277

Modeling the future of the North Sea

An evaluation of quantitative tools available to explore policy, space use and planning options

T. van Kooten & S.T. Glorius

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Modeling the future of the North Sea

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Approved: P. de Vries,
Scientist

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Approved: J.H.M. Schobben,
head of Environment Department

Signature:

Date: 30 December 2011

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Wageningen, December 2011

Abstract
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The goal of this study is to inventorise and categorise the modeling expertise at IMARES in order to gain insight into the possibilities to use this expertise for studies of policy space use and planning options on the Dutch continental shelf, as well as to identify useful additions to this expertise. An inventory of expertise has been compiled to answer these questions. This has been analysed in a workshop with the relevant experts of IMARES and the commissioner. This document is a report of that workshop. The main conclusion is that the models available within IMARES do not cover the entire spectrum of necessary tools. In particular, for effects of activities which disturb the seafloor on the bottom fauna and the translation of those effects to the fish community, no tools are available. This is a reflection of the situation in Europe in general: this type of models is not available anywhere else. Currently, IMARES is working to develop such tools. Furthermore, there is a great need for a well-posed food web model for higher trophic levels. To provide such a tool, IMARES is currently working to develop the OSMOSE modeling framework for the North Sea.

Keywords: Ecosystem model, Marine strategy framework directive, North Sea, Spatial planning

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Preface

This work is an inventory of the current state of development of a number of modeling tools available at IMARES. This forms by definition a snapshot, because many of the models are constantly being developed. Hence, this report is already upon appearance somewhat outdated. Nevertheless, it provides valuable insight into the current state of affairs and the direction in which the modeling expertise at IMARES is developing.

Tobias van Kooten & Sander Glorius

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Summary

This study has the following research objectives:

1. Compile an inventory of expertise and models present at IMARES, which can be used for coupling the effects of human activities to the MSFD (Marine Strategy Framework Directive) indicators 'Biodiversity', 'Food webs', 'Commercial species' and 'Seafloor integrity'.
2. Assess the synergy, possible coupling and complementarity of models and identify knowledge gaps.
3. Suggest strategic investment in development of expertise and tools to fill the most urgent knowledge gaps found, with a time horizon of 1-3 years, which should provide a platform to study –on short notice- relevant options for policy- management- and space use on the Dutch Continental Shelf.

Based on the relationship between human activities and a set of EC-defined ecosystem pressures, and the assumed relationship between these pressures and the MSFD indicators, a ranking was compiled of which are the most urgent pressures for which we need quantitative tools. The top ranking pressure was abrasion, which is the disturbance of the seabed from commercial fishing, anchoring, etc.

A list was compiled of all relevant quantitative tools for which IMARES has in-house expertise. Each tool was categorized for its relevance to each of the four MSFD indicators. The indicator for which the most tools were available was commercial fish species. The fewest tools were available for the study of seafloor integrity. This is striking, as seafloor integrity is the indicator most strongly related to abrasion, the highest priority pressure. Exploration of ecosystem models used in the EU project MEECE (Modeling Ecosystem Evolution in a Changing Environment) indicates that this pattern is not unique for IMARES: there are very few ecosystem models in the EU research community which are able to deal with the effects of abrasion.

A workshop was held where these findings were presented. Furthermore, a number of new and relevant quantitative tools in various stages of development were presented. A main conclusion of the workshop was that no single model can be constructed which can be used for all possible future questions. A better approach would be to develop a toolbox of various models which can be coupled and decoupled dependent on the questions at hand. This report gives an outline of how the tools presented at the workshop can be coupled in various ways in order to obtain such a flexible toolbox to study scenarios related to the four MSFD indicators.

1 Introduction

Background

In recent decades, human use of het Dutch continental shelf has strongly increased both qualitatively (emergence of new types of use) and quantitatively (higher intensity of use). Traditional activities like fisheries and recreation are increasingly joined by new uses such as wind farms and large infrastructural projects such as the 2nd Maasvlakte and nature conservation (Natura 2000 areas). At the same time, the traditional activities such as shipping and exploitation of oil and gas have strongly increased. On the longer term, aquaculture and new forms of green energy (such as wave and tidal) are expected to claim more and more space. The effects of all these forms of human space use are strongly dependent on the policy which guides the development of this space use. Much of this policy is guided by the effects it has on certain aspects of the ecosystem, such as for example laid out in the descriptors of the Marine Strategy Framework Directive (MSFD) of the European Committee. While policy targets are set by using such indicators, management is applied to human uses of the ecosystem. Describing and understanding the relationships which shape how management of human activities results in a certain ecosystem state is very complex. Therefore, a model approach, which can describe the acting mechanisms in a formal mathematical way, is necessary. Such models are a requirement when insight is to be gained in the effects of certain policy-, management- an space use options on the policy indicators.

Project goal

Goal of this project is to compile an inventory and organize the quantitative expertise at IMARES, in order to set out guidelines for how to re-structure, consolidate and expand this knowledge and expertise, in order to develop a wide set of tools in order to study MSFD indicators as a function of human activities in the North Sea. This process aims at developing a strategic view of necessary investments in quantitative tools, shared among IMARES, the Netherlands Environmental Assessment Agency (PBL) and the WOT Natuur & Milieu unit (part of Wageningen UR), in particular with respect to studying questions put to IMARES by PBL.

Research questions

1. Compile an inventory of expertise and models present at IMARES, which can be used for coupling the effects of human activities to the MSFD indicators 'Biodiversity', 'Food webs', 'Commercial species' and 'Seafloor integrity'.
2. Assess the synergy, possible coupling and complementarity of models and identify knowledge gaps.
3. Suggest strategic investment in development of expertise and tools to fill the most urgent knowledge gaps found, with a time horizon of 1-3 years, which should provide a platform to study –on short notice- relevant options for policy- management- and space use on the Dutch Continental Shelf.

2 Materials and Methods

This project revolves around a workshop organized at IMARES with experts in a large number of relevant fields. The goal of the workshop was to discuss and formulate answers to research questions 2 and 3 as outlined in Chapter 1. The invitees and participants at the workshop were chosen on the basis of relevant expertise (Table 1). The workshop was held on the 22th of November 2010 at IMARES in Den Helder.

