285

Scaling human-induced pressures to population level impacts in the marine environment

Implementation of the prototype CUMULEO-RAM model

P. de Vries, J.E. Tamis, J.T. Tjalling van der Wal, R.G. Jak,
D.M.E. Slijkerman & J.H.M. Schobben

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Scaling human-induced pressures to population level impacts in the marine environment

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Abstract
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This document describes the implementation of a prototype of the CUMULEO-RAM model in a case study of the Wadden Sea and the Dutch North Sea coastal zone. The prototype is designed to quantify pressures of human activities in the marine environment and translate those pressures to (potential) effects on ecosystem indicators. The prototype was developed for the Netherlands Environmental Assessment Agency (PBL) in order to assess its potential use in strategic management decisions. The implemented prototype scales impacts from human activities to population relevant indicators, although actual population size and distribution are not determined. Focus for future work should be on expansion of the list of included human activities and pressures and not so much to attempt to incorporate population dynamics. The strength of the approach is in the transparency, it can be relatively easily understood. It combines spatial data to get insight in effects on survival and reproduction. The simplicity makes adjustments and extensions uncomplicated. The visual aspects combined with the speed of the calculations makes it a powerful tool to support discussions with experts, and it can guide or focus future research.

Key words: Wadden Sea, North Sea coastal zone, Cumulative Effect Assessment (CEA), modelling strategy

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Preface

Acknowledgement
The work presented in this document is largely based on work performed earlier in the nineties for the Rijksinstituut voor Kust en Zee (RIKZ). Many of the staff that was involved on the presented work back then, are currently employed elsewhere or currently working on other projects. Although they are currently not involved as authors, they are acknowledged for their contribution to the work presented here. In alphabetical order we thank: J.G. Harthold, N.H.B.M. Kaag, C.C. Karman, H.P.M. Schobben and M.C.Th. Scholten.

Reading guide
The actual assessment of the Wadden Sea and the Dutch North Sea coastal zone at itself was not a goal of the present study and are therefore not the major results of the project. The structure of the text also reflects this point of view. The general framework for Cumulative Effect Assessment (CEA) is therefore described in the Methods section. Whereas the specific implementation of the prototype model (CUMULEO-RAM), based on the generic CEA framework, is presented in the Results section. Discussion and conclusions will focus on the strengths and limitations of the implemented CEA approach and to lesser extent the results of the assessment. Therefore, no conclusions will be or should be made based on the assessment itself. This report will end with recommendations for improving the presented implementation.

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Contents

Summary

Background and goals
Until recently, Dutch coastal waters and the North Sea were primarily used for fisheries and transportation; the last 20 years the number of user functions have increased strongly. Human uses (such as wind farms, mineral extraction, coastal defences and fisheries) will lead to a decrease of biodiversity and also a reduction of (ecosystem) resources. Driven by several European policies and conventions, member states must come to a sustainable management of the marine environment, which in turn is in need of a careful spatial management at sea, to avoid conflicts between nature and economic use.

In the 'WOT Werkplan 2010' (WOT Plan of Work 2010), the Netherlands Environmental Assessment Agency (PBL) has expressed a need for a simple and robust model to evaluate effects of fisheries, eutrophication, wind farms, protected areas and sand extraction on the most important ecological indicators. This should provide a reliable source of information to base upon strategic management decisions regarding social activities that affect marine biodiversity. To this end an implementation of Ecopath with Ecosim (EwE, www.ecopath.org) (Mackinson & Daskalov 2007), was investigated for their applicability. The limits for the use of the EwE implementation appear to have been reached in the current perspective (Van Kooten & Klok 2011).

Rather than constructing a complex model in an attempt to support all potential strategic management decisions, a generic methodology framework which can be used to quantify cumulated effects of human activities is described in this document. The major goals are:
- Development of a prototype of a spatial model to analyse cumulated effects of human activities on a selection of indicators in a case study.
- Describing the options for future developments of the implemented prototype.

Generic framework
A generic framework for Cumulative Effect Assessment (CEA) is followed. It assumes that effects are a function of the intensity of pressures resulting from human activities and the sensitivity of ecosystem components to those pressures. Each activity can cause several types of pressure: for example: trawl fishery causes both abrasion and visual disturbance. Each pressure in turn can affect multiple but not necessarily all ecosystem components: for instance visual disturbance will affect birds, but will not affect cockles. A stepwise approach, adapted from (Van der Walt 2005, Therivel & Ross 2007), is used for the CEA:
1. Scoping phase,
    a. Define spatial and temporal boundaries;
    b. Identify ecosystem components, pressures and human activities.
2. Assessment phase,
    a. Describe intensity of activities;
    b. Assess intensity of pressures;
    c. Describe sensitivity of ecosystem components;
    d. Assess cumulated effects.

Prototype CUMELEO-RAM model
The generic framework above is implemented as the prototype CUMULEO-RAM model. Where CUMULEO is the name assigned to the collection of cumulative (of either effects, pressures or effects) tools within IMARES. The RAM methodology that is presented here stems from work

done in the nineties of the previous century (Karman & Schobben 1995, Schobben *et al.* 1996, Jak *et al.* 2000, Karman *et al.* 2001). RAM stands for Risk Assessment for the Marine environment.

In the scoping phase it was decided to use work from a 'Nadere Effect Analyse' (NEA) project (Jongbloed et al. 2011a) as a basis. For this project pressures where quantified for a selection of human activities in the Dutch North Sea coastal zone and the Dutch Wadden Sea. The pressures were spatially explicit and are managed in a Geographical Information System (GIS). In the present study, we use the same list of 26 activities but limited the pressures to only abrasion and visual disturbance. Ecosystem components were limited to seven species: the oystercatcher, common eider, heart urchin, Baltic tellin, common mussel, common cockle. These limitations were based on the data that was readily available, but also the budget and time available within the present study. The GIS pressure maps where derived for two half years (summer and winter) in order to reflect the seasonal variation in the pressures. The spatial resolution used in the present study is 1 min. latitude by 2 min. longitude (approximately 1 by 1 nm at the latitude of the Netherlands), which originates from the Vessel Monitoring System (VMS).

