should be noted however, that an increased primary production level may not always be a favourable situation for the ecosystem functioning. Simulations under this scenario show a decrease in the ratio fodder zooplankton to total zooplankton.

The share of large fish is significantly higher in the V3 and V1 scenarios compared to BAU. This can be attributed to the fact that the predatory fish turbot and whiting, have an advantage by a decrease in fishing mortality under the BAU+ scenarios which is much higher than the decrease in fishing mortality of prey fishes anchovy and sprat. As predatory fish prey on these prey species, the difference in decrease of fishing mortality between the two, implies that the fishing pressure on the prey species could limit the development of large, predatory species in the ecosystem. This shows the importance to manage all harvested species, both the predatory and the prey fish.

5.4.2 Results assessment top predators

Because of a lack of data on predator-prey relationships, the top predators were incorporated in the model as one functional group. Therefore it was not possible to quantitatively assess the changes in top predators on a species specific level.

The current state of cetaceans in the Black Sea is largely unknown and there are many threats. Habitat degradation, lost fishing gear, epizootics, contaminants and bycatch are identified as the largest threats for cetaceans in the Black Sea. These uncertainties left aside, the increase in total fish biomass under scenarios BAU+ v1 and v3, will probably lead to an increase in food availability for piscivorous organisms like dolphins. Oguz and Gilbert (2007) showed, that certain combinations of fishing mortalities for small and medium pelagic fish, could lead to a restoration of marine mammal populations in the Black Sea.

The increasing biomass of fish under BAU+, could possibly also have a positive effect on the cormorant abundance. The expectation is that the population of cormorants in the Ukrainian region will increase or stay at the same level.

A change in the management of fishery or eutrophication, will probably have no effect on the sturgeon populations in the Black Sea. The decline of this species-group is related to poaching and illegal caviar trade, and might also be connected with the construction of dams in the area.

5.4.3 Conclusion

The outcomes of the model assessment suggest that a stricter fisheries management applying Fmsy in combination with a control over nutrient riverine load should result in an improvement of the Black SEA foodweb.

The outcome of the model evaluations show that the total fish biomass as well as the catch composition significantly changes with the different BAU+ scenarios. Under all BAU+ scenarios, the fish composition will be dominated by small pelagic fish of limited economic value. However, when the fishing pressure decreases in combination with a control over eutrophication (BAU+ V1 and BAU+ V3), the share of large fish will increase.

Even if the increase in primary production will result in total increase of the productivity of the ecosystem (BAU+ V3), it might also have negative consequences inducing further imbalance in the ratio fodder/total zooplankton that might result in undesirable further disruption of the Black sea lower trophic food web.

On the contrary reducing the fishing effort under high trophic conditions, with an increase in small pelagic fish stocks, causes an advantage of the small pelagic fish in competition for food with jelly fish. This may result in a reduction of the impact of jellyfish predators on the ecosystem.

Although the largest threats for marine mammals in the Black Sea are not food related, recovery of the populations of fish species can be beneficial. An increase in the four fish species, as is simulated in the model assessment for scenario BAU+ v1 and BAU+ v3, would be an advantage for predator species like marine mammals, seabirds and piscivorous fish, because of better food conditions. When the mammals' by-catch is forced back at the same time, this will have a positive effect on the marine mammal abundance. An increase in total fish biomass will possibly also have a positive effect on cormorants in the Ukrainian region. The sturgeons in the Black Sea will probably not benefit from management strategies involving fisheries or eutrophication. Their decline is related to poaching and the construction of dams in the Black Sea region.

6 North East Atlantic – sea floor integrity case study

Full details of this case study are given in Bloomfield *et al*. (2013) with all steps and outcomes summarised below.

6.1 Step 1: Scoping

6.1.1 Step 1.a: Development and identification of impact chains

The extraction of the high-treat impact chains for the North East Atlantic – sea floor integrity case study resulted in a selection of several sector-pressures combinations.

6.1.2 Step 1.b: Identification of high–risk impact chains

The case study focussed on sublittoral sediment which is the predominant sea floor habitat within the North Sea and had the highest number of high threat combinations (18) as identified in the pressure assessment (Robinson and Knights, 2011; Piet *et al.*, 2012). These pressures arise from 5 sectors (Agriculture, Fishing, Non-renewable energy (oil and gas), Shipping and Telecommunications) allowing consideration of management across multiple sectors and pressures. Two expanding sectors, Aggregates and Renewables, were also identified as relevant to the case study, and these have the potential to negatively impact on the state of seafloor integrity going forward (Table 14).

The majority of the issues related to seafloor integrity are due to physical impacts of human activities on the seafloor, thus the focus was on exploring spatial management of activities to improve seafloor integrity with the key assumption that removal of pressure will lead to improvement of state.

Sectors were reviewed in light of the case study focus on spatial management, and this resulted in the exclusion of agriculture and shipping (Table 14). The key pressure from Agriculture was Nitrogen (N) and Phosphorus (P) loading, and as the main issue here is to do with the intensity of the pressure, spatial management would not be relevant and thus this sector/pressure combination was not considered further. Furthermore, current management plans are leading to a reduction in N and P loading, so this is not considered to be an on-going problem. The key pressure from shipping is the introduction of non-indigenous species, which again was not deemed to be able to be spatially manageable.

The final list of sectors-pressure combinations to be taken forward in the case study was (see Table 14):

- Fisheries - Selective extraction of species
- Fisheries – Substrate loss
- Fisheries – Abrasion
- Fisheries – Changes in siltation
- Non-renewable Energy (oil, gas and hydro) – Substrate loss
- Telecommunications – Substrate loss
- Renewable Energy (emerging) - Smothering
- Renewable Energy (emerging) - Substrate loss
- Renewable Energy (emerging) - Changes in siltation
- Renewable Energy (emerging) - Abrasion
- Aggregates (emerging) - Smothering
- Aggregates (emerging) - Substrate loss
- Aggregates (emerging) - Changes in siltation
- Aggregates (emerging) - Abrasion
- Aggregates (emerging) - Selective Extraction of Non-living Resources
- Aggregates (emerging) - Selective extraction of species

The fishing sector was further split into 5 subsectors based on the gear: otter trawl, beam trawl, static gear, dredging and other gears.

Table 14. High threat sector-pressure combinations for the NEA sea floor integrity case study (green cells) and the combinations that were taken forward in scoping exercise (blue cells). Not Applicable means the specific sector-pressure combination does not occur in the extraction of the high threat impact chains.

Sector / Pressure	Coastal Infrastructure*	Fisheries	Non-renewable Energy (oil, gas and hydro)	Telecommunications	Agriculture	Aquaculture	Military	Research	Shipping	Renewable Energy (emerging)**	Aggregates (emerging)**	Included in further scoping exercise?	Comment based on regional perspective and the case study context, pressures that are not manageable using MSP are excluded from the case study
1. Smothering	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	MAIN FOCUS OF CASE STUDY
2. Substrate Loss	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	MAIN FOCUS OF CASE STUDY
3. Changes in siltation	No	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	MAIN FOCUS OF CASE STUDY
4. Abrasion	No	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	MAIN FOCUS OF CASE STUDY
5. Selective Extraction of Non-living Resources	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Should be included as emerging threat through aggregates
6. Underwater noise	No	No	No	No	No	No	No	No	No	Yes	Yes	No	Pressure not relevant for benthos
7. Marine Litter	No	Yes	No	No	No	No	No	No	No	Yes	No	No	Cannot be spatially managed
8. Thermal regime changes	No	No	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
9. Salinity regime changes	No	No	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
10. Introduction of Synthetic compounds	No	No	Yes	No	No	No	No	No	No	Yes	Yes	No	Cannot be spatially managed
11. Introduction of Non-synthetic compounds	No	No	Yes	No	No	No	No	No	No	Yes	Yes	No	Cannot be spatially managed
12. Introduction of Radionuclides	No	No	No	No	No	No	No	No	No	No	Yes	No	Cannot be spatially managed
13. Introduction of other substances	No	No	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
14. Nitrogen and Phosphorus enrichment	No	No	No	No	Yes	No	No	No	No	Yes	No	No	Intensity of pressure most relevant and thus not a spatial management issue
15. Input of organic matter	No	No	No	No	No	No	No	No	No	Yes	Yes	No	Cannot be spatially managed
16. Introduction of microbial pathogens	No	No	No	No	No	No	No	No	No	Yes	No	No	Cannot be spatially managed
17. Introduction of non-indigenous spp. and translocations	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	Cannot be spatially managed
18. Selective extraction of	No	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	MAIN FOCUS OF CASE STUDY

species													
19. Death or injury by collision	No	No	No	No	No	No	No	No	No	No	No	Not applicable	Pressure not relevant for benthos
20. Barrier to species movement	No	No	No	No	No	No	No	No	No	No	No	Not applicable	Pressure not relevant for benthos
21. Emergence regime change	Yes	No	No	No	No	No	No	No	No	No	No	No	Cannot be spatially managed
22. Water flow rate changes	Yes	No	Yes	No	No	No	No	No	No	Yes	Yes	No	Cannot be spatially managed
23. pH changes	No	No	No	No	No	No	No	No	No	Yes	No	No	Cannot be spatially managed
24. Electromagnetic changes	No	No	No	No	No	No	No	No	No	No	No	Not applicable	Cannot be spatially managed
25. Change in wave exposure	Yes	No	No	No	No	No	No	No	No	No	No	No	Cannot be spatially managed
26. Climate change												No	These factors are considered as unmanageable and not the focus of the main offshore case study
26a SST/SBT changes													
26b Sea level rise													
26c Precipitation (rainfall/freshwater/salinity changes)													
26d Intensity and frequency of storms (exposure)													
26e Ocean acidification (pH)													
26f Large scale ocean circulation (e.g. NAO)													

* Coastal infrastructure was not considered in NEA as EU member states were assumed to have already largely developed coastal infrastructure where this is needed and it is unlikely this will be removed in the future.