Table 1: Invitees and participants to the project workshop

Invitee name (replacement if relevant)	Expertise
Tobias van Kooten (chair)	Food web models
Adriaan Rijnsdorp	Fish ecology
Jan Jaap Poos	Fisheries dynamics and stock assessment
Mardik Leopold	Bird ecology
Meike Scheidat (present: Steve Geelhoed)	Marine mammal ecology
Sander Glorius (co-chair)	Food web models
Pepijn de Vries	Cumulative effect models
Floris Groenendijk	Department head 'Ecosystems'
GerJan Piet	Ecosystem models & indicators
Diana Slijkerman	Marine Strategy Framework Directive
Bert Brinkman	Lower trophic level models
Erik Meesters (present: Geert Aarts)	Statistical modelling
Oscar Bos	Calculation of 'nature values'
Lorna Teal	Energy budget and growth models
Rick Wortelboer	PBL representative, client
Marijke Vonk	PBL representative, client
Rogier Pouwels	WOT Natuur & Milieu representative

In preparation for the workshop, we conducted an analysis aimed at answering research question 1 above. The research question was split in two parts which were treated separately. One part was to analyse the four MSFD indicators which limit the scope of this study. Using the framework from Karman *et al.* (2008), we related human activities through pressures to specific MSFD indicators (Figure 1). This gives insight into which indicators are affected by which human activities and allows for a ranking of 'most disturbing' human activities and structured discussion.

The second part of answering research question 1 consists of compiling an inventory of the tools that IMARES has available. The resulting tools can then be classified in several ways. Here we have chosen to group them by relevance to the various MSFD indicators, the extent to which they are dynamic in time, and the extent to which they deal with spatial variations.

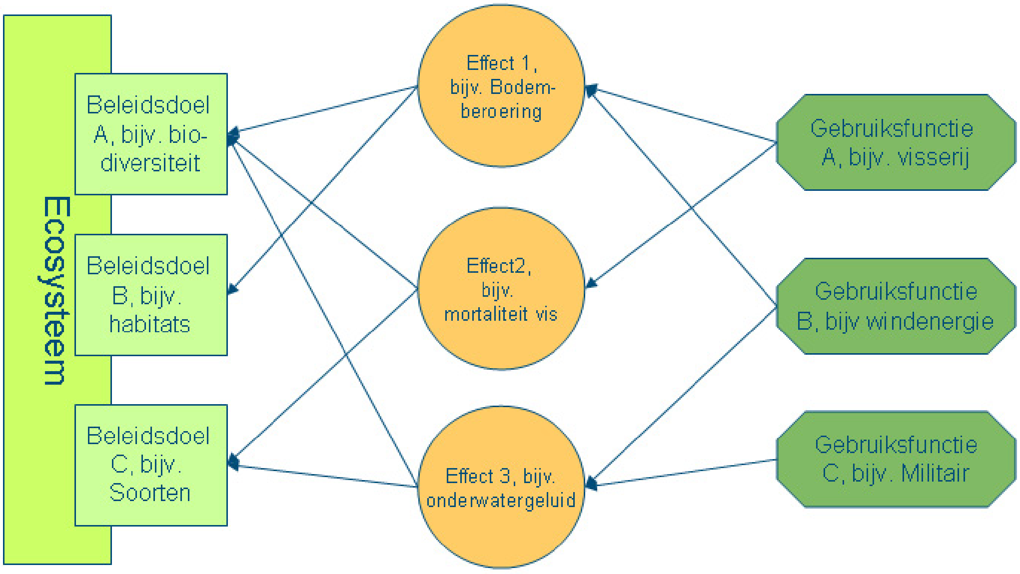

Figure 1: The framework used in Karman et al. (2008) to relate pressures (effects, middle column) to human activities (Gebruiksfunctie, right hand side) and ecosystem properties or indicators (left hand side). We use this scheme to organize and prioritize the existing and necessary research effort.

3 Results

3.1 Analysis of activities, pressures and indicators

In the documentation outlining the implementation of the MSFD, the European union has published a table with all pressures that should be considered for implementation of the MSFD (Table 2). As part of on-going work within IMARES regarding the implementation of the MSFD in Dutch Waters, a table has been constructed relating these pressures to human activities (Table 3).

Table 2: Pressures and impacts defined in the MSFD (EC, 2008).

Pressures and impacts	
Physical loss	— Smothering (e.g. by man-made structures, disposal of dredge spoil), — sealing (e.g. by permanent constructions).
Physical damage	— Changes in siltation (e.g. by outfalls, increased run-off, dredging/disposal of dredge spoil), — abrasion (e.g. impact on the seabed of commercial fishing, boating, anchoring), — selective extraction (e.g. exploration and exploitation of living and non-living resources on seabed and subsoil).
Other physical disturbance	— Underwater noise (e.g. from shipping, underwater acoustic equipment), — marine litter.
Interference with hydrological processes	— Significant changes in thermal regime (e.g. by outfalls from power stations), — significant changes in salinity regime (e.g. by constructions impeding water movements, water abstraction).
Contamination by hazardous substances	— Introduction of synthetic compounds (e.g. priority substances under Directive 2000/60/EC which are relevant for the marine environment such as pesticides, anti-foulants, pharmaceuticals, resulting, for example, from losses from diffuse sources, pollution by ships, atmospheric deposition and biologically active substances), — introduction of non-synthetic substances and compounds (e.g. heavy metals, hydrocarbons, resulting, for example, from pollution by ships and oil, gas and mineral exploration and exploitation, atmospheric deposition, riverine inputs), — introduction of radio-nuclides.
Systematic and/or intentional release of substances	— Introduction of other substances, whether solid, liquid or gas, in marine waters, resulting from their systematic and/or intentional release into the marine environment, as permitted in accordance with other Community legislation and/or international conventions.
Nutrient and organic matter enrichment	— Inputs of fertilisers and other nitrogen — and phosphorus-rich substances (e.g. from point and diffuse sources, including agriculture, aquaculture, atmospheric deposition), — inputs of organic matter (e.g. sewers, mariculture, riverine inputs).
Biological disturbance	— Introduction of microbial pathogens, — introduction of non-indigenous species and translocations, — selective extraction of species, including incidental non-target catches (e.g. by commercial and recreational fishing).