After the scoping phase, the pressures need to be quantified from the list of activities. Annex 1 contains an overview of all data and assumptions used to derive a GIS pressure map for abrasion and visual disturbance. The abrasion is expressed for each grid cell on the map as the number of times the total seabed area within the grid cell is disturbed by each activity. The visual disturbance is expressed as the total number of hours the disturbing object (boat, people or offshore construction) is present within the grid cell.

Effect maps
In order to translate the pressure maps into effect maps, disturbance effect relationships are defined in order to quantify the effect on both survival and reproduction as a function of the pressure intensity. Abrasion is assumed only to affect mortality, and the disturbance effect relationship needs to be parameterized for each combination of activity and species, where the parameters describe the sensitivity of each species for a specific activity. Visual disturbance is assumed to affect reproduction, where the effect on reproduction is assumed to be linearly related to the fraction of space and time that is not available to a species (as a result from the disturbance). This can be calculated from the pressure (speed of the object and the number of hours present within a grid cell) and the critical reaction distance and specific recovery time of the species (Table 5).

The effects on survival and reproduction are combined into a single indicative population measure called the net reproductive rate (from here on referred to as reproductive rate). The reproductive rate is defined as "the number of adult individuals that are expected to be produced by a just matured juvenile during its entire adult life stage" (Schobben *et al.* 1996). It can be seen as an indicator for population growth: if the reproductive rate is less than 1 the population is expected to decline, whereas it is expected to growth if it is larger than 1. For all species the reproductive rate is scaled to 1 in the undisturbed situation (the situation without human activities). Effects of population density and migration are not included, assessment of actual population development is therefore not possible with the proposed methodology.

Reproductive rate maps
Using the methodology described above, the pressure maps can be translated into reproductive rate maps. These maps give information on potential population effects, but at the moment the tool doesn't include information on habitat suitability. In other words, if the map shows a low reproductive rate (near zero), this means that there is a potential population

effect. However, if that specific location is by nature not suitable to support the species, there is no actual effect of the pressures.

When translation to actual population effects is necessary the spatial resolution used here might not be suitable as (bird) populations are generally larger than one grid cell. Note that no interaction between grid cells is currently implemented. Also the distinction between summer and winter half years might need to be refined, depending on the type of strategic management decision required.

Some processes are simplified in the implemented prototype. Important simplifications to keep in mind are: the assumption of linear relation between reproductive effect and disturbed fraction of time and space; populations are assumed to be stable in undisturbed situations (in other words the reproductive rate equals 1 in the situation without human activities); cumulation of effects from different pressures is done by assuming that the effect of each pressure is an independent chance; the generic life-cycle defined for calculation of the reproductive rate is not suitable to describe all types of organisms (such as plants).

Conclusions and recommendations

It is concluded that the implemented prototype CUMULEO-RAM model is a tool to scale impacts from activities to population relevant indicators, although actual population size and distribution cannot be determined with the prototype. Focus for future work should therefore be expansion of the human activities and pressures and not so much to attempt to incorporate population dynamics. The latter should be modelled separately when more detailed answers are necessary.

The strength of the presented approach lies in the transparency of the methodology, assumptions and parameterisation. Therefore, it is an approach that can be relatively easily understood. It combines spatial data to get insight in effects on survival and reproduction. It's simplicity makes adjustments and extensions uncomplicated. It's visual aspects combined with the speed of the calculations makes it a powerful tool to support discussions with experts: does the model produce results experts would anticipate? As a result the approach is also useful to guide or focus future research. Future work should also focus on aggregation of the results into a single, easy to interpret, indicator.

The implemented prototype currently assesses potential population effects. The methodology would become much more powerful if it is combined with habitat suitability maps: actual effects can only occur if pressures are located in suitable habitats. For birds, distinction between resting, reproduction and forage habitat should be made. It is therefore recommended to work on the combination of reproductive rate maps with habitat suitability maps.

Obviously, linking the prototype with Marine Strategy Framework Directive descriptors is also a desirable future improvement. In addition, further study should also focus on alternatives for the reproductive rate and testing of the model. This could include a sensitivity and/or uncertainty analysis. The tools should also be extended with more human activities, pressures and species (ecosystem components). The transparency of the model can also be improved by setting up a database with all parameters linked to their source.

1 Introduction

1.1 Background

Until recently, Dutch coastal waters and the North Sea were primarily used for fisheries; the last 20 years, the number of user functions have increased strongly. Human uses (such as wind farms, mineral extraction, coastal defences and fisheries) will lead to a decrease of biodiversity and also a reduction of (ecosystem) resources. Driven by several European policies and conventions, member states must come to a sustainable management of the marine environment, which in turn is in need of a careful spatial management at sea, to avoid conflicts between nature and economic use.

Spatial management at sea should be facilitated by common approaches and tools. The common fisheries policy promoted the ecosystem based approach in earlier days already for fisheries, and the latest European policy (Marine Strategy Framework Directive, MSFD) applies the ecosystem based approach at a broader maritime level. The ecosystem-based approach to the management of all human activities, ensures that the collective pressure of such activities is kept within levels compatible with the achievement of good environmental status and that the capacity of marine ecosystems to respond to human-induced changes is not compromised (EC 2008). This should enable the sustainable use of marine goods and services by present and future generations. Currently, the MSFD is being implemented by the Dutch government.

In order to manage activities to a sustainable level, knowledge on the relation between the impact of activities and the marine environment is crucial. In this respect, an important but often difficult aspect is to assess the contribution of each of the activities to cumulated effects on the ecosystem.

Despite all efforts to publish guidance documents on cumulative effects assessment, a common understanding of cumulative effects assessment (CEA) is still lacking (Karman & Jongbloed 2008), hampering the development of a transparent and widely (globally) accepted approach. In the meantime, environmental impact assessments of projects or plans often attempt to address the issue of cumulative effects but mainly at a highly qualitative level and incomparable to other environmental impact assessments. A (rather comparable) suite of methods and tools that can be used for CEA fall into two groups:

- Scoping and impact identification: methods to assist in the identification of how and where a cumulative effect would occur.
- Evaluation: methods to quantify and predict the magnitude and significance of effects, based on their context and intensity.