** These pressures did not came out of the high threat selection, but were included in the case study scoping as these sectors are expanding and have the potential to negatively impact the sea floor of the North Sea.

6.1.3 Step1.c

This case study focused on sublittoral sediment (EUNIS level 2) as this habitat makes up the highest proportion of the sea floor within the case study area. In terms of assessing threats to this habitat, the characteristic species and habitat features of sublittoral sediments were considered. However, no priority species or foci taxa were identified or required in the case study; instead, the focus was on the spatial extent of sectors and thus the area of sublittoral sediment impacted by sector-pressures. Different levels of ambition for spatial management were applied and management effects on sector spatial extents (and growth) were used to examine changes in the area of sublittoral sediment impacted by sectors both individually and in combination (all sectors combined into a single footprint). Potential benefits for the "state of sea floor integrity" of different spatial management options were inferred based on the assumption that the removal of physical disturbance will reduce impacts, such as the loss of large, long lived species and increasing dominance of small, short-living, opportunistic species, on the benthic environment.

6.2 Step 2: Identification of BAU and BAU+ management measures

As stated, the majority of the issues related to seafloor integrity are due to physical interactions (predominantly habitat loss), therefore we only considered spatial management measures where the objective was to reduce the area impacted by sector-pressures. The management measures considered under BAU and BAU+ scenarios are summarised in Table 15. The basis of BAU+ scenarios was that, where possible, impingement of economic activities would be avoided in the application of closures.

Table 15. Current and future (BAU and BAU+) scenarios and summary of different levels of ambition for spatial management for the case study. Refer to Bloomfield *et al*. (2013) for data sources used for sector extents

<table>
<tr><th colspan="2">Management option</th><th>Description</th></tr>
<tr><td colspan="2">Current</td><td>Current (2009 to 2012, depending on the most recent available data) spatial extents of sector activities, taking account of the effect of existing spatial management.</td></tr>
<tr><td rowspan="4">Future</td><td>BAU</td><td>Extents of sectors with no implementation of additional spatial management measures, therefore same as Current.</td></tr>
<tr><td>BAU+ 1:</td><td>Extents of sectors when 10%[*] of the sublittoral sediment habitat in the North Sea case study area is protected with closure of those protected areas to any of the impacting sectors.</td></tr>
<tr><td>BAU+ 2</td><td>Extents of sectors when 30%[+] of the sublittoral sediment habitat in the North Sea case study area protected with closure of those protected areas to any of the impacting sectors.</td></tr>
<tr><td>BAU+ 3:</td><td>Extents of sectors when 70%[#] of the sublittoral sediment habitat in the North Sea case study area protected with closure of those protected areas to any of the impacting sectors.</td></tr>
</table>

[*] Convention on Biodiversity target for marine protected areas is 10% by 2020. This value has been applied across all of the region's EEZs.
[+] The UK Turning the Tide report recommended that 30% of the seafloor should be protected. This value has been applied across all case study EEZs.
[#] A very high level of ambition for protection of the seafloor in MPAs was investigated to explore a scenario focused on conservation of rare and low dispersal species, and examine potential impacts on the sectors.

6.3 Step 3: Evaluation of BAU/BAU+ management options

Evaluation of the different management options focussed on changes in the spatial extent of sectors and the proportional change in sector size, as a result of protecting different total areas of sublittoral sediment. The size of the EEZs within the case study region and the sector spatial extents varied among countries, thus impacts of BAU and BAU+ management options were considered at a whole case study level and at a country level.

The integrity of the seafloor was assessed on the basis of the spatial extent of affected area caused by various human activities. The potential of management measures was assessed on the basis of the difference in affected seafloor-areal, that the measure brings about. A Geographical Information System was used for the assessment of the impact of the sector-pressures and the effect of the management measures. Most of the sector data were available in the form of shapefiles. Where this was not the case, maps from printed literature were digitalised.

Data on the current sector spatial extents (see details in Bloomfield *et al*. (2013) were sourced for all countries with Exclusive Economic Zones (EEZ) within the case study area where available and imported into ArcGIS v.9.3. For the current impact of the high threat pressures in the North Sea, information came from the licenses that were granted for the year 2012, for offshore renewables (wind); oil and gas; and aggregates. For the telecoms, structures existing in 2012 were used.

For the current fishing extent, data coming from Vessel Monitoring System records (2009) were used. For the assessment of the fishing impact, a division was made on basis of the gear type being employed. Every fishing gear type was considered as a separate sector.

For the extent of the sectors in 2020 it was assumed that all activities would be excluded from the MPAs. Due to the absence of data on potential expansion of sectors up to 2020 of many of the sectors being considered (e.g. Aggregates) and uncertainty in interpreting sector expansion where data were available (e.g. future licensed areas for Renewables), sector extents under BAU were considered to be the same as those mapped under the current scenario (Table 15).

6.4 Step 4: Discussion of management options

6.4.1 Results 1: Regional level management, impacts on a combined sector footprint

This approach combines the spatial extent of all sectors into a single footprint, and considers this single spatial extent across the case study region and the application of the different levels of ambition under BAU+1, +2 and +3 to the case study region as a whole. In doing so, it does not consider the impact spatial closures would have on individual sectors, nor any difference in effect between countries.

The main result is that at the higher levels of management ambition (BAU+2 and +3), larger areas of sublittoral sediment are protected. There is an effect on sector activities and thus the total area of sublittoral sediment impacted by sectors and their associated pressures decreases (see Table 16). The assumption is, that under these scenarios the risk to 'Seafloor Integrity' is therefore reduced and there is potential for improvements in the state of sublittoral sediments overall.

Table 16. Changes in the percentage of North Sea seafloor soft sediments impacted based on a combined sector footprint under the BAU and BAU+ management scenarios up to 2020

Scenario	Percentage of sublittoral sediment impacted by one or more sector	Effects on seafloor integrity compared to BAU
Current	81.7%	n/a
BAU	No change in total extent (81.7)	n/a
BAU+ 1 (10% protected)	No change in total extent (81.7%)	0
BAU+ 2 (30% protected)	Reduction in total extent to 70%	+ (63% increase in area unimpacted)
BAU+ 3 (70% protected)	Reduction in total extent to 30%	++ (283% increase in area unimpacted)

Legend
(0) No effect compared to the current level
(+) Positive effect compared to the current level
(++) Very positive effect compared to the current level

Under the **current and BAU scenarios**, 81.7% of the sublittoral sediment in the case study region is impacted by one or more sectors. This is 368,641 km^2 of the total sublittoral sediment area of 451,492 km^2.

For the **BAU+ scenario 1**, 10% protection of the seafloor could be implemented outside of areas of sector activity, therefore there would be no impingement of sector activity. Thus there is no change from BAU in the area of sublittoral sediment impacted.

For the **BAU+ scenario 2**, 30% protection of the seafloor would impinge on at least one sector's activity and would reduce the area of sublittoral sediment impacted by one or more sectors by 52,597 km^2 (reduction of 14% of combined sector area) from BAU. Thus the area of sublittoral sediment impacted by one or more sectors would reduce to 316,045 km^2 and benefits for seafloor integrity could be realised against the BAU scenario.

For the **BAU+ scenario 3**, 70% protection of the seafloor would result in restrictions on several sectors' activities and would reduce the area of sublittoral sediment impacted by one or more sectors by 233,193 km^2 (reduction of 63% of combined sector area) from BAU. Thus the area of sublittoral sediment impacted by one or more sectors would reduce to 135,448 km^2 and benefits for seafloor integrity could be greater than for BAU+2 against the BAU scenario.