Table 3: Relations between pressures and human activities on the Dutch Continental Shelf. Arrows indicate direction of trends. Red cells are considered strong effects, orange are strong but localized in space, and yellow are considered less strong but still relevant (Source: Marine Strategy Framework Directive- Initial Assessment (Ilse de Mesel, Theo Prins, Martine van den Heuvel-Geve, Cor Schipper, Diana Slijkerman)).

Pressure	Physical loss		Physical damage			Other physical disturbance		Interference with hydrological processes		Contamination by hazardous substances			Nutrient and organic matter enrichment		Biological disturbance		
Activity	Smothering	Sealing	Changes in siltation	Abrasion	Selective extraction	Underwater noise	Marine litter.	Significant changes in thermal regime	Significant changes in salinity regime	Introduction of synthetic compounds	Introduction of non-synthetic substances and compounds	Introduction of radio-nuclides.	Inputs of fertilisers and other nitrogen- and phosphorus-rich substances	Inputs of organic matter	Introduction of microbial pathogens	Introduction of non-indigenous species and translocations	Selective extraction of species, incl. incidental non-target catches
Extraction of marine aggregates	↑		↑	↑	↑	↑					↑		↑	↑			↑
Dredging for navigational purposes	↑		↑	↑	↑	↑				↑	↑		↑	↑			↑
Dumping of wastes and other material	↓	↓	↓			↓				↓	↓	↓	↓	↓	↓	↓	
Exploration for oil and gas and placement of structures for the exploration of oil gas		→	→	→		→		→	→	→	→	→					
Placement and maintenance of cables and pipelines		↑		↑		↑		↑									
Maritime transportation				↑		↑	↑			↑	↑		↑		↑	↑	
Wind energy		↑↑		↑↑		↑↑										↑	
Land reclamation	→	→				→		→	→								
Coastal defence	→		→		→	→			→								
Maritime tourism				↑		↑	↑			↑	↑		↑	↑	↑	↑	
Marine commercial fisheries				↓		↓	↓			↓	↓						↓
Land-based emissions (river discharges, atmospheric deposition)						↓				↓	↓		↓		↓		
Military activities						→											
Overall change in pressure	→	↑	→	↓	→	↑	↑	→	→	↓	↓	→	↓	↓	↓	↑	↓

In order to be able to relate pressures to the MSFD indicators which are relevant for this report, we have compiled a table relating these two (Table 4). It must be noted that compiling this table is notoriously subjective. It is impossible to develop an objective criterion to determine exactly in what amount a pressure will affect an indicator. Most pressures can one way or another be hypothesized to have an effect on any of the indicators. The results in the table are used to obtain a starting point for a discussion on priorities and not as an objective end result.

Table 4: Relationships between pressures and relevant MSFD indicators

	Pressure	Physical loss		Physical damage			Other physical disturbance		Interference with hydrological processes		Contamination by hazardous substances			Nutrient and organic matter enrichment		Biological disturbance		
Indicator		Smothering	Sealing	Changes in siltation	Abrasion	Selective extraction	Underwater noise	Marine litter.	Significant changes in thermal regime	Significant changes in salinity regime	synthetic compounds	non-synthetic substances	Introduction of radio-nuclides.	nitrogen- and phosphorus-rich substances	Inputs of organic matter	Introduction of microbial pathogens	Introduction of non-indigenous species	Selective extraction of species
Biodiversity	Species	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x
	Habitat	x	x	x	x	x		x	x	x				x			x	
	Ecosystem		x	x	x	x			x	x	x	x	x	x			x	x
Commercial species	Fishing pressure				x	x							x					
	Reproductive capacity	x	x		x	x	x	x		x	x	x	x	x				x
	Age and size distribution				x	x												x
Food web	Productivity of key species/groups		x		x	x		x	x				x	x				x
	Fraction predators					x		x			x	x					x	x
	Presence/distribution of key species/groups	x	x	x	x	x	x		x	x	x	x	x	x		x	x	x
Seafloor integrity	physical damage to substrate	x	x	x	x	x												
	Condition of the benthic community	x	x	x	x	x				x			x	x	x	x	x	

In order to determine the number of human activities related to each pressure, we simplified Table 3, by counting for each pressure the number of human activities marked with a color, or with an upward arrow, indicating important links and increasing trends respectively. We counted the number of 'points' for each pressure. We conducted a similar count for the number of indicators each pressure relates to (Table 4). The result is a score for the prevalence of each pressure (related to activities) and the breadth of the effect in the ecosystem (related to indicators). We then compiled a combined 'urgency score' by multiplying the two criteria (Table 5). This way of combining the scores means that pressures which either relate to very few activities or pressures which affect very few indicators score low. Those with high scores are both caused by many activities and affect many indicators. The value of this analysis is limited to the scope of a discussion tool, because we simply count the number of interactions, assuming that they are all equally important. Nevertheless, this ranking gives an indication of which types of quantitative tools and models will be most in demand in the next few years. It is also a good starting point for a discussion on which are the most important items to focus on with regards to the development of modeling tools.

The resulting ranking indicates abrasion as the most important pressure to study, by far. Abrasion is the physical damage to the marine substrate which results from for example anchoring, laying pipes and cables, dredging, fishing, etc. The second most important pressure is inputs of fertilisers and other nitrogen- and phosphorus-rich substances. After that, differences in score become smaller.

Table 4: Ranked pressures by prevalence and breadth.