In the 'WOT Werkplan 2010' (WOT Plan of Work 2010), the Netherlands Environmental Assessment Agency (PBL) has expressed a need for a simple and robust model to evaluate effects of fisheries, eutrophication, wind farms, spatial reservation and sand extraction on the most important ecological indicators. This should provide a reliable source of information to base upon strategic management decisions regarding social activities that affect marine biodiversity. To this end an implementation of Ecopath with Ecosim (EwE, www.ecopath.org) (Mackinson & Daskalov 2007), was investigated for their applicability. The limits for the use of the EwE implementation appear to be reached in this perspective (Van Kooten & Klok 2011).

1.2 Project goals

In the search of *the* model to answer all questions stated (or related to those mentioned) above, the re-emerging question is whether a single model for this purpose is desirable or even possible. This is nicely illustrated in the novel “Hitchhikers Guide to the Galaxy”, where a group of hyper-intelligent pan-dimensional beings demand to learn the Ultimate Answer to the Ultimate Question of Life, The Universe, and Everything from the supercomputer, Deep Thought, specially built for this purpose. It takes Deep Thought 7.5 million years to compute and check the answer, which turns out to be 42. Unfortunately, The Ultimate Question itself is unknown.

Rather than constructing a complex model in an attempt to support all potential strategic management decisions, in this document, a generic methodology framework is described which can be used to quantify cumulated effects of human activities. In theory, the results might be used to identify where, when and how an activity contributes to an effect. Secondly, the methodology is demonstrated through the implementation of a prototype of a case study on the Dutch North Sea coastal zone and Wadden Sea; The results from this implementation are in turn being used to discuss the practical applicability of the method.

The major goals are:

- Development of a prototype of a spatial model to analyse cumulated effects of human activities on a selection of indicators in a case study.
- Describing the options for future developments of the implemented prototype.

In the present study the prototype does not compute Marine Strategy Framework Directive (MSDF) (EC 2008) descriptors directly, nor was it intended to do so. However, as the MSFD is important for (future) marine policy, the possibilities of linking the prototype with these descriptors are discussed briefly in this report.

2 Methods

2.1 Generic framework

As with environmental assessments in general, there is not one approach or methodology for all assessments of cumulative environmental effects (Karman & Jongbloed 2008). Different circumstances, such as the location of a project and the type of potential environmental effects will dictate appropriate methodologies. A great challenge in cumulative effects assessment (CEA) is recognizing and predicting the numerous interactions and (indirect) effects. Modelling, expert systems and geographic information systems are being increasingly used. However, where information is lacking, qualitative approaches and best professional judgement are used. It is obvious that the qualitative methods provide results for which it is more difficult to evaluate the significance and acceptability. This section describes our general approach to CEA, together with approaches and examples from available literature.

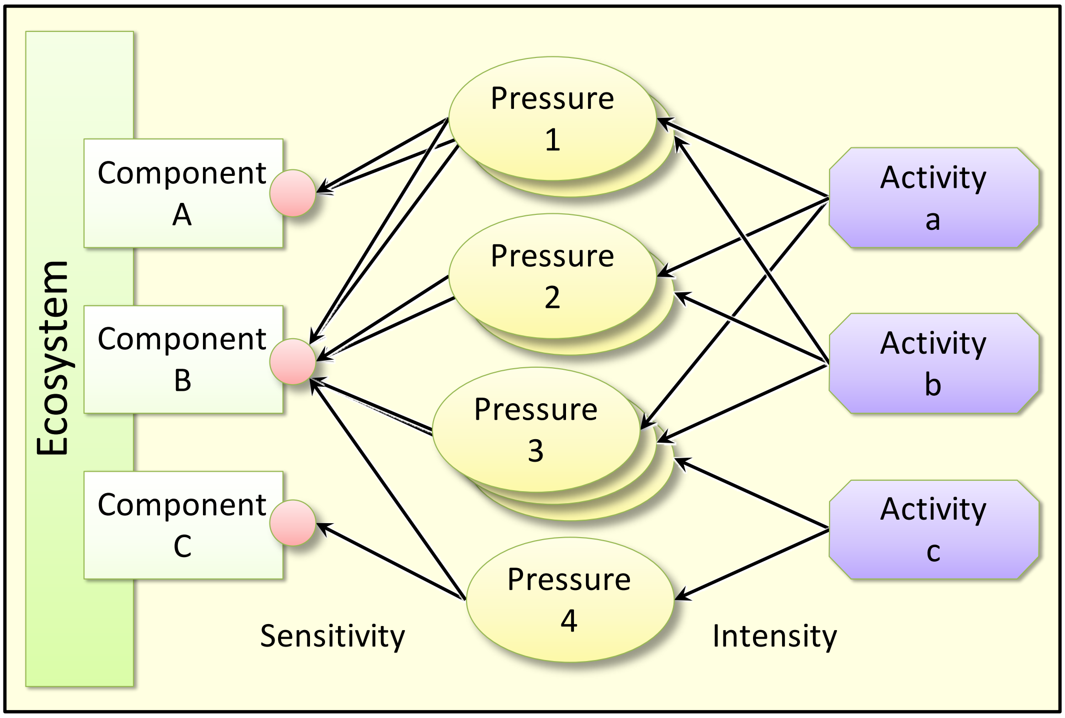

Figure 1: A generic outline of cumulative effect assessment (CEA) in which relationships between activities, pressures and ecosystem components/indicators need to be elucidated

The basic approach of our CEA is schematically represented in Figure 1. It assumes that effects are a function of the intensity of pressures caused by activities and the sensitivity of ecosystem components to those pressures. Each activity can cause several types of pressure: for example: trawl fishery causes both abrasion and visual disturbance. Each pressure in turn can affect multiple but not necessarily all ecosystem components: for instance visual disturbance will affect birds, but will not affect cockles. A stepwise approach, adapted from (Van der Walt 2005, Therivel & Ross 2007), is used for the CEA:

1. Scoping phase,
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2. Assessment phase,
    a. Describe intensity of activities;
    b. Assess intensity of pressures;
    c. Describe sensitivity of ecosystem components;
    d. Assess cumulated effects.