6.4.2 Results 2: Regional level management, impacts on individual sectors

This approach treats each sector individually, and considers it's spatial extent across the case study region and the application of the different levels of ambition under BAU+1, 2 and 3 to each sector across the case study region as a whole. Therefore is does not require consideration of sector overlap and does not consider differences between countries.

The fishing subsectors otter and beam trawling have the largest footprint and combined across the whole case study region impact on 59% and 50% of sublittoral sediment respectively; the spatial extents of some sectors (e.g. telecoms, aggregates and renewables) are effectively "negligible" in comparison (Table 17). However, these data demonstrate that significant proportions of sublittoral sediment within the case study region could be protected without impinging on the individual sectors. For example, >40% of sublittoral sediment could be protected without the need to impinge on even the most widespread activity (otter trawling). As such, only under the BAU+3 scenario would there be any impact on the extent of individual sectors (otter and beam trawling only) which would result in a reduction in the area of sublittoral sediment impacted and thus could yield benefits for seafloor integrity.

However, sectors co-occurrence has important implications in terms of management application to yield benefits in seafloor integrity. For example, locating closures on a sector-by-sector (and independent of other sector) basis could results in a very different reduction in the TOTAL area impacted by one or more sectors. If the actual location of the closures (proposed by each of the sectors) all occur where sectors operate in isolation the reduction in total area impacted would be greatest. However, if location of the closures proposed by each of the sectors all overlap with one another, or overlap with the spatial extent of another sector then the reduction in the TOTAL area impacted would be smaller.

It is also possible to think about management in terms of targeting areas where multiple sectors overlap (and where conflict may occur among sectors). However, whilst targeting areas where more than one sector occur may allow a smaller effect on some of the larger sectors to achieve benefits for seafloor integrity there may be a disproportionate effect (and effectively closure) of sectors with relatively small spatial footprints.

Table 17. Spatial extent of the individual sectors in the case study region under BAU (as a percentage of the total area of sublittoral sediment (SS), and the proportion and area of the SS that could be protected without impacting on that sector

Sector	Spatial extent km^2 (% of total SS)	% of SS that could be protected without restricting the sector	Area in km^2 of SS that could be protected without restricting the sector
Telcoms	84 (0.02%)	99.98	451,293.71
Renewables	1,737 (0.38%)	99.62	449,640.91
Aggregates	2,572 (0.57%)	99.43	448,805.88
Other Gears	16,622 (3.68%)	96.32	434,755.32
Dredges	21,074 (4.67%)	95.33	430,303.63
Oil & Gas	24,589 (5.45%)	94.55	426,789.18
Static gears	58,757 (13.02%)	86.98	392,620.67
Beams	223,572 (49.53%)	50.47	227,806.19
Otter trawls	267,039 (59.16%)	40.84	184,338.80

6.4.3 Results 3: Country level management, impacts on a combined sector footprint

This approach combines the spatial extent of all sectors into a single footprint, and considers this single spatial extent per EEZ and the application of the different levels of ambition under BAU+1, +2 and +3 in each EEZ. In doing so, it does not consider the impact spatial closures would have on individual sectors.

The size of the EEZ, the spatial extent of the combined sector footprint and the percentage of the sublittoral sediment impacted by one or more sectors varies among countries. The UK has the largest combined sector footprint but also the largest EEZ, thus the percentage of sublittoral sediment utilised by one or more sectors is comparatively small (~80%) compared to other countries (e.g. >99% of the Belgian and French EEZs are subjected to pressures from at least one sector).

These data demonstrate that if the different levels of management ambition are applied at the EEZ level, there are differences among EEZs in terms of: (1) the actual size of the area that ultimately is protected; (2) whether or not *any* of the sectors operating will be affected; and (3) where sectors are affected, this will be to different degrees depending on the proportion of the EEZ they utilise (see full details in Bloomfield *et al*. (2013).

6.4.4 Results 4: Country level management, impacts on individual sectors

The number of sectors and their spatial extent varies amongst countries. This approach treats each sector individually, and considers its' spatial extent in each EEZ and the application of the different levels of ambition under BAU+1, 2 and 3 in each EEZ. This approach does not consider sector overlap.

Whilst the footprint of some sectors by country EEZ may be large, the area impacted by a sector as a proportion of the total area of the country's EEZ may be "low". For example, by far the largest area of the regional sea impacted by beam and otter trawling is in the UK EEZ, yet the proportion of the UK's EEZ affected by these activities is lower than for other countries due to the size of the EEZ. In contrast, the spatial extent of beam trawling in Belgian and French waters is lower than in most countries, yet this activity impacts on >98% of Belgium's, and >90% of France's EEZ. Therefore even a low level of management ambition (BAU+1, 10% protection applied to each countries' EEZ) would impinge on beam trawling activity and yield potential benefits for seafloor integrity within Belgium's and France's EEZs. Yet at this level of management ambition there would be no effect on this sector nor on seafloor integrity within any of the other countries' EEZs.

Under BAU+3, beam trawling activities would be affected across all country EEZs. Due to the size of the beam trawling sector in Belgian and French waters, the reduction in the spatial extent of beam trawling at the regional scale is small in Belgian and French waters under BAU+3 (and thus the benefits in terms of an increase in realised benefits for seafloor integrity are small at the regional scale), however the impacts on beam trawling activities within these EEZs are large as this subsector occurs across >90% of these countries' EEZs. See full details of differences in sectoral restrictions under the different scenarios at a country level in Bloomfield *et al*. (2013).

6.4.5 Conclusion

It is important to note that the results generated here are limited by the availability and resolution of the data used to map the current sector extents. Information (and associated data) on the likely expansions of the sectors up to 2020 was also lacking, therefore the sector extents considered under the BAU and BAU+ scenarios may be an underestimate. For example, we are aware that there is planned expansion of the Renewables sector which is likely to be significant in some EEZs (e.g. in the UK EEZ, the total area licensed for Renewables is approximately 21 times larger than the current 2010 licenced area). Saying this, this planned enlargement may still be fairly insignificant in terms of adding impacted area at the regional sea level.

The data show that sector activities are widespread in the North Sea case study region and 81.7% of the sublittoral sediment within the case study area is subject to pressures from one or more of the sectors considered. However, there are differences in the spatial extent of the sectors and thus their contribution to the pressures and resultant impacts on sublittoral sediments within the case study area. Benefits for seafloor integrity from the current state, are only likely to be achieved through a reduction in the spatial extent of sublittoral sediment impacted by sectors. Here we have explored the effects of a range of management ambitions on sector extents, based on the premise that sector activities will be avoided where possible, and considered the potential benefits (if any) for seafloor integrity.

This approach has demonstrated that implementation of higher levels of management ambition (BAU+2 and BAU+3) will impact on some sectors (e.g. otter trawling and beam trawling) even if the intention is to avoid economic activities, because their spatial extents within the case study region are very large. Thus only at the higher levels of management ambition is there potential for benefits for seafloor integrity through a reduction in the total area of sublittoral sediment impacted by sectors. Consideration of management implementation at the country levels demonstrates different effects on sectors among countries, in terms of which sectors are affected, what the change in spatial extent will be, and what the proportional change in sector extent will be. This has important implications for the total area of sublittoral sediment that will be protected within each EEZ and the economic impacts of management.

A key point to note is that in consideration of the combined footprint that there are some sectors (Telecoms, Oil and Gas, Renewables) that cannot have their spatial extents reduced as they utilised of permanent structures that are unlikely to be removed. Therefore, sectors which are mobile (predominantly the fishing subsectors) are likely to be disproportionately affected by management.

At the resolution considered here, there are significant areas of the seabed where sectors co-occur and this has important implications for management, as management targeted at one sector may remove the pressures from that sector but may not lead to improvements in seafloor integrity as pressures from the other sector(s) remain. Thus, the ability of single sector management to yield benefits for seafloor integrity are limited where sectors co-occur and efforts for multi-sector management are required.

7 Mediterranean Sea - sea floor integrity case study

Full details of this case study are given in Papadopoulou *et al*. (2013) with all steps and outcomes summarised below.

7.1 Step 1: Scoping

7.1.1 Step 1.a: Development and identification of impact chains

The extraction of the high-threat impact chains for the Mediterranean Sea – sea floor integrity case study resulted in a number of sector-pressures combinations.