Pressure	Prevalence (A)	Breadth (B)	Rank (A*B)
Abrasion	8	10	80
Inputs of fertilisers and other nitrogen- and phosphorus-rich substances	6	7	42
Selective extraction	3	11	33
Sealing	4	8	32
Introduction of synthetic compounds	5	6	30
Introduction of non-synthetic substances and compounds	6	5	30
Changes in siltation	4	7	28
Smothering	4	6	24
Selective extraction of species, incl. incidental non-target catches	3	7	21
Underwater noise	10	2	20
Introduction of non-indigenous species and translocations	3	6	18
Marine litter.	3	4	12
Introduction of microbial pathogens	3	3	9
Inputs of organic matter	3	2	6
Significant changes in thermal regime	1	5	5
Significant changes in salinity regime	0	6	0
Introduction of radio-nuclides.	0	8	0

3.2 Inventory of current tools

A table with a short description of relevant modelling tools available at IMARES is provided in Annex 1. In total we have found 20 such tools. The tools in this set have been categorized in terms of their relevance for the four focus indicators of this study (Figure 2 and Annex 1). Clearly, tools to assess the dynamics of commercial fish species are well represented. IMARES is actively involved in, and has a lot of expertise in the quantitative assessment work which lies at the foundation of the quota advice which the International Council for the Exploration of the Seas (ICES) provides every year to the European Commission. Most of these tools are set up to determine the abundance and age distribution of fish one year in the future, given estimates of the state of the population in the past and the fisheries intensity. Hence, they are time dynamic in a strict sense, but only with a very short time horizon.

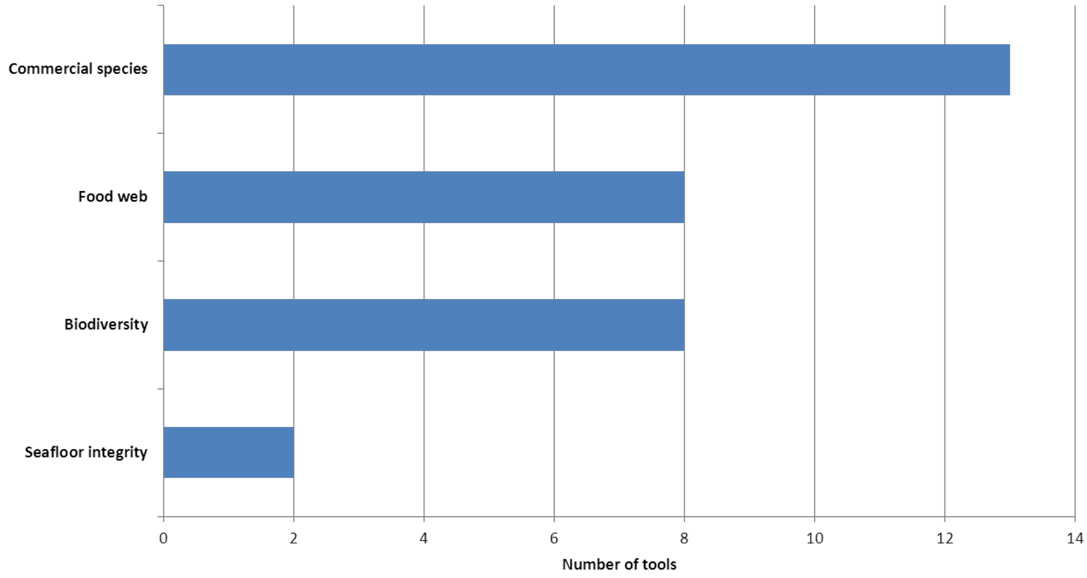

Figure 2: Number of tools available with relevance to the 4 MSFD indicators relevant to this project.

This limitation is solved for a special class of such models, which are used to evaluate the efficacy of multi-year management plans. Here, assumptions about the stock-recruitment relationship of the population are used to project the population dynamics further into the future. Generally, models developed for these purposes target the entire managed stock, and ignore any spatial variation within the stock and are hence deemed 'nonspatial' (Table 6).

Other models in this category are not built for stock assessments, but with strong applicability to commercial fish species. These include the EcoPath/EcoSim/EcoSpace model which IMARES has studied extensively in relation to effects of policy options on biodiversity in the North Sea (Van Kooten & Klok, 2011). Other examples are the empirically based model of plaice distribution in the North Sea, which was at the basis of the installment of the Plaice box closed area in 1989. The model was used again in an assessment of the plaice box in 2010 (Beare *et al.*, 2010). It uses catch records to calculate a relative distribution of plaice over the north sea, which are used to project total abundances in space. Another spatially explicit tool is that developed to calculate scope for growth for Plaice in the North sea, based on a sophisticated dynamic energy budget model and temperature and benthic productivity output from a lower trophic level model (ERSEM) (Teal *et al.*, 2010).

Table 5: Occurrence of non-spatial, spatially implicit or explicit models among the tools to address the four MSFD indicators.

	Nonspatial	Implicit	Explicit
Food web	5	1	2
Biodiversity	3	0	5
Commercial fish	9	2	4
Seafloor integrity	1	0	1

Of the assessed tools, eight target the indicator 'food web'. These are all models set up to explore the consequences of feeding interactions between two or more explicitly modeled species or functional groups. All these models are dynamic in time, but only three are spatial. The EcoSpace model replicates a non-spatial food web model over a number of ices quadrant-sized grid cells (Van Kooten & Klok, 2011). EcoWasp models the lower trophic levels of the Wadden Sea in detail, and features a variable grid cell size. The Plaice box model used to explore hypotheses about density- and temperature dependent offshore movement of young plaice (Beare *et al.*, 2010) models space implicitly, by assuming an offshore and an onshore population of plaice, with migration between the two.

Tools relevant to biodiversity are equally abundant. A tool was deemed relevant for biodiversity if it addresses more than two species, or, in the case of two or fewer species, it addresses a common indicator species. The majority of the tools for biodiversity are spatially explicit, while a few study changes in biodiversity for the North Sea as a whole.

Seafloor integrity is clearly an under-represented area in the current IMARES modeling inventory, especially since it comes out as the most important pressure listed in the MSFD. Only two tools exist which explicitly study it. Of these, one is spatially explicit (CUMULEO-RAM) while the other (North Sea Functional Benthos model) is presently in the initial stages of development.