2.2 Scoping

Following the general stepwise approach (Van der Walt 2005, Therivel & Ross 2007), the first step of the assessment is scoping. It is used to determine the range and extent required for CEA. Scoping includes the identification of the ecosystem components, pressures and activities. Most often used instruments in the scoping process are consultations and questionnaires, matrices, spatial analysis and expert opinion (Johnston & Walker 1999, Karman & Jongbloed 2008). It is important to consider that much of the confusion in classifying, defining, assessing and managing cumulative effects is due to poorly defining the resources of concern and the spatial and temporal scales of the analysis (MacDonald 2000). "Scoping" is therefore an important aspect of CEA. The scope of the CEA depends on the level of the assessment. Strategic assessments, early in the process, should have a broad scope whereas later and more specific assessment should be more focused on the relevant issues.

First, the spatial and temporal boundaries are defined, i.e. the area and time frame of concern. Next, the ecosystem components, pressures and activities are identified. These elements are identified in such a way that the framework enables linking (manageable) human activities with the pressures and (potential) effects they cause in the marine ecosystem.

Pressures can be selected from existing lists, such as Annex II from the European Marine Strategy Directive (EC 2008) and adapted to regional specifications. For legislative purposes it is important to have a good overview of activities that should (or could) be subject to a cumulative effects assessment. An extensive overview of activities is provided in the EU EIA Directive (EC 1997), taken over in the Kiev Protocol to the Espoo Convention.

Ecosystem components or indicators have a prominent and legitimate role in monitoring, assessing, and understanding ecosystem status, impacts of human activities and effectiveness of management measures in achieving objectives. Given all these roles, the suites of indicators intended to fulfil them must be chosen with care. (Rice & Rochet 2005) presented a framework for selecting a suite of indicators from the long list of diverse, potential indicators. Although intended for fisheries management, the framework has a wider applicability and can be used for selection of indicators for ecosystem management. Ecosystem components can also be based on (inter)national policy objectives, such as the European Natura 2000 network (Jongbloed *et al.* 2011a).

A well performed scoping process should lead to information that can be represented schematically according to Figure 2. The basic elements (ecosystem indicators, impacts and activities) are now identified and related to each other. No information is provided in the scoping process with regard to the intensity of the impacts or with regard to the sensitivity of the indicators for the selected impacts.

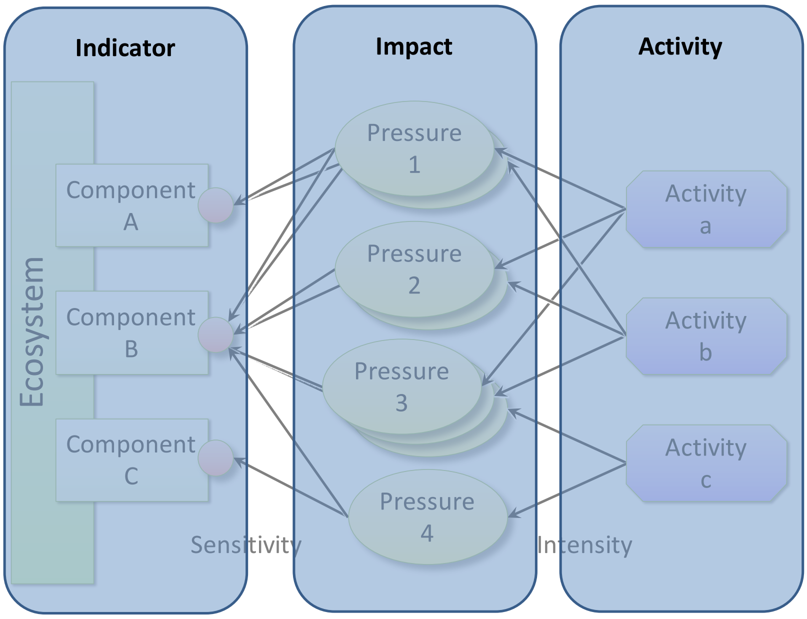

Figure 2: The scoping process allows for the identification of the basic elements for Cumulative Effects Assessment: (ecosystem) indicators, activities and impacts.

Although now the basic elements of CEA, i.e. activities – pressures – ecosystem components are identified, it does not show the elements of space and time, which are the two aspects in which effects can cumulate (MacDonald 2000).

The element of time can be disregarded in the assessment by assuming all elements are present at the same time. This can be considered as a worst case, conservative approach. Depending on the available information and the goal of the CEA, temporal distribution can be implemented, e.g. by including seasonal differences (Jongbloed *et al*. 2011a).

A simple approach to include spatial dimension in the CEA is described by (Halpern *et al*. 2008). They mapped the intensity of pressures in geographic cells and included whether or not a specific ecosystem was present (0 or 1). Instead of using this binary 'yes' or 'no' approach, a more refined approach is also possible. The assessment could also include the probability of pressures and ecosystem components being present, as implemented by (Zacharias & Gregr 2005) for example.

2.3 From activity to pressure

In the assessment phase, two stages can be distinguished: describing and assessing intensity of activity and describing and assessing the sensitivity of ecosystem components for the different pressures (Figure 3). Once both the intensity of impacts and the sensitivity of the ecosystem indicators are known (Figure 3), the actual cumulative effects analysis can be carried out.

Information on the activities is collected for CEA in order to quantify the intensity of the pressures caused by the activities. Such information is usually available in a project CEA, but limited and scattered available for management CEA. The intensity of pressures is then assessed based on the intensity of related activities.