7.1.2 Step 1.b: Identification of high–risk impact chains

Each of the high-risk impact chain combinations were considered to decide whether the combinations were taken forward in the case study (see Table 18). As the case study focused on spatial management scenarios that restricted activity of sectors in areas where *Posidonia* is prevalent (see Section 7.2), only those pressures that have a spatial footprint that is closely associated with the sector were deemed relevant. Pressures that are much more dispersive in nature (e.g. marine litter, spread of non-indigenous species) were not considered in terms of the potential to manage threats in the scenarios explored here, but the implications of these pressures on the ability to achieve clear improvement (in terms of the recovery of the habitat and its associated biodiversity) are considered in the conclusions (Section 7.4.5.). Other sectors which were excluded included non-renewable energy, which although relevant to sublittoral habitats in general, are located offshore and do not overlap with *Posidonia*. Tourism and Recreation was also not taken forward as its relevance to *Posidonia* is mostly through interactions with the dead *Posidonia* banks, which are removed to improve the "look" and attractiveness of the beaches. Although this dampens the erosion prevention service it does not constitute a high-threat to live *Posidonia* beds. Anchoring and mooring of tourist and pleasure boats has been seen to cause significant reduction in seabed cover (Boudouresque *et al.*, 2012). However, no quantitative spatial data are available on boating anchoring and on frequency/intensity, and thus this sector was not considered in the case study.

As such, the following sector-pressure combinations were taken forward for this case study:

- Fisheries - Selective extraction of species
- Fisheries – Substrate Loss
- Fisheries – Abrasion
- Fisheries - Smothering
- Coastal infrastructure – Substrate loss
- Coastal Infrastructure – smothering
- Coastal Infrastructure – changes in siltation
- Aquaculture – Substrate loss
- Aquaculture – Smothering
- Aquaculture – changes in siltation

Table 18. High threat sector-pressure combinations for the Mediterranean Sea floor integrity case study (green cells) and the combinations that were taken forward in scoping exercise (blue cells). NA means the specific sector-pressure combination does not occur in the extraction of the high threat impact chains.

Pressure / Sector	Fisheries	Coastal Infrastructure	Aquaculture	Tourism/ Recreation	Non-renewable Energy (oil & gas construction)	Aggregates	Agriculture	Navigational dredging	Shipping	Included in further scoping exercise?	Comment based on regional perspective and the case study context
1. Smothering	Yes	Yes	Yes	No	No	Yes*	No	Yes*	No	Yes	This is a pressure associated with at least 2 key sectors acting on the habitat. There are no quantitative data, only experimental studies looking at the effects of smothering to *Posionia*.
2. Substrate Loss	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	This is a key pressure for the habitat and the region, linked to at least 2 sectors and backed up with some historical/anecdotal data. There are no published estimates of loss at the scale of the basin and with a sectoral breakdown. Loss is typically seen through permanent structures (e.g. ports, defences etc.) and through change and repeated impacts via fishing.
3. Changes in siltation	No	Yes	Yes	No	No	Yes*	No	No	No	Yes	This is a secondary pressure, however there are no quantitative data available except experimental studies looking at impacts on *Posidonia*.
4. Abrasion	Yes	No	No	Yes	No	Yes*	No	Yes*	No	Yes	Historically, when trawling was allowed on the *Posidonia* habitats (in EU and non-EU MS), abrasion was the key pressure. Although this is now spatially reduced (in considerable parts of the *Posidonia* in the EU MS), abrasion through recreation/small boating is a secondary pressure acting upon the habitat even in MPAs. There are no quantitative data on abrasion, only indirect assessment can be made through estimates of areas/times allowed fishing on or areas where anchoring takes place. There are some recent studies looking at anchoring in MPAs and associated intensity of the phenomenon as this is an important factor.
5. Selective Extraction of Non-living Resources	No	No	No	No	No	Yes*	No	No	No	No	No overlap of the only sector relevant here with the specific sub-habitat type.
6. Underwater noise	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
7. Marine Litter	Yes	No	Yes	Yes	No	No	No	No	Yes	No	A relevant threat as in other littoral/sublittoral habitats that cannot however be managed spatially.
8. Thermal regime changes	No	No	No	No	No	No	No	No	No	Not	No high threat issues

										applicable	
9. Salinity regime changes	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
10. Introduction of Synthetic compounds	Yes	No	Yes	No	No	No	Yes	No	Yes	No	Cannot be managed spatially (e.g. by MSP)
11. Introduction of Non-synthetic compounds	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
12. Introduction of Radionuclides	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
13. Introduction of other substances	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
14. Nitrogen and Phosphorus enrichment	No	No	Yes	Yes	No	No	Yes	No	No	No	Cannot be managed spatially (e.g. by MSP)
15. Input of organic matter	Yes	No	Yes	Yes	No	No	Yes	No	No	No	Cannot be managed spatially (e.g. by MSP)
16. Introduction of microbial pathogens	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
17. Introduction of non-indigenous spp. and translocations	Yes	No	Yes	No	No	No	No	No	Yes	No	Cannot be managed spatially (e.g. by MSP)
18. Selective extraction of species	Yes	No	No	No	No	No	No	No	No	No	The pressure (mortality caused by trawling) is relevant as it indirectly impacts the habitat, associated species and ecosystem services but is not the main focus of case study.
19. Death or injury by collision	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
20. Barrier to species movement	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
21. Emergence regime change	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
22. Water flow rate changes	No	Yes	No	No	No	No	No	No	No	No	No high threat issues
23. pH changes	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
24. Electromagnetic changes	No	No	No	No	No	No	No	No	No	Not applicable	No high threat issues
25. Change in wave exposure	No	Yes	No	No	No	No	No	No	No	No	No high threat issues
26. Climate change										No	Climate change cannot be managed spatially (e.g. by MSP)
26a SST/SBT changes											
26b Sea level rise											
26c Precipitation (rainfall/ freshwater/ salinity changes)											
26d Intensity and frequency of storms (exposure)											
26e Ocean acidification (pH)											
26f Large scale ocean circulation (e.g. NAO)											

* Aggregates and navigational dredging do not overlap with *Posidonia* and is therefore not included in the case study.

7.1.3 Step 1.c: Further selection of most relevant high-risk impact chains

Posidonia oceanica is an important Mediterranean ecosystem in terms of biodiversity as it supports hundreds of marine species, providing habitat and refuge functions for many benthic species and acting as a spawning and nursery ground for many commercial species (UNEP 2009). *Posidonia* is endemic to the Mediterranean and is listed as a Priority species under the Habitats Directive as it is a natural habitat type in danger of disappearance. *Posidonia* is present on most Mediterranean shores, is characteristic of the sublittoral and infralittoral zone, and can be found from very shallow depths to up to as deep as 50 m. It is found on sandy and mixed bottoms and rarely as small patches on rock.

As a key habitat *Posidonia* is considered a biological indicator for overall quality of coastal waters and an indicator for the Mediterranean for the Water Framework Directive (Boudouresque *et al.*, 2012).This case study focussed on *Posidonia* (a EUNIS level 5 habitat) as an indicator of state of sublittoral habitat (EUNIS level 2 habitat A5) and sublittoral macrophytic dominated sediments (EUNIS level 3 habitat A5.5). Although one of the best studied habitats in the Mediterranean, extent data are limited for this ecosystem and mapping efforts are incomprehensive and geographically variable.

The sectors that are considered in this case study are documented past and current threats linked to both degraded and locally disappearing *Posidonia* meadows.

7.2 Step 2: Identification of BAU and BAU+ management measures

The case study focussed on those threats which could be managed using a spatial approach and therefore focussed on physical loss and damage. BAU scenarios considered the likely situation of sector extents up to 2020, taking into consideration management already in place or coming into force, as well as expected expansion of sectors. BAU+ scenarios, depending on the sector, considered alternative possibilities of sector growth or implementation of management measures to reduce the spatial footprint of the sector. Data on the current sector spatial extent were sourced for all countries where available and the use of expert judgement was also employed where data were unavailable (Papadopoulou *et al.*, 2013). Due to the absence of data on potential expansion of sectors up to 2020, hypothetical growth scenarios were considered based on current extent and distribution of sectors. The management measures and potential growth in sectors considered under BAU and BAU+ are summarised in Table 19.

For the BAU management options in aquaculture, it was assumed that the non-EU states would expand their aquaculture activities and part of this expansion will overlap with the *Posidonia* habitat. States currently without the sector were excluded from future scenarios. It was assumed that the size of the cages used by the non-EU countries would increase to the size used in Europe, which is nearly 50% larger. The sector would remain unchanged in EU states i.e. no further overlap with the habitat. There is currently no EU regulation specifically forbidding aquaculture farming on the habitat, however there is increasing evidence that farms should not be set directly above or in the vicinity of *Posidonia* in addition to regulations including the Habitats Directive, WFD and MSFD, which require protection of the habitat. In some EU countries there are also national regulations (see Boudouresque *et al*. (2012)) which require environmental impact assessments aimed at stopping further expansion of the sector on *Posidonia*. Under the BAU+ scenario, it was considered that all aquaculture activity would be removed from *Posidonia*.