The first tool is spatially explicit by design. Based on equilibrium conditions, it calculates the cumulative effect of disturbances on the potential for a species to maintain equilibrium state in a certain location. It relies heavily on spatial distributions of such disturbances. While seafloor integrity is one of the effects that can be studied, it was designed to relate changes in human use into effects on biodiversity. The second tool (The functional benthos food web model) is specifically set up to study the functional changes in the benthic food web, and how these changes are channeled up the food web. It hence combines the indicators seafloor integrity and food webs. It is currently non-spatial but a spatial model could be developed in the future, given funding. Both models hence relate strongly to multiple MSFD indicators.

More in general, the analysis conducted above can also be expanded to show how independent or intertwined the tools in the inventory are, with respect to the MSFD indicators. This is visualized in Figure 3. It shows that tools for commercial fish are very specific to that MSFD indicator, while those addressing food webs always cover a combination of indicators. Biodiversity and seafloor integrity are intermediate in this sense, although there are only 2 tools dealing with seafloor integrity.

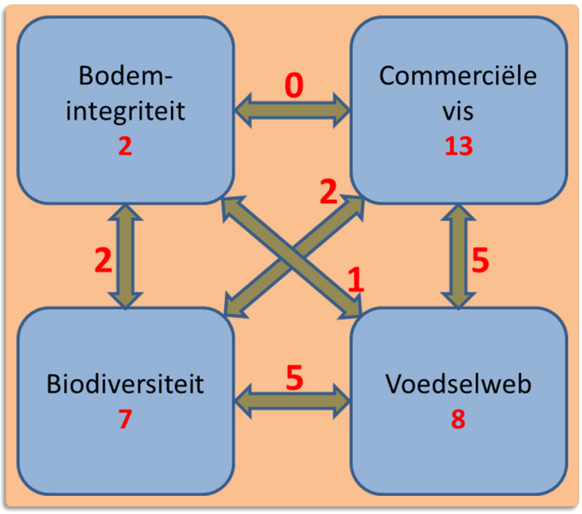

Figure 3: Visualization of connectivity between the MSFD indicators as expressed in the tools listed in Annex 1.

3.3 Report of workshop

The workshop on the 22th of November 2010 was attended by all people listed in Table 1. This report will follow the structure of the workshop, which was:

1. Introduction by *Rick Wortelboer* about the kind of questions which PBL sees appear in the near future.
2. Introduction by *Tobias van Kooten*, focusing on the above pre-workshop analysis for research questions 1 and 2.
3. Plenary discussion regarding research questions 1 and 2.
4. Presentations of four relevant tools developed or in development at IMARES, three of which IMARES sees as important in light of this project, and one of which reflects the background of the current project.
5. Discussion on what strategic investments are needed (research question 3).

Points 2 and 3 are discussed above, the other points will be described here.

Future questions of PBL (Ad 1)

Rick Wortelboer briefly presents the needs of PBL with respect to offer scenario studies of space use, policy and management options on the North Sea. Particularly urgent are tools that can deal with the effects of new spatial options such as wind farms and marine protected areas. Rick indicates that biodiversity is becoming a more and more important indicator for Dutch policies. Eutrophication is also highlighted as an important issue for the coming years.

Four relevant IMARES tools (Ad 4)

The presentations which correspond to these talks have been incorporated in Annex 2. Table 7 gives a summarized overview of the relation of each of the approaches to the four MSFD indicators.

Tobias van Kooten presented results of an exploration of the Mackinson Daskalov EcoPath/Sim/Space model which IMARES has conducted for PBL during the last two years. This model seemed promising, because it uses a food web approach, is spatially explicit, incorporates human activities in the form of fishing and can in principle also deal with eutrophication. The focus was to assess to which extent this model is suited for evaluating space use, policy and management scenarios on in particular the biodiversity of the North Sea. The main conclusions are that despite some issues and drawbacks, the model has potential in this respect. This is particularly true for the non-spatial ecosim model, less for the spatially explicit ecospace model, because the distribution of species is to a large extent not a result of the state of the system, but rather is imposed by the modeler. → Annex 2_Tobias_van_Kooten.

Pepijn de Vries presented developments of the CUMULEO-RAM model. This model starts purely from the human activities, not from ecology. In the model, the effects of different activities are expressed as effects on population reproductive capacity. This way, effects of very different nature can be added, to obtain a cumulative disturbance effect. A large advantage of this model is that it is conceptually very straightforward and that all assumptions are clearly tracked and described. It is also spatially explicit on a relatively fine scale (VMS grid). The model can be used to find areas with high and low disturbance and which activities are causing this. This can in turn be related to species distributions (comparison of model with other data). Used in this way, the model forms an excellent basis for scientific discussions. A detailed description of the model can be found in De Vries *et al.* (2012). → Annex 2_Pepijn_de_Vries.

Lorna Teal presented her work on 'scope for growth models', which couple a dynamic energy budget model to productivity and temperature output from sophisticated lower trophic level models. She has developed an application for plaice, using output from the ERSEM model developed at the NIOZ. The model shows how the scope for differently sized plaice changes throughout the year, and indicates that growth optimization may drive the offshore migration of young plaice as it grows. Coupling model to plaice abundance data, she also showed that areas predicted to be favourable indeed harbour high densities of plaice. This model can be parameterized for other species, given that enough literature data exists for the individual-level model. This is most likely the case for well-studied commercial fish species, but dynamic energy budget models are also being developed for several shellfish. → (Annex 2_Lorna_Teal

Adriaan Rijnsdorp described the recently started development of a functional model of the North Sea benthic food web. The model is firmly rooted in established ecological theory, especially size-structured modeling and food web theory. The benthic community is highly speciose. Modeling each species separately is unpractical and leads to highly complicated models. To prevent this, a functional group approach is chosen, where species are grouped according to several 'guilds'. These are: filter feeders, subsurface deposit feeders and surface deposit feeders/scavengers. The effect of different fishing gears can be modeled as direct mortality, but also in terms of extra energetic costs which species must spend due to disturbance of built structures (sand tunnels, etc.). A first start is made with modeling. An inventory of knowledge concerning the benthic food web is being compiled. A challenge for the future will be to couple this model to the benthic fish community and eventually the pelagic food web. Tools to exist for such work (Andersen & Pedersen 2009, Blanchard *et al.*, 2009). Another intended future extension is to develop a spatially explicit model. → Annex 2_Adriaan_Rijnsdorp.