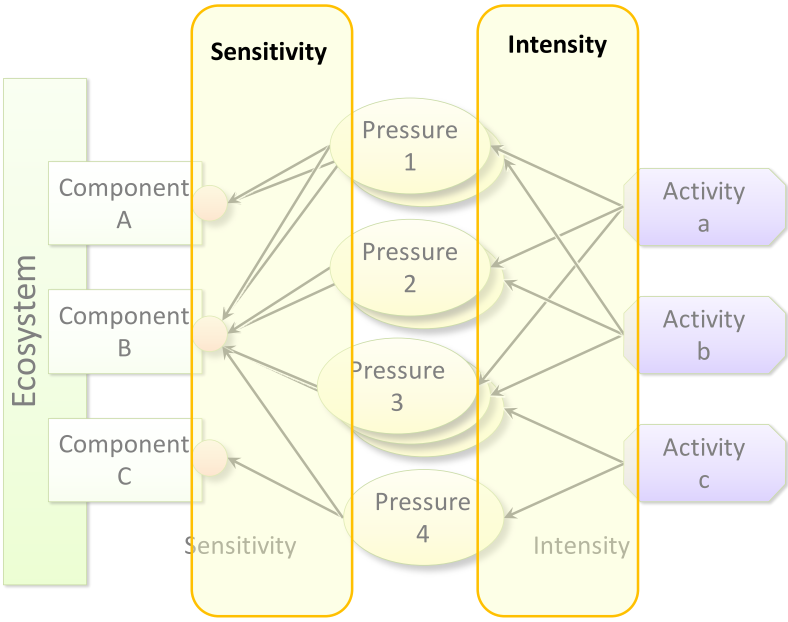

Figure 3: For effects assessment the relations between the basic elements (indicator sensitivity and impact intensity) need to be quantified.

2.4 From pressure to ecosystem component

The sensitivity of ecosystem components can be described in various ways, either qualitative (e.g. (Connor 2008, Robinson *et al.* 2008)) or (semi-)quantitative (e.g. (Zacharias & Gregr 2005, Hiddink *et al.* 2007)). This sensitivity should be specific for the type of effect that is considered of interest for the assessment (e.g., mortality, reduced feeding efficiency or evasive behaviour). Sparse data sets and system complexity have compelled conservation scientists to estimate data through expert judgment and other scoring, ranking, and rating procedures (Wolman 2006). Qualitative and semi-quantitative methods thus mostly rely on expert judgement to classify the sensitivity of ecosystem components to specific pressures. A quantitative method is to use dose-response relationships (Jak *et al.* 2000, Karman *et al.* 2009).

To combine all individual effects, similar endpoints should be used. In case the CEA is not based on one uniform endpoint, e.g. mortality, an additional step should be included in the assessment to derive one single endpoint. (Jak *et al.* 2000, Karman *et al.* 2009) describe a method to integrate the effects of potential exposures. They combined mortality with reproduction to derive a single population measure. As a final step all effects are combined to assess the cumulated effects.

3 Results

3.1 Scoping

Constructing the dataset used in the present study was started for a project ('Nadere Effect Analyse' or NEA) assessing the combined or cumulated impact of human activities on two marine protected areas in the north of the Netherlands (Jongbloed *et al.* 2011a). These areas (Wadden Sea and North Sea Coastal Zone) are both part of the European Natura 2000 network. Significant numbers of various bird species, mammals such as seals, and harbour porpoise, a few fish species and habitats such as H1110 – submerged sandbank and H1140 – intertidal mud and sand flats are present in these area. To suit that study the boundaries were set to coincide with the boundaries of the Natura 2000 areas North Sea Coastal Zone and Wadden Sea.

From the same NEA cumulative effect study (Jongbloed *et al.* 2011a) and previous work on the Natura 2000 areas North Sea Coastal Zone and Wadden Sea (effect studies of individual activities (Jonker & Menken 2008, Slijkerman *et al.* 2008a, Slijkerman *et al.* 2008b, Slijkerman *et al.* 2008c, Jongbloed *et al.* 2011b)) a list of human activities having a possible impact on the conservation targets was available. These studies also conserved a wider list of possible impacts including: visual disturbance, sound (underwater and atmospheric), contamination, eutrophication, turbidity, food availability and physical changes to the environment such as sediment composition, currents, emergence conditions. In order to make mapping the geographical extent of the activities feasible, a selection was made to limit the impacts to just two: presence (expressed in hours) and abrasion (measured in relative area). The terminology used does not match exactly with the list presented earlier. For our purposes presence is a prerequisite and thus a good proxy for visual disturbance. Abrasion is linked with food availability, turbidity and with physical changes to the sea bed. This choice was also guided by the availability of reliable datasets for a number of important human activities on presence and abrasion resulting from several types of fishery.

The same fisheries datasets, mainly on shrimp fisheries and beam trawl (Euro-cutter, up to 300 hp), set the geographical resolution of 1 min. latitude by 2 min. longitude (roughly equivalent to 1 x 1 nautical mile, at the latitude of the Netherlands). This resolution is the regular resolution on which fisheries activities are analysed, the underlying data feeding into these datasets comes from the Vessel Monitoring System (VMS) (Rijnsdorp *et al.* 1998, Piet & Quirijns 2009). Analysis by for example the Fisheries department of IMARES has shown that this is an appropriate resolution for presenting this type of data. The presence of a VMS is mandatory for larger fishing vessels (length > 15 m.) according to European legislation (EC 2003). Smaller vessels are also regularly fitted with the system. The system logs time, position, direction and speed of a fishing vessel; most installations are set to log at 2-hourly intervals. The system does not log the state of the fishing vessel (fishing, steaming, berthed etc.), such information is deduced from the speed. The speed of a vessel is discernably lower while actively fishing, then when steaming to a destination. The available dataset only contained aggregated data for vessels that were actively fishing. Information with respect to the pressures are stored per grid cell and are used to calculate effects per grid cell.