Another high threat sector-pressure for the Mediterranean Sea is Coastal infrastructure. In this case study all artificial coastal defence structures were included except ports, marinas, roads, hotels etc. (for details see Papadopoulou *et al*. (2013)). For the BAU scenario, there was no additional regulations coming into force that would restrict the coastal defence part of the sector but it was assumed that there would be no further substantial growth of the sector. Therefore, it was considered that the extent of coastal infrastructure in 2020 (BAU) would be equivalent to the extent in 2012 (Current). For BAU+ it was assumed that in 2020, the percentage of artificial coastline in the non-EU member states would increase to average level of EU member states. No increase in coastal infrastructure was considered in EU Member States.

The third high threat sector-pressure for the Mediterranean are the bottom trawl fisheries. To determine the impact under the BAU scenario, it was assumed that in 2020 all trawl-fishing activities will be excluded from the areas with *Posidonia* in the EU member states (caused by the full implementation of EC regulation (EC/1967/2006), which bans all trawling on *Posidonia* in EU member states). For the non-EU states it was assumed that the fishing (trawling) would remain unchanged. For the BAU+ scenario it was considered that all trawling activities would be excluded from the areas with *Posidonia* in both the EU member states and the non-EU states. In both EU and non-EU MS other forms of fishing (e.g. gillnetting) were not considered in the scenarios.

Table 19. Overview of management options for the Mediterranean Sea case study

Management Scenario	Sector	Management	Spatial extents
Current spatial extent	Aquaculture	Existing	The total spatial extent of the sector estimated to currently overlap with *Posidonia*.
	Coastal infrastructure	Existing	The total spatial extent of the sector estimated to currently overlap with *Posidonia*.
	Fisheries - trawling sector	Existing	The total spatial extent of the sector estimated to currently overlap with *Posidonia*.
BAU	Aquaculture	Requirements for environmental impact assessments (EIA) for new licences could stop further increases of sector overlapping with or adjacent to *Posidonia*. Although the implementation of these EIAs varies and may not guarantee this, it was assumed to be true. Therefore, the scenario is no further increases of sector overlapping with *Posidonia*, applied to EU countries only.	EU: same as for current Non-EU countries: increase in sector extent (measured as an increase in average cage area) in countries where aquaculture already exists and thus increase in overlap with *Posidonia* in these countries to EU equivalent levels (unless bigger)
	Coastal infrastructure	No additional management applied to either EU or non-EU countries but sector not expected to increase.	EU: same as current spatial extent Non-EU: same as current spatial extent
	Fisheries - trawling sector	Full implementation of EC regulation (EC/1967/2006) which bans all fishing on *Posidonia* in EU member states, the assumption being that all areas of *Posidonia* in EU Member States will start recovering from this pressure. In non-EU states, it was assumed that this regulation is not adopted and the fishing sector would continue to operate unchanged.	EU: no overlap of fishing (trawling) with *Posidonia* Non-EU: same as current spatial extent
BAU+	Aquaculture	As a very high ambition conservation scenario, all states to protect all known *Posidonia* from aquaculture impacts. The outcome for the aquaculture sector is that the footprint is completely removed from all *Posidonia* areas.	EU: reduction in spatial extent so no overlap of aquaculture with *Posidonia* Non-EU: reduction in spatial extent so no overlap of aquaculture with *Posidonia*
	Coastal infrastructure	No regulations relating to coastal infrastructure in non-EU countries. The outcome for the sector is a predicted expansion in coastal infrastructure impact footprint to match current EU levels; no change from current in EU states.	EU: same as current spatial extent Non-EU: increase from current spatial extent to EU equivalent levels
	Fisheries - trawling sector	EC regulation (EC/1967/2006), which bans all fishing on *Posidonia* in EU member states, extended to non-EU member states. The outcome for the trawling sector is that the footprint is completely removed from all known *Posidonia* areas.	EU: reduction in spatial extent so no overlap of fishing (trawling) with *Posidonia* Non-EU: reduction in spatial extent so no overlap of fishing (trawling) with *Posidonia*

7.3 Step 3: Evaluation of BAU/BAU+ management options

For the present state of the ecosystem in the Mediterranean Sea, the current extent of *Posidonia* habitat was based on mapped beds. Although under the Habitats Directive there is a requirement for identification of sites with *Posidonia* and notification of candidate Natura 2000 sites, EU Member State mapping efforts fall short of legal expectations. Mapping efforts in the non-EU MSs is even less comprehensive. Despite its priority status, there is no recent estimate for mapped or modelled spatial extent of the habitat. We used the UNEP (2009) estimate of 35000 km^2 and we are aware of modelling exercises under the MAREA/MEDISEH project that bring the extent of the modelled habitat closer to the 50000 km^2 (MEDISEH/MAREA/DG MARE Project, unpublished data).

7.3.1 Aquaculture assessment

For the current impact of the high threat pressures in the Mediterranean Sea, the total area of fish cage farms per member state was calculated (for data sources see Papadopoulou *et al*. (2013)). Expert judgement was used to estimate the likelihood of overlap between *Posidonia* habitat and fish farms. The area of *Posidonia* habitat impacted is calculated by multiplying the likelihood of overlap with the total area occupied by fish cages. For BAU, the average EU cage size was applied to non-EU states to consider an increase in the sector. For BAU+, removal of the entire sector extent was considered.

7.3.2 Coastal infrastructure assessment

To calculate coastal infrastructure for each country, the percentage of artificial coastline was estimated from maps and Google Earth Imagery (for details see Papadopoulou *et al.* (2013)). It was assumed that coastal infrastructure can affect the *Posidonia* habitat up to 100 m from the shore and that 5% of all *Posidonia* habitat occurs within this limit. Based on this assumption the overlap of coastal infrastructure with *Posidonia* habitat was calculated.

7.3.3 Fisheries assessment

To determine the impact under the current scenario, existing maps of trawling and dredging disturbance (e.g. Coll *et al*. (2010)) were cross-referenced with distribution maps of *Posidonia.* Expert judgement was used to modify this overlap to include protected areas as the resolution of the maps used was coarse. The total extent of affected *Posidonia* habitat was calculated by multiplying the area of *Posidonia* habitat by the level of protection per state.

7.4 Step 4: Discussion of management options

7.4.1 Results aquaculture assessment

Aquaculture had the smallest overall spatial extent of the three sectors considered with a total of 0.9km^2 of the sector overlapping[3] with *Posidonia*, impacting less than 0.01 % of *Posidonia* habitat. Expansion of the sector in non-EU states to match the average cage area in EU states under the BAU scenario resulted in a marginal overall increase in the footprint on *Posidonia* to 1km^2, still less than 0.01% of the habitat. Measures under BAU+ to remove the sector from the habitat would result in a very small benefit to *Posidonia* (0.9km^2 improvement).

Years of evaluation 2012-2020

	Area of *Posidonia* Impacted (km^2)	Potential Benefits to *Posidonia*
Current	0.9	REF
BAU	1	-
BAU+	0	+

Legend:
REF: reference level
(+) Positive effect compared to the current level
(-) Negative effect compared to the current level

[3] Assuming the sector overlaps with *Posidonia* 25% of the time

7.4.2 Results coastal infrastructure assessment

Coastal infrastructure had a relatively small impact footprint on *Posidonia*, although larger than the aquaculture sector. No change in the sector was considered under BAU. Under BAU+, an increase in non-EU countries to match EU levels of development was considered. This would result in an increase in impact of *Posidonia* of 27.5km^2, leading to 0.2% (75km^2) of total *Posidonia* habitat impacted by coastal infrastructure.

Years of evaluation 2012-2020

	Area of Posidonia Impacted (km^2)	Potential Benefits to Posidonia
Current	48.0	REF
BAU	48.0	0
BAU+	75.5	-

Legend:
REF: reference level
(+) Positive effect compared to the current level
(-) Negative effect compared to the current level

7.4.3 Results fisheries assessment

Fishing (bottom trawling) was by far the largest sector impacting *Posidonia* habitat with a total of 41% (14,271 km^2) of the habitat currently used for trawling. Under BAU, the full implementation of an EC directive which bans trawling on *Posidonia* was considered. This would reduce the total area of impacted *Posidonia* to 16.5% (5,784 km^2). Under BAU+, the extension of the EC regulation to all Mediterranean states, removing the whole sector (14,271 km^2), was considered. This would result in potentially large benefits for *Posidonia*.