Table 6: Summary of relevance of the 4 presented approaches to the 4 MSFD indicators

	Biodiversity	**Food webs**	**Commercial species**	**Seafloor integrity**
Ecopath/sim/space	many species (68 functional groups of which many are individual species)	Very complete in terms of species and interactions, but heavily simplified description of interactions between them	Many of the commercially important fish species are included	-
CUMULEO-RAM	Few species	-	Currently commercially harvested shellfish, but can be extended to fish	Currently not included, but can be.
Plaice model	Only when applied to specific indicator species	-	one species, but can be extended to others	-
Benthic food web	Benthic functional groups	Food web indicators an be studied on a functional level, not on species level	-	Effect of trawling on benthic invertebrates, abundance of long-lived and structure forming biota

Discussion (Ad 5)

Here follows a bulleted list of issues which were brought up in the discussion:

- One important issue which repeatedly came up during the discussion was that questions asked to scientists by policy makers are changing all the time. This means that modeling tools used to study such questions need to be versatile enough to be able to deal with a wide range of questions. On the other hand, we should be careful not to develop tools which can do everything, but nothing very well. We referred to this as the 'swiss army knife metaphor'. We would rather have a toolbox with a few strategically chosen well-developed tools than a swiss army knife with myriad functions but all in an inconvenient miniaturized form.

- One particularly relevant international project which is ongoing at the moment is MEECE, the goal of which is to develop modeling tools for policymakers and managers, based on an ecosystem approach to marine management. IMARES is an important partner in MEECE. Below is a summary of how we think MEECE can cross-fertilize model developments within IMARES.
- Within PBL, not all human activities are considered equally important. The most important are considered to be fisheries, wind farms, eutrophication and marine protected areas (such as Natura 2000 areas). Wind farms can in principle be considered a special case of a marine protected area, unless fishing becomes allowed with in them.
- There is wide consensus in the group that beam trawl fisheries has very strong effects on the benthic ecosystem, and that this system is a crucial compartment in the North Sea food web. It also is highly speciose, so that such disturbances have potentially large consequences for biodiversity. Many indicator species such as birds are dependent on benthic productivity.
- The spatial component is important for all human activities. For explorations of space use and spatial management of the North Sea, incorporating space in models is indispensable.
- There is discussion about whether or not the DCS is the appropriate spatial scale to conduct such exploratory calculations. It is obviously not a closed system and is in fact based on an arbitrary boundary in an ecological context. On the contrary, there are certain unique aspects to the DCS. The sandy bottom and the intensive use by the beam trawl fishery makes it a part of the North Sea Ecosystem with fairly unique aspects and drivers.
- There is a general feeling in the group that 'models of everything', of which the presented EcoPath/Sim/Space model is an example, are not the way forward. Such models can perhaps be compared to the 'swiss army knife': can do everything a little bit, though nothing very well. The general consensus is that we need a set of tools, which among them can address all relevant questions regarding spatial planning scenarios.
- The models are not expected to give actual predictions of 'the truth'. The approach with scenario studies is generally to define caricature 'extremes' and discuss the effects of those in relation to more realistic policy options. For specific policy or management related questions, the tools are expected to indicate the general response of the ecosystem and the indicators, not the exact outcome.

3.4 Possible cross-fertilization with MEECE

From the MEECE (Marine Ecosystem Evolution in a Changing Environment) project website:

> *"MEECE is a European FP7 Integrated Project which aims to increase ecosystem modelling predictive capacities. Both natural and human-induced climate pressures have an impact on the structure and function of marine ecosystems. Using a combination of data synthesis, numerical simulation and targeted experiments MEECE intends to boost our knowledge and develop the predictive capabilities needed to learn about the response of marine ecosystems.*
> *MEECE will also develop methods to integrate the dynamic response of marine ecosystems to the combined effects of various anthropogenic and natural drivers in order to provide decision making tools to support the EC Marine Strategy, EC Maritime Policy and the EC Common Fisheries Policy."*

An important part of MEECE is to develop a library of (partial) ecosystem models and develop a system where they can all be coupled to one another. On the MEECE website (www.meece.eu) is a library of models, where one can select models incorporated into the MEECE project on the basis of their relevance to the different MSFD indicators.

A quick scan of the tools for the four indicators which are the focus of this study, limited to the North Sea area.

Biodiversity
Lower trophic level models: ECOSMO, ERSEM, POLCOMS-ERSEM.
Higher trophic levels: SMS, Ecopath with Ecosim (EwE).

A relatively large number of tools is present to study this indicator, both lower and higher trophic levels. This is however the EwE model which IMARES has recently assessed in relation to exactly this indicator, and for which a number of problems have been indicated which limit its potential. SMS is a stock assessment model which uses empirical correlations between species abundance to relate their dynamics. To our knowledge, it is non-spatial. The lower trophic level models indicated here are generally considered well-developed and represent the state of the art in the field.

Commercial fish
Lower trophic level models: none.
Higher trophic levels: Size-structured fish community model (developed at IMARES/DTU Aqua), EwE.

Commercial fish do not belong to the lower trophic levels, and hence it is no surprise that this model category is empty. The size-structured fish community model is originally developed at DTU (Andersen & Pedersen 2009), and is operational at IMARES. It models a number of size-structured species and a 'rest community', which feed on a size-structured food source of which they themselves are also part. It follows the size-spectrum approach (Andersen & Beyer 2006). The EwE model is again the Mackinson-Daskalov North Sea model described above.

Food web
Lower trophic level models: NORWECOM, POLCOMS-ERSEM.
Higher trophic levels: Size-structured fish community model (developed at IMARES/DTU Aqua), EwE.

The first lower trophic level model was developed specifically for the Norwegian coast, but we cannot oversee whether this limits its applicability for modeling the north sea. The other models are discussed above.

Seafloor integrity
Lower trophic level models: ECOSMO (only with regard to 'physical damage').
Higher trophic levels: none.