For the prototype a choice was made to perform the analyses on two periods: a summer half year spanning the month of April through September and a winter half year combining the months from October through December and January through March. This choice is a compromise. The fisheries datasets were available as quarterly data, and could readily be aggregated to this level. By making this choice the need for estimates or assumptions on the levels of each activity was cut down considerably. Also when considering the geographical accuracy of some datasets, attempting to add finer temporal detail was judged as unwise. A draw-back of the chosen temporal split is that it does not necessarily fit well with the timing of life cycle events of the ecosystem element included in the study. However as this timing is different for each species, accommodating these intricacies could prevent any further research. The effort required to refit to time scale for each species (or species group) would be enormous and also requires more and better data than is presently available. The latter problem goes for both species as well as most human activities. For the present study the half year subdivision is what we have to work with.

Table 1: Human activities included in the cumulation of pressures (total number: 26)

Human activity	**Summer**		**Winter**	
	Presence	**Abrasion**	**Presence**	**Abrasion**
Ferry services	Yes	N/A	Yes	N/A
Commercial shipping	Yes	N/A	Yes	N/A
Recreational shipping	Yes	N/A	Yes	N/A
Tiding over on sand flats	Yes	No[a]	Yes	Yes
Gas Extraction	Yes	No	Yes	No
Hiking in tidal areas	Yes	No	Yes	No
Kite surfing	Yes	N/A	Yes	N/A
Seal watching	Yes	N/A	Yes	N/A
Angling trips	Yes	N/A	Yes	N/A
Mussel cultivation	Yes	Yes	Yes	Yes
Mussel seed collector	Yes	No	Yes	No
Mussel seed fishery	Yes	Yes	No	No
Fishery for Ensis	Yes	Yes	Yes	Yes
Shellfish collecting (personal use)	Yes	No[a]	Yes	Yes
Beam trawl fishery	Yes	Yes	Yes	Yes
Shrimp fishery	Yes	Yes	Yes	Yes
Otter trawl fishery	Yes	No	Yes	No
Cockle collecting	Yes	Yes	Yes	Yes
Lugworm collecting	Yes	No[a]	Yes	Yes
Mechan. Lugworm extraction	Yes	No[a]	Yes	Yes
Coastal defence (suppletions)	Yes	Yes	No	No
Shell extraction	Yes	Yes	Yes	Yes
Navigational dredging	No	No	Yes	Yes
Fyke net fishery	Yes	No	Yes	No
Gillnet fishery	Yes	No	Yes	No
Seine net fishery	Yes	No	Yes	No

Yes: included in the calculations

No: not included in the calculations

- negligible contribution or
- awarded to summer, but minimal activity level during winter period possible
- etc.

N/A does not occur, not applicable

[a] Abrasion does occur but was not included in the present effect assessment as disturbance effect relations could not be parameterized within the present study.

The list of activities included in the studies of (Jonker & Menken 2008, Slijkerman *et al.* 2008a, Slijkerman *et al.* 2008b, Slijkerman *et al.* 2008c, Jongbloed *et al.* 2011b) was longer than that still considered in the NEA cumulative effect study (Jongbloed *et al.* 2011a) and consequently in our study. The focus towards activities that occur in the marine environment, rather than being located on the beach or otherwise on-shore and also are present with some regularity and predictability. They should also be a source of either presence or abrasion. As a result such activities as intake and release of cooling water, Search and Rescue (SAR), beach recreation and large events (sport, tourism) where not considered in the present study. A number of activities relating the maintenance on buoys and beacons, cables an pipelines or dams and other coastal defence systems were also disregarded. Their location is mostly erratic, and will almost always include the presence of a ship. Thus a judgement was taken that for these activities the location and presence would be sufficiently represented by other (commercial) shipping activities.

The selected human activities are 26 in number and are listed in Table 1. For each of these presence and sediment abrasion (if present) was determined, mapped and aggregated to the same level as the fisheries datasets. Datasets that were originally available in the VMS grid are shown in italic faced text in Table 1.

In the present study we selected the 'net reproductive rate' (Karman *et al.* 2009) for a selection of species as indicator for effect on ecosystem components (Figure 1). The species selected are listed in Table 2. These species were selected as for most of them parameterisation was already described and information on their whereabouts in the selected area could relative easily obtained.

Table 2: Species included in the implementation of the prototype

Species group	Common name	Scientific name	Related Ecosystem Component
Birds	Oystercatcher	*Haematopus ostralegus*	- (Waders)
	Common eider	*Somateria mollissima*	Seabirds
Echinoderms	Heart urchin	*Echinocardium cordatum*	Seabed habitats
Molluscs	Baltic tellin	*Macoma balthica*	Seabed habitats
	Common mussel (bed)	*Mytilus edulis*	Seabed habitats
	Ensis	*Ensis Americanus*	Seabed habitats
	Common cockle (bed)	*Cerastoderma edule*	Seabed habitats

3.2 From activity to pressure

To assess the combined pressure of human activities maps showing the location of each activity were collected or in some cases constructed. The basis of the dataset is formed by a fishery datasets on shrimp, beam trawl and otter trawl fisheries originating from a database with Vessel Monitoring System (VMS) records. These dataset included both presence of fishing vessels (hours actively fishing) and abrasion (fraction of cell area disturbed) For assessing abrasion a representative width of the deployed fishing gear is used. As a result the abrasion resulting from otter trawling is not included in the calculations. This type of fishing net does not have a fixed width. Because otter trawling is not a large fishery within the study area this does not pose a problem for our purposes. In addition to these larger fisheries the data on the fishery for Ensis is also VMS based.

For all other human activities some additional data and in some cases assumptions were required to reach a situation where available Geographic Information System (GIS)-maps could be put to use to award numbers for presence and/or abrasion to the final cumulation dataset.

Ferry services offer a straight forward example of the process. Ferries do not cause abrasion so only presence is considered for this activity. A GIS map of shipping routes of the study area was available, including which routes are used by ferries. By visiting the websites of the ferry companies operating a given services the number of departures and the time each trip takes is known. Often this information results in less frequent departures in the winter period then in the summer period. By combining this data the total number or hours presence during summer/winter for a given ferry route can be calculated. The final step towards the VMS grid is to determine the relative length of ferry route for each VMS cell, each VSM-cell receiving a number of hours presence of ferries based on the relative length (Figure 4).