Years of evaluation 2012-2020

	Area of Posidonia Impacted (km^2)	Potential Benefits to Posidonia
Current	14,271	REF
BAU	5,784	+
BAU+	0	++

Legend:
REF: reference level
(+) Positive effect compared to the current level
(++) very positive effect compared to the current level

7.4.4 Overlap assessment

Years of evaluation 2012-2020

	Percentage of seafloor affected
Current	REF
BAU	+
BAU+	++

Legend:
REF: reference level
(+) Positive effect compared to the current level
(++) very positive effect compared to the current level

Under the current scenario, 40,9% of *Posidonia* area is impacted by all the sectors together.
Under the BAU scenario only 16,7% of the *Posidonia* area is impacted by all the sectors together.
Under the BAU+ scenario only 0,2% of the *Posidonia* area is impacted by all the sectors together.

7.4.5 Conclusion

Human activities in the Mediterranean Sea impact large areas of the existing *Posidonia* habitat, e.g. fishing impacts 41% of *Posidonia* meadows.

Trans-boundary governance issues are likely to be a significant factor in the Mediterranean. Not all states in the Mediterranean region are obligated under the same (EU) environmental policies and conservation objectives. Based on best available knowledge of the distribution of *Posidonia*, most of the known habitat extent is found in the EEZs of six countries, five of which are EU member states (Spain, France, Italy, Cyprus and Greece), the remaining one being Tunisia. This means that focusing measures in areas where the greatest concentration of existing *Posidonia* is still found will place most of the burden on less than half of the countries bordering the Mediterranean (with the vast majority of the habitat that is mapped found in Italy and Greece). However, mapping efforts in the region are far from comprehensive and thus it is possible that unmapped areas of the habitat could continue to be degraded and lost, with the burden of responsibility being left to those countries that have existing maps. There are numerous examples of infringements of community law in several EU MS for not mapping/reporting their *Posidonia* beds and for approving port/marinas coastal projects associated with the tourism and recreation sectors (as seen for example in the WWF Complaint (2009) to the European Commission and the Oceana (2011) Question to the European Parliament).

For 'immobile' seafloor habitats and sessile species, the use of spatial management tools like the establishment of Marine Conservation zones, might be an effective strategy. For mobile species, it might be more difficult to find a good solution. A regional approach to management is often necessary.
Furthermore, there are also pressures to be managed that are not bound by country borders such as climate change, marine litter or the introduction and spread of NIS. A spatial management approach may achieve limited results in improving the status of *Posidonia* habitat if other issues such as these continue to degrade habitats, even in protected areas.

However, objectives for improving *Posidonia* would not only contribute to achieving the objectives for the seafloor integrity descriptor, but also for biodiversity (Descriptor 1). *Posidonia* is the leading Mediterranean ecosystem in terms of biodiversity as it supports 25% of marine species in the Mediterranean for only 1.5% of the seabed. It provides habitat and refuge functions to numerous benthic species and is a spawning and nursery ground for many commercial species as well as an important feeding habitat for green turtles. *Posidonia*'s role in the Mediterranean has been compared to that of a forest or a coral reef. Thus, loss of, or even just damage to *Posidonia*, can potentially result in habitat loss for a large proportion of Mediterranean species.

8 Synthesis of Case Studies

ODEMM aims at developing and evaluating options for ecosystem-based management of the marine ecosystem. In five regional case studies, management strategy evaluations were carried out. Within these case studies the potential of different management strategies were evaluated. This chapter compared the different case studies and presents the overall conclusions.

8.1 Comparisons between case studies

8.1.1 Identification and interpretation of BAU and BAU+

The case studies each identified one or more BAU and BAU+ scenarios. In Table 20, an overview can be found of the BAU and BAU+ scenarios per case study.

Some distinct differences could be observed between the case studies. In the foodweb case studies management involved measures aimed mostly at one sector-pressure combination (i.e. fisheries-extraction) sometimes in combination with one specific pressure (i.e. eutrophication in addition to fisheries-extraction), while in the seafloor integrity case studies management is explicitly multi-sector. The Mediterranean seafloor case study considered different sectors separately and also conducted an overlap assessment while the NEA sea floor integrity case study assessed the implications of scenarios on combined sector footprints and on individual sectors.

The measures studied in the NEA foodweb case study are only targeted at fisheries (both benthic and pelagic). In the Baltic case study, two different management strategies are proposed, one for fisheries and one for eutrophication. As the management strategy for eutrophication was not sector specific, it aimed at reducing the eutrophication which involves different sectors. The effects of both management strategies were studied separately and any potential cumulative effects were not considered. In the Black Sea we also assessed two management strategies targeted at eutrophication and the selective extraction of species by fisheries. However, in this case study these measures are implemented in concert and cumulative effects were considered in the assessment.

The seafloor integrity case studies in the Mediterranean Sea and the NEA study focused on measures that diminish the area of affected seafloor. The management strategy aims at conserving the state of sub-littoral sediment independent of the sectors or pressures affecting it and may therefore include multiple sectors causing multiple pressures. Because of regional differences in sectoral activities, the focus of the measures to conserve the sub-littoral sediment in the Mediterranean Sea involved aquaculture, the construction of coastal infrastructure and benthic fisheries, whereas the NEA case study involved the sectors oil and gas, aggregates, benthic fishing, renewable energy and telecommunications.

Some differences in interpretation of BAU and BAU+ were observed between the foodweb case studies. While all case studies adopted MSY as the main reference point that determines future fisheries management, one case study (NEA) considers it as part of BAU, because ICES already implemented this in its advice, whereas two others (Baltic and Black Sea) chose Fmsy as a future management option (BAU+ scenario). Within the sea floor integrity case studies, more than one BAU scenario was considered.

Table 20. Identification of BAU and BAU+ scenarios per case study

	Foodwebs case studies				Sea floor integrity case studies			
	NEA - Fisheries	**Baltic Sea - Fisheries**	**Baltic Sea - Eutrophication**	**Black Sea – Combined Fisheries and eutrophication**	**NEA – Multisector**	**Mediterranean - Aquaculture**	**Mediterranean – Coastal infrastructure**	**Mediterranean - Fisheries**
Current	-	-	-	-	This scenario concerns the current state of the ecosystem and the present extent of the sector-pressure, with the effect of the existing management included.	-	-	-
BAU scenario	For the BAU scenario, Fishing mortality for all 12 fish species under the current management objectives derived was set at MSY levels according to the ICES advice 2012.	For the business as usual scenario, the *status quo* fishing mortality was the management objective. Selectivity differed depending on the mesh size: Option 1: L50%=38cm Option 2: L50%=40cm	The BAU scenario describes a situation equal to the current management situation.	For BAU, the current fishing mortality and primary productions levels are used.	This scenario assumes the future state in 2020 is the same as the current state of the ecosystem and the present extent of the sector-pressure, with the effect of the existing management included.	In this scenario, an increase in the average size of a fish cage in non-EU member states to the average size of cages in EU Member States was considered.	No change in the extent of coastal infrastructure up to 2020.	Here, the assumption is that all areas of *Posidonia* in EU Member States will be freed of trawling/dredging impacts. In non-EU states, it was assumed that regulations are not adopted and the fishing sector continues to operate unchanged.
BAU+ scenario 1	Knife edge selection - Fishing mortality is at MSY but each species is harvested at or above the size at which a cohort reaches its maximal biomass.	In this scenario the objective was Fmsy or ICES transition to Fmsy for all stocks and years. Option 1: L50%=38cm Option 2: L50%=40cm	The BAU+ scenario assumes a reduction in nutrient as required by the Baltic Sea action Plan (BSAP).	In this option the current primary production is maintained, but for the fishing mortalities, Fmsy is applied.	In this BAU+ scenario, 3% of the sea floor of all Member State EEZs in the North Sea were assumed protected from detrimental activities.	In this scenario we considered the removal of the sector from the Posidonia habitat in both EU and non-EU MS	In this scenario, an increase in non-EU states was considered to average levels found in EU member states (an increase from 4 to 14%).	Under the BAU+ scenario, we considered that the regulations banning trawling on *Posidonia* would be extended to non-EU member states.
BAU+ scenario 2	Protect old - Fishing mortality is at MSY but the older ages are protected.	-	-	Fmsy is applied for the fishing mortalities and for eutrophication, a 50% decrease in primary production level is used.	In this BAU+ scenario, 30% of the sea floor of all Member State EEZs in the North Sea were assumed protected from detrimental activities.	-	-	-
BAU+ scenario 3	Balanced fishing - Fishing mortality is at MSY but the fishing mortality is based on productivity of the age-/size groups.	-	-	Fmsy is applied for the fishing mortalities and a primary production level, 50% above the current value, is used.	In this BAU+ scenario, 70% of the sea floor of all Member State EEZs in the North Sea were assumed protected from detrimental activities.	-	-	-

8.1.2 Measures aimed at the reduction of the impact of fisheries through the selective extraction of species

Here we explore the overall effect of the different measures on important aspects of the ecosystem. For the foodweb case studies the effect of the measures was assessed against (1) the species composition (i.e. predator versus prey), (2) the size structure of the fish community and (3) the top-predators (i.e. marine mammals and seabirds).