It is striking that there pattern we find within IMARES so obviously holds on an EU wide scale as well. ECOSMO only assesses the physical damage done to the seafloor in terms of its effects on the biogeochemistry of the seafloor. There are no ecosystem models to explicitly study the North Sea Benthic community.

Another tool which we see as promising is OSMOSE. A java-based modeling framework which is in essence a spatial extension of a size-structured fish community model. This has been developed at IRD in France for the African Benguela Upwelling. There is an ongoing effort to couple this model with state of the art lower trophic level models within MEECE, and to parameterize it for the North Sea. At this time it is unclear to what extent these developments are going to succeed (due to people changing career). IMARES is currently considering to take over the development of this application.

4 Towards a consistent toolbox

4.1 IMARES vision on future development

It is a generally shared opinion that developing one model for all indicators and pressures is not the most productive way forward. Experience with the Mackinson-Daskalov EcoSpace model of the North Sea (Van Kooten & Klok, 2011) strengthens us in this view. It would be more productive to have a toolbox available of models of different parts of the ecosystem. The toolbox should be suitable for the study of specific MSFD indicators separately, but should have enough overlap among them so that they can be coupled as needed, depending on the question. In order to obtain this flexibility, for the three of the presented modeling approaches, this means *in concreto* that:

1. The concept of 'replacement value' which is used in the CUMULEO-RAM model should be extended, so that it can (a) deal with habitat improvement as well as deterioration and (b) the habitat quality change criterion can be applied as a modifier to the ecological carrying capacity or productivity. With this extension, the model can be used in conjunction with for example the scope for growth model (or Osmose, see below), to modify the spatial availability of benthic productivity as a consequence of (changes in) human use. This would lead to a tool which can be used in relation to the MSFD indicators **biodiversity**, **seafloor integrity** and **commercial fish species**. Future development of the CUMULEO-RAM model should aim at adding more species that relate to biodiversity values (such as Habitat and bird directive species) and commercial species.
2. The functional benthos model needs to be able to take as a first step benthic productivity input from sophisticated lower trophic level models, and translate this into food available for higher trophic levels (fish, birds). As a second step it should also be able to incorporate temperature effects. It is important that this model can function as a 'filter' between the lower trophic level models and the scope for growth model. The incorporation of a size-structured food source for the scope for growth models would significantly increase their quality and their ability to capture the effects of bottom disturbance. This will lead to a tool for the MSFD indicators **seafloor integrity** and **food web**.
3. The scope for growth model should be developed for other species, particularly flatfish, so that it can be used as a spatial management tool for mixed fisheries. Another useful extension would be to parameterize it for potential indicator species like rays and sharks, for which it is impossible to determine spatial distributions on the basis of observational data (surveys). This way, it can be developed into a tool for the study of the MSFD indicators **commercial fish species**, **food web** and **biodiversity.**

What is missing in the above is a tool which combines the possibility to study more explicitly the effects of fisheries management on the food web. Such a tool is indispensable for scenario studies where the aim is to study the ecosystem effect of fisheries management decisions. To address this issue, we are currently investigating the possibility of developing this within the Osmose framework (http://www.meece.eu/library/osmose.html) for a selection of North Sea species. This would also mean we have to extend the Osmose framework and include dynamic notion of fishing fleets. Imares has considerable experience in modelling fleet dynamics in space and time (Poos, 2010)

4.2 Planned and ongoing further development

The current developments with regards to the above models is as follows:

1. The functional benthos model is in a development stage. A first step has been made within the project 'appropriate assessment beam trawl'. We are currently employing a PhD student who will

develop the tool further. The student is expected to start within the next few months. Models which can be used to study the general effects of selected human activities on the structure and function of the benthic ecosystem are expected to be operational within 2 years.

2. The work conducted on developing a prototype CUMULEO-RAM model is currently prepared for submission in a peer-reviewed journal. Other developments will be carried out as funding becomes available, which will also determine the direction of further research.
3. The scope for growth model is complete for plaice and is currently being implemented for sole. When that is complete, MEECE funds will be used to extend the tool for exploration of spatiotemporal area closures for certain types of fisheries. MEECE runs until the end of 2012.
4. We are currently exploring the possibility to develop an Osmose application for the North Sea. This is very preliminary. Some funds are available within MEECE and other EU- projects. As a first step, we will most likely focus on a ‘proof of principle’ application with only a few species represented. Such a simple application is scheduled to be operational in late 2011.

5 Conclusions

The inventory reflects clearly that fish stock assessments are a core business for IMARES. Sea floor integrity is clearly underrepresented at IMARES but even on a European level there are not many tools available. Tools to address 'food webs' and ' commercial fish' are predominantly non-spatial.

The general opinion among participants of the workshop is that large models which attempt to be comprehensive, of which the Mackinson Daskalov EwE North Sea model is an example, are not the most suitable option given the applications we are looking for. These models can be used for explaining the current and past state of an ecosystem,, are less suitable for exploring the effects of possible future scenarios (Van Kooten & Klok, 2011).

It would be desirable to have a suite of models of varying complexity. That way, scenarios can be explored in different degrees of detail. This would give insight into the robustness of effects (if a result occurs in all models, it could be classified as robust), and give an idea of which aspects of the effects relate to which types of model complexity (spatial, temporal, functional, etc.).

All three new models presented at the workshop (CUMULEO-RAM, Functional benthos model and scope for growth model) fit into this multi-model concept. The second and third models can be coupled with relative ease. This would allow the use of a sophisticated lower trophic level model such as ERSEM, coupled to a spatially explicit functional benthos model, coupled to a fish growth model. Such a coupled set of models would relate to all four MSFD indicators focused on in this study. ERSEM is well-suited to deal with eutrophication questions. The effect of bottom integrity and disturbance can be studied using the benthic model, while the potential production of commercial fish can be computed from the scope for growth model. An important missing effect here is the feedback from fish feeding on the benthos dynamics. One promising framework to develop a model for fish grazing on the bottom would be an implementation of OSMOSE, focused on modeling of a selection of fish species based on their biomass abundance, commercial importance and value for conservation. The possibility to develop this last layer is currently investigated at IMARES. This would then offer a framework to study biodiversity effects of scenarios on all levels of the ecosystem (ERSEM: phyto/zooplankton – benthic model: benthic invertebrates – Osmose: fish). The general lack of good tools to study the ecological effects of seafloor integrity is striking. We see this as a clear opportunity for IMARES, and aim to hire a PhD student to work specifically on this topic.