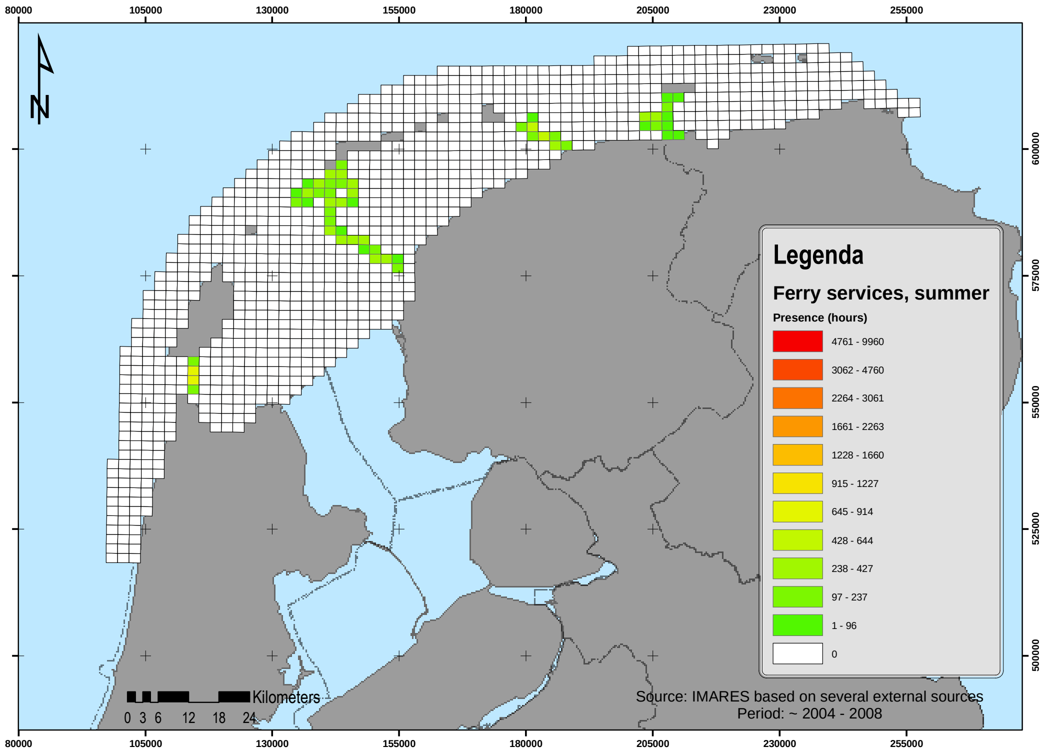

Figure 4: Map showing presence (hours) for ferry services, as included in the cumulated pressure

Cockle collecting is a more complicated example. There are no recorded maps of where and how intensively this activity is. However from available reports on cockles (Brinkman *et al.* 2008) and cockle collecting (Agonus 2007), it is clear that cockle collecting focuses on the higher density areas and that these are found in the mid-tidal range, preferably with a heightened silt content of the sediment. This area can be identified from maps on emergence time and sediment type. Additionally some areas are out-of-bounds because of restrictions by law or in the license governing this activity. Also known are the number of licensed persons, how much time they spent and how much area is actually disturbed on an annual basis. Cockle collecting comes to an almost complete stop during the months January through March, as the flesh weight becomes too low during that period. From all this data combined a map of both presence and abrasion by cockle collecting can be made. Awarding this to the VMS cells is done by relative area (Figure 5).

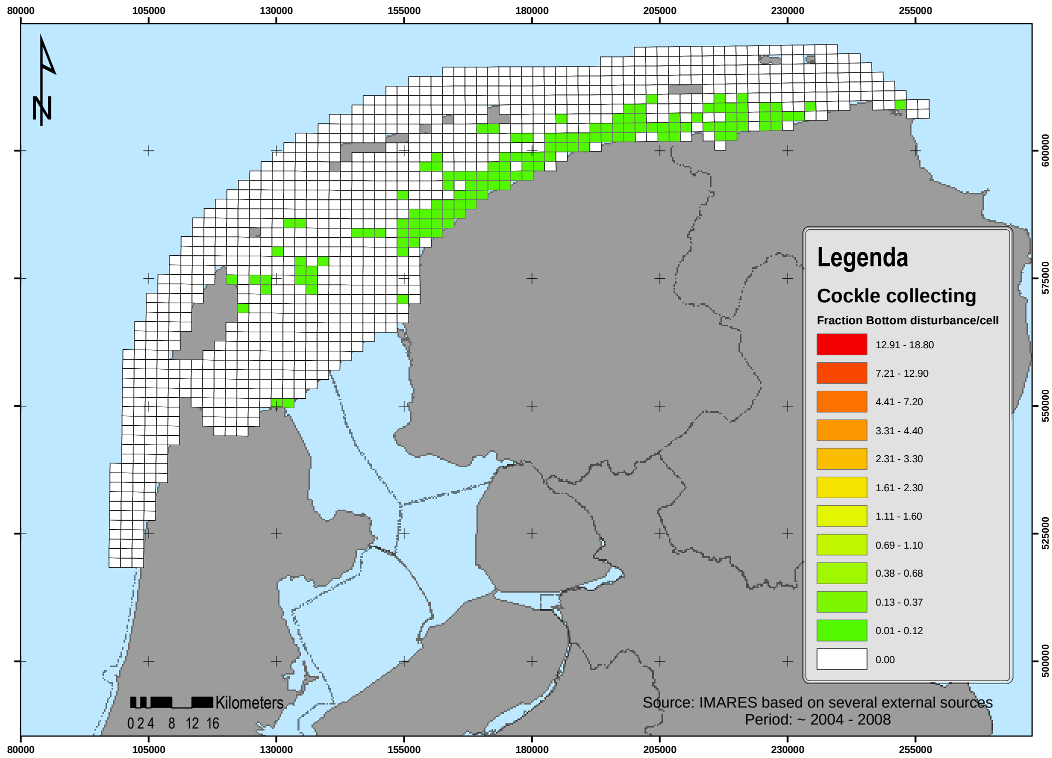

Figure 5: Map showing abrasion (fraction abrasion/cell) for cockle collecting, as included in the cumulated pressure

A series of fact sheets documenting the basic maps used and the assumptions is available in Annex 1.