Species composition

Functional groups: biomass of Predator and Prey species

	NEA		Baltic Sea		Black Sea	
	Prey	**Predator**	**Prey**	**Predator**	**Prey**	**Predator**
Fsq	ref	ref	ref	ref	ref	ref
Fmsy	0/+	0/+	+	0/+	0/+	+
Selectivity	+	+	NA	+	NA	NA

The performance of key predator species using their production per unit biomass and the abundance of key trophic species are phrased as indicators for the food web situation by the EU (see Table 1).

The NEA foodweb case study results were size- and species-specific. In this study herring, sandeel and sprat are considered prey species, as are the smaller specimen of cod, pout, haddock and whiting. The other species and larger specimen are considered predators. In the NEA foodweb case study, Fmsy was considered BAU. Under this scenario, nearly all stocks show very little fluctuations in their development in biomass. An increase was seen in the standing stock biomass of predator cod, but also in the prey species sandeel and sprat.

In the Black Sea case study, the following prey-predator interactions were considered: sprat and anchovy are both prey for whiting and turbot, and whiting is a prey for turbot. Under BAU+1 (Fmsy) there was an increase in biomass of all four modelled fish species, but the biggest increase was seen for the predator fish species turbot and whiting (relative change in biomass compared to the BAU 32% and 26%, respectively). This is probably due to the fact that the Fmsy for whiting and turbot is much lower than the current fishing mortalities. For sprat and anchovy (relative change in biomass compared to BAU 4.8% and 1.3%, respectively), the Fmsy value is close to the current fishing mortality, which might explain the lower increase in biomass compared to turbot and whiting. In the Black Sea case study the predator species gained more biomass than the prey species when changing fishing mortality to Fmsy.

In the Baltic Sea study cod is considered a predator and herring and sprat are included as prey species. Under the BAU+ Fmsy scenario in the Baltic Sea case study, there is a high probability (73%-95%) that the biomass of cod, herring and sprat will be higher than the observed average levels (1987-2011). An improvement can be seen for the biomass results for prey species herring, compared to BAU. Here again, the Fmsy is much lower than the Fsq for herring. For cod and sprat both mortality numbers are relatively close, explaining why for cod and sprat there are no big changes in terms of biomass between BAU and BAU+. As expected, since the Fmsy was close to the current F, changing to Fmsy did not have a big effect on the increase of biomass of the specific species. The change in biomass for predator or prey species seems more depending on the previous fishing mortality than cascading changes in the foodweb.

Overall it can be concluded that, judged by the performance of predator species and abundance of key trophic species, a conversion to Fmsy only has a minor effect on the foodweb and in none of the case studies this reduction in fishing mortality had any negative consequences.

A change in selectivity has positive effects in the analysed case studies. In the Baltic Sea case study, an increase in lengths at which 50% of the fish are retained in the cod-end was analysed. This increase from L50% of 38 to 40 cm means that small individuals will not be caught anymore. This resulted in an increase in cod biomass. In the model study the effect of this higher selectivity on the other species is not considered, but the increase in cod will probably also cause an increase in the predator/ prey ratio.
In the NEA case study three different selectivity scenarios were modelled; knife edge where smaller individuals are protected, protect old where large fish are protected and balanced fishing where the fishing mortality is based on productivity of the age-/size groups. The knife edge scenario shows only an increase for predator species cod and pout on the short term, but when analysed until 2060 other (prey) species also show a positive effect. For the protect old and balanced fishing scenario, both predator and prey species will profit on the long term.

Overall it can be concluded that measures based on a higher selectivity will be positive for the foodweb, judged by the performance of predator species and abundance of key trophic species.

Size structure

Proportion Large Fish			
	NEA	**Baltic Sea**	**Black Sea**
Fsq	ref	ref	ref
Fmsy	+	0/-	+
Selectivity	+	+	?

The share of large fish is phrased as an indicator for the food web situation by the EU (see Table 1). Both the NEA foodweb case study and the Black Sea case study looked at the proportion of large fish within the community. In both areas the introduction of Fmsy led to a larger proportion of large fish. In the run to 2020, the values for the Large Fish Indicator went up in the NEA foodweb case study, mainly due to an increase in cod biomass. Most other species remain the same.
In the Black Sea case study, reducing the fishing pressure by reducing the mortality to msy-level, resulted in increasing proportions of large fish within the whole fish community, even though the fishing mortality levels were not different for large fish than for small fish.

In the Baltic Sea case study, the share of large fish is not chosen as an indicator for the food web situation, but might be deduced from the stock biomass of the different species. For cod, LFI should decrease to some extent with higher F (i.e. BAU+ as Fmsy is > Fsq), and therefore, the expected small decrease of cod biomass (under Fmsy) will rather lead to increase in mean size of herring and sprat. From this it can be deduced that introducing Fmsy will have a neutral to negative effect on the share of large fish in the Baltic Sea.

Besides catch limitations, increasing the size-selectivity of the gear, is also a possibility to reduce the negative effects of benthic and pelagic fisheries on the foodweb. Both the Baltic as well as the NEA foodweb case studies, incorporated a change in selectivity in their BAU+ scenarios. The Black Sea case study did not include size selectivity.

The changed selectivity in the Baltic Sea case study had a positive effect on the cod biomass (both under Fsq and Fmsy) and considering the relative increase of cod it probably resulted in an increase in the share of large fish in this region. The NEA food web case study also showed selectivity can be an important tool in achieving more large fish. An increase in LFI could be found for two of the three scenarios, and in the third scenario it is expected that LFI will recover on the long term.

Judged by the share of large fish it might be concluded that measures involving a change in selectivity may have a positive effect on the foodweb according to the chosen LFI indicator. Applying size-selectivity can help improving the LFI beyond BAU.

8.1.3 Measures aimed at the reduction of eutrophication

Here we explore the overall effect of the different measures on important aspects of the ecosystem. Eutrophication was considered as an ecosystem feature affected by management but also as an environmental factor affecting the outcome of management aimed at other policy objectives (i.e. descriptor 3, commercial fish).

In the NEA foodwebs case study, eutrophication was not considered. Due to the scale of the NEA, eutrophication effects on the foodweb are small, compared to the effects of other major pressures. Local eutrophication effects might influence the foodweb, but will not have an impact on the NEA foodweb as a whole.

In the Baltic Sea case study, the results were shown of other projects where eutrophication was modelled using DIN, DIP, summer chlorophyll a concentrations, summer cyanobacteria and other phytoplankton biomasses. Measures under BAU+ were set to reach HELCOM targets by load reductions. Under the BAU scenario the DIN, DIP and chlorophyll a concentrations continue to increase in the coming decades. Also the cyanobacteria and other phytoplankton biomass are predicted to increase for the next 1-4 decades, but this increase will be slower after the 2030's.
Under the BAU+ scenario the DIN, DIP and chlorophyll a concentrations will decrease during the coming decades but targets will not be met in the 21st century. The cyanobacteria and phytoplankton biomasses also show a decrease under BAU+.

The Black Sea used in their case study a combined model, modelling both fish and eutrophication at the same time. To estimate the effect of eutrophication, primary production was taken as input variable in the model used in this case study. The Black Sea case study shows us that the influence of a reduction in

eutrophication on top of Fmsy leads to a reduction in fish biomass, instead of a small increase which was found when only Fmsy was implemented without measures reducing eutrophication.
Higher nutrient levels enhanced fish production by increasing the productivity of the whole ecosystem in the Black Sea case study, but it might also have negative consequences because of an increase in opportunistic species in the plankton community and increase of areas under hypoxic or anoxic conditions. Reduction of the eutrophication in combination with fishery measures (Fmsy) results in a negative effect on the fish biomass.
The Black sea study clearly shows that eutrophication affects the fish community and that therefore these measures should be considered together.

The Baltic Sea case study showed that the HELCOM nutrient targets will not be reached in either of the two scenarios (BAU and BAU+) for eutrophication in the 21st century, even when eutrophication load reductions are taken in 2010. Up to 2030, concentrations stay the same or might even continue to increase, before a decrease is shown. If the same change over time applies to the Black Sea, the effects of a reduction in eutrophication on the fish stock might be unnoticeable up until the 2030's.

8.1.4 Effects mammals/birds

Here we explore the overall effect of the different measures on important aspects of the ecosystem as an environmental factor affecting the outcome of management on the other aspects (i.e. top-predators such as fish, birds and marine mammals).