It would also be worthwhile to parameterize scope for growth models for more species, including shellfish species for which DEB models are available. A brief analysis of the ecosystem modeling tools available on a European scale shows that models which address the effects of bottom disturbance on the functioning of the benthic community (a sub-indicator of the MSFD indicator 'seafloor integrity') are practically non-existent. It is important that the such a model is spatially explicit. A frequently heard argument against explicit treatment of space is that animals are highly mobile. This may be the case for fish, but the bulk of benthic invertebrate organisms are immobile on the spatial scale relevant to marine spatial planning scenarios.

An advantage of the CUMULEO-RAM model is its simplicity and transparency and has potential as a discussion support tool in its current form. It is specifically developed for assessing the effects of increasing human activities. A current limitation is that studying the effect of decreasing human activities requires rethinking of the exact calculations used to compute the replacement value. The model can be coupled to a habitat suitability model, so that a spatially explicit integrated assessment of innate suitability and human disturbance can be calculated. This habitat suitability model could take the form of the scope for growth model for certain species, but other formulations are also possible. There is also the potential to couple the framework to a population dynamical model for some species. The most important and urgent work with this model is to incorporate more species.

With the development of the tools outlined above and in Chapter 4, IMARES will have a toolbox suitable for studying the relevant MSFD indicators, and which also cover the areas which PBL considers most urgent: fisheries, wind farms, eutrophication and marine protected areas.

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Annex 1 Tools used in inventory and categorization

Name	Description	Contact person	Time dynamic	Spatial (n=no, e=explicit, i=implicit)	Food webs	biodiversity	Commercial species	Seafloor integrity
Single species assessment models	Models such as used for determining fishery quota. Different varieties exist for different species.	Doug Beare, Jan Jaap Poos, Niels Hintzen	Y	n			x	
spatial distribution model zeehonden	Statistical model for spatial distribution of seals in the Wadden sea and North Sea	Geert Aarts, Erik Meesters	N	e		x		
vogelwaardenkaart plus	Spatial valuation on the basis of 'nature value'	Oscar Bos, Mardik Leopold	N	e		x		
Prototype model cumulatieve effecten	CUMULEO-RAM: Calculate cumulative effects of human activities and disturbance on suitability of the spatial domain as a habitat for specific species in the Waddensea and North Sea coastal area.	Pepijn de Vries	N	e		x		X
Scholbox Spatial	Empirically based spatial model for plaice	Adriaan Rijnsdorp	Y	e			x	
Aal groeimodel	Growth model for eel geared towards fisheries management	Stijn Bierman/Willem Dekker	Y	n			x	
Management strategy evaluation	Assessment models projected on longer time scales with multi-year management plans.	David Miller	Y	n			x	
Ecopath with Ecosim/Ecospace	end-to-end model based on mass balance, feeding interactions and local migration	Tobias van Kooten	Y	e	x	x	x	
Ecowasp	Chemically oriented model of the flows of energy in the lower trophic levels of het Wadden sea.	Bert Brinkman	Y	e	x	x		

Name	Description	Contact person	Time dynamic	Spatial (n=no, e=explicit, i=implicit)	Food webs	biodiversity	Commercial species	Seafloor integrity
Forage Fish model	Size-dependent competition between small and large species of small pelagic fish	Tim Schellekens	Y	n	x		x	
Haring/Kabeljauw model	Stage based biomass model for the interaction betwen cod and herring.	Daniel van Denderen/Tobias van Kooten	Y	n	x		x	
Mecosm model	Simple model of zoo- and phytoplankton in saltwater mesocysms for evaluation of toxicants on the food web.	Sander Glorius/Tobias van Kooten	Y	n	x	x		
North Sea Functional Benthic model	Functional food web model for benthos	Adriaan Rijnsdorp/Tobias van Kooten	Y	n	x	x		x
Scholbox stage-based biomass model	Stage-based model of plaice with temperature- and food-dependent growth.	Tobias van Kooten	Y	i	x		x	
Size spectrum model North sea	Size spectrum model with implicit species defined in the spectrum.	Niels Hintzen/Ralf van Hal	Y	n	x	x	x	
Tong pspm	Size structured population model of sole based on dynamic energy budget model.	Tobias van Kooten	Y	n			x	
Haring pspm	Size structured population model of herring based on dynamic energy budget model.	Niels Hintzen/Tobias van Kooten	Y	n			x	
ERSEM-DEB	Dynamic energy budget model of plaice built to translate ERSEM output into spatiotemporal patterns of growth potential for plaice.	Lorna Teal	Y	e			x	
Fishery dynamics models	Models for the interaction between the behavior of fishermen, policy and the abundance and distribution of fish.	Jan Jaap Poos/Jurgen Batsleer	Y	n/i/e			x	
Ensis-deb	Dynamic energy budget model for growth of *Ensis*	Jeroen Wijsman	Y	n				

Annex 2 Presentations of selected modeling approaches

In order to keep file sizes manageable, the four presentations are appended (downloadable) as separate files. The presentations are as follows:

Annex 2 Beleidsverkenning met het Mackinson-Daskalov Noordzee Ecospace model
(http://content.alterra.wur.nl/Webdocs/WOT/Overig/Annex2_A.pdf)

Annex 2 Activity impact to marine biodiversity. A proto-type model
(http://content.alterra.wur.nl/Webdocs/WOT/Overig/Annex2_B.pdf)

Annex 2 Scope for growth models: Case study: North sea plaice
(http://content.alterra.wur.nl/Webdocs/WOT/Overig/Annex2_C.pdf)

Annex 2 Quantifying human impact on benthic structure and functioning
(http://content.alterra.wur.nl/Webdocs/WOT/Overig/Annex2_D.pdf)

Verschenen documenten in de reeks Werkdocumenten van de Wettelijke Onderzoekstaken Natuur & Milieu vanaf 2009

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