Performance key predator species

Biomass mammals and birds

	NEA	Baltic Sea	Black Sea
Fsq	ref	ref	ref
Fmsy	+	+	+
Fmsy and an increase in primary production	?	++	++
Fmsy and a decrease in primary production	?	-	-

The performance of key predator species using their production per unit biomass is included as an indicator for the food web situation by the EU (see Table 1). Both measures concerning catch regulation and changing the input of nutrients might influence the abundance of the top predator species.
All foodweb case studies considered the status of mammals and seabirds. Because of a lack of data, this could be done only qualitatively. Both the Baltic and the Black sea study analysed the modelled effects on the foodweb of measures concerning eutrophication. The NEA case study did not include eutrophication measures. In this case study only inferences were made on the basis of how the changes in the fish community calculated by the model may affect these key predator species.

It is assumed that an increase of fish biomass will have a positive effect on the predator species by means of increased food availability. The Black Sea study refers to Oguz et al. (2007), who showed that only certain combinations of fishing mortalities for small and medium pelagic fish, lead to a restoration of marine mammal populations in the Black Sea. In the Atlantic region a relation is found between sandeel densities and breeding success of various seabird species (Furness, 2007). However, it is also possible that there is a trade-off between achieving the objectives for mammals and seabirds, due to competition.

In all three foodweb case studies, a switch to Fmsy resulted in an increase in fish biomass. Depending on the case study, this increase would mostly benefit either prey or predator fish species, or both. This increase in food availability will probably benefit the top predators. For example in the Black Sea case study, an increase is found for both prey fish species biomass as predator fish species biomass. Therefore it is expected that both mammals and sea birds will benefit from this. However, the increase in predator fish biomass is higher than for prey species, which may lead to an increased competition between fish predator species and seabirds and mammals.

An increased primary production level, may increase the productivity of the whole system. In the Black Sea modelling study, the fish biomass increased significantly with a raised primary productivity and decreased when the primary productivity was lowered.
Eutrophication may increase the productivity of the ecosystem but may also have some undesirable side effects like anoxic or hypoxic conditions, limiting the fish feeding and spawning areas. The Black Sea modelling study also shows a decrease in the fodder zooplankton/ total zooplankton under increased eutrophic circumstances. Besides, it should also be mentioned that the largest threats for mammals and

seabirds in the Black and Baltic seas are not food related. Therefore it is not certain that a higher fish and zoobenthos biomass will automatically lead to more birds and mammals in these regions.

8.1.5 Comparison sea floor integrity case studies

The NEA and Mediterranean Sea case studies focussed on sea floor integrity. The NEA focussed on sublittoral sediment, which is the dominant habitat in terms of areal extent in the region, whereas the Mediterranean case study zoomed in on *Posidonia* habitat, which although restricted in area, contributes disproportionately to the overall biodiversity of this regional sea. The extent of the sector impacts affected over 80% of the seafloor habitat being considered in the NEA SFI and over 40% in the Mediterranean case study. In contrast to the North East Atlantic case study, in the Mediterranean Sea case study, there is limited overlap between the sectors/sub-sectors chosen, although various other sectors do operate on the habitat (e.g. desalination, power cables) and some of their pressures can co-occur (e.g. different types of fishing, fishing and boating etc.).

Fishing came out as the sector requiring greatest attention to reduce impacts to seafloor integrity in both case studies. Other sectors may be important in certain areas or countries' EEZs. Both case studies illustrated that there may be no requirement for restriction on activities in some areas or countries of the regional sea to achieve lower levels of ambition in terms of improvement in seafloor integrity. At high levels of ambition, some sectors would require restriction in all countries' EEZs in the NEA region considered, but this would not be the case for the Mediterranean because the specific habitat requiring protection is not distributed evenly (based on current knowledge of mapped habitat) between the coastal areas of the different countries bordering the Mediterranean. Current sector extent and future growth might also be different.

Achieving high conservation targets such as those required for priority species such as *Posidonia* in the Mediterranean (e.g. 60% under the Habitats Directive) would require multiple management measures on numerous sectors/sub-sectors, but ultimately the physical disturbance caused by benthic trawling would require the highest levels of restriction (as is reflected in current policy commitments for the habitat). However, it is also identified that there are pressures to be managed that are not bound by country borders such as climate change, marine litter or the introduction and spread of NIS. A spatial management approach may achieve limited results in improving the status of *Posidonia* habitat if other issues such as these continue to degrade habitats, even in protected areas. Management plans should thus be informed by the increased risks associated with such pressures.

Although it is clear that *Posidonia* contributes disproportionally to biodiversity targets and thus there are numerous reasons for instigating spatial restrictions on damaging activities, there is less known on how much recovery of broad sublittoral sediment habitats in the NEA would impact on other aspects of ecosystem resilience and health. In the work undertaken in the NEA case study we made the basic assumption that removing physical impacts would lead to improvement in seafloor integrity. There is certainly evidence from experiments and long-term studies to suggest that there would be changes in characteristic species and features where high levels of disturbance are removed, but overall what would be the consequences for the ecosystem? If one were to consider consequences across the MSFD's full set of GES targets it is conceivable that there may actually be negative effects on some Descriptors at least in the short or medium term (e.g. Commercial Species, see work on the Plaice Box in the North Sea). Our work has shown that large spatial restrictions would have to be put on benthic fisheries to reach high levels of seafloor protected in the NEA, and it would seem that there is still much work to be done to ascertain whether on balance this would reach the aspirations of ecosystem-based management, where all ecological, social and economic considerations are taken into account.

8.2 Overall conclusions

In three different case studies, management strategies were aimed at mitigating the selective extraction of species by the fisheries sector. The types of measures evaluated were the decrease in fishing mortality toward sustainable levels, in some case studies together with additional measures involving a change in selectivity. These additional measures could help in achieving one or more of the foodweb objectives without compromising the Descriptor 3 objective of achieving MSY.

The reduction of fishing mortality towards Fmsy seemed to have a positive effect on the biomass of several fish species, especially those where the current fishing mortality is (much) higher than the Fmsy. However, due to foodweb relationships this is not always straightforward; for example cascading effects of a reduced fishing mortality on predator species can lead to a decrease in smaller prey species. Changing the selectivity could then lead to a further increase of the biomass and/or a change in the species composition favouring larger or smaller fish. This, in turn, could result in a move towards

foodweb objectives like larger fish (LFI) or more top predators. It is worth noting, however, that there may be a trade-off between these two objectives where achieving one will result in failing the other.
Due to the foodweb relations, it is also advisable to look at the effect of measures on different eco system components and not only the ones that are directly influenced by the proposed measures (for example gulls feeding on discards). What might be a good option for one ecosystem component, is not always the best option for the foodweb overall.

Another trade-off to consider, is between the foodweb objective and those of conventional fisheries management (and thus Descriptor 3) where implementing size selectivity measures resulting in a bigger proportion of large fish or an increase of top-predators may compromise fishing yields.

When considering more than one pressure simultaneously, in this case fisheries combined with eutrophication, showed yet another trade-off: reducing nutrient input towards achieving eutrophication targets may compromise fishing yields.

Finally, we found that marine spatial planning is an important tool to consider as most of the areas where spatial measures could be applied are covered by more than one sector. When there is an overlap, the removal or reduction of only one of the threats may not automatically lead to an improvement, if the other threats remain unchanged. Saying this, in both case studies considering the reduction of threats to seafloor habitats, fishing as a sector was dominant in terms of introducing the most widespread detrimental pressures to the habitats considered. Without restrictions on the major demersal fisheries overlapping with the habitats being considered, little improvement on the current state of those habitats would be possible. At the same time, it is important to note that in some areas of these regional seas there are considerable areas of seafloor habitat that appear to be unimpacted by any of the sectors considered and considerable parts of protected areas that are only protected on paper.

The case studies demonstrate that an integrated approach has an added value above a single sector approach. The different setting of the case studies also make clear that an integrated approach is suitable for various management issues in different habitats and regions. The case studies also reveal other bottlenecks to overcome:

- There are major knowledge gaps and data limitations, for example concerning sea mammals, the prey species they depend on and their foraging behaviour. Habitat maps and information on the distribution of human activities and pressures are also key to understanding and evaluating management strategies for aspects of seafloor health and biodiversity. These are lacking in many regions and confidence in assessments related to these aspects is therefore much lower for some regional seas than for others.
- Furthermore, we need to understand much more about how area of habitats protected from physical impacts actually affects seafloor integrity, and how both the restrictions on sectoral activities associated with MPAs and the broader ecological responses to changes in habitat state, actually translate into a balanced view on the benefits of such management measures where multiple ecosystem objectives in a sustainable use context are being considered.
- Knowledge gaps make it difficult to assess the real impact of pressures and their mitigation through management measures, and therefore prevent a fully integrated and quantitative evaluation of management strategies.

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