All cumulation calculations were performed by combining GIS calculations (ESRI) and database manipulations (Microsoft Corporation 2010a). The final dataset consist of four separate tables (summer/ winter and presence/abrasion), with a row for each VMS cell and a column for each activity. With this data maps showing cumulative pressure can be made, statistics calculated and graphs prepared. For the purpose of grouping VMS cell into larger units, several subdivisions of the area are available. A relevant subdivision was by tidal drainage area and this shows clear differences between busy and quiet areas. For the purpose of this study a three-way split of the study area will be used for presenting the results: North Sea Coastal Zone, Western Wadden Sea and Eastern Wadden Sea, where the Eastern part is quieter than the Western part (Figure 6 and Figure 7). Pressure maps of individual activities are presented in Annex 2.

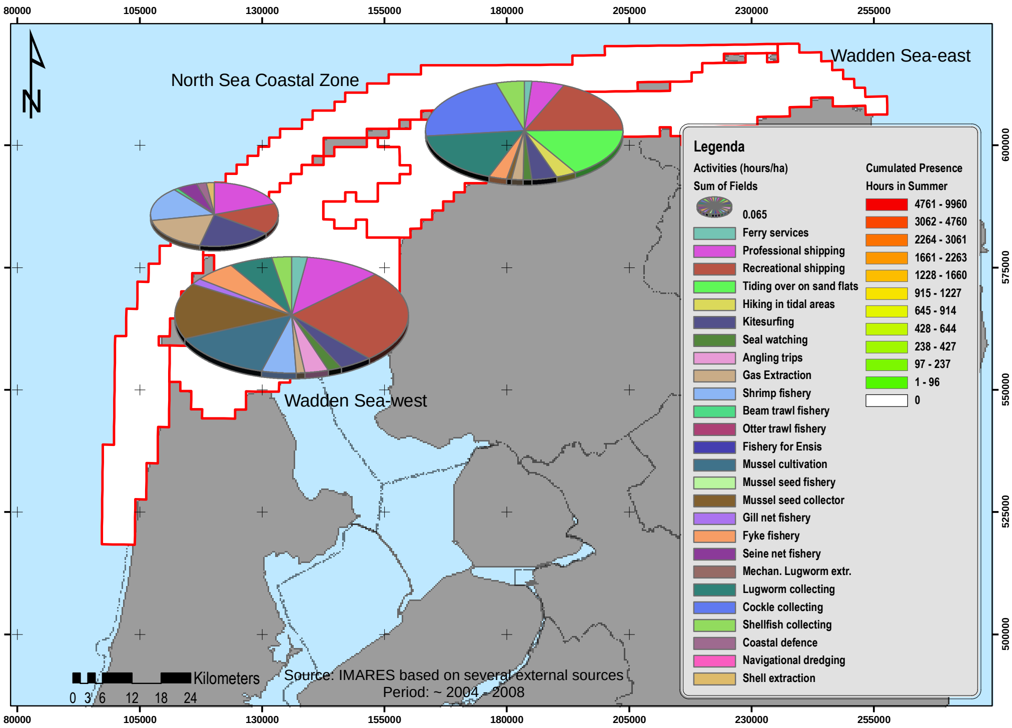

Figure 6: Map showing Summer presence by cell and contribution per activity, pie diagrams show contributions of activities to pressure for the three defined areas (North Sea coastal zone, Western Wadden Sea and Eastern Wadden Sea)

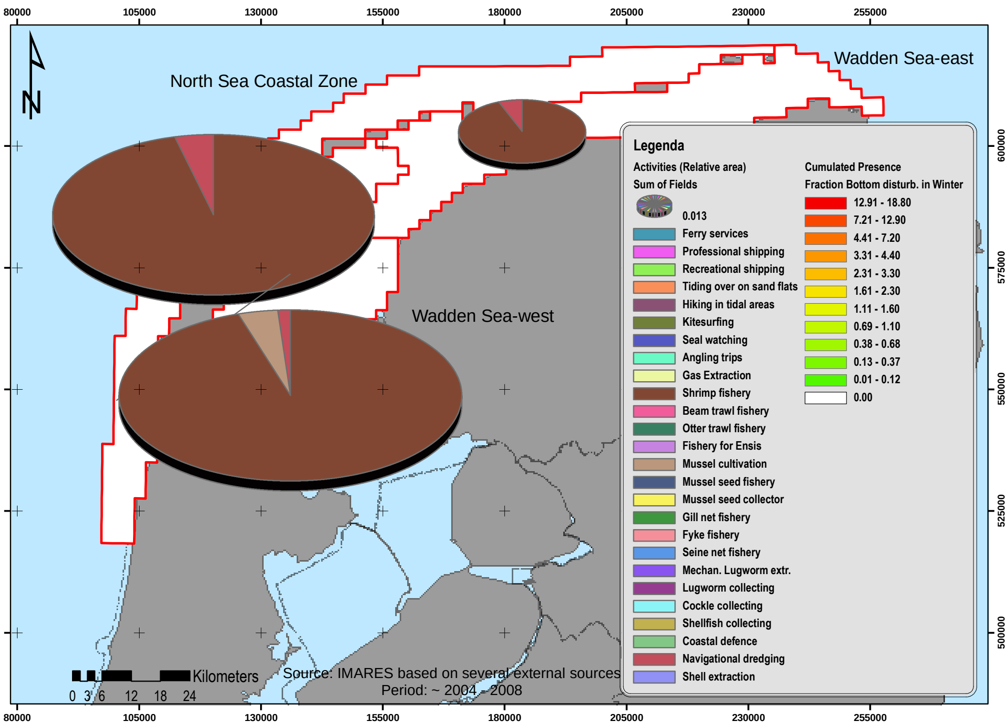

Figure 7: Map showing Winter abrasion and contribution per activity, pie diagrams show contributions of activities to pressure for the three defined areas (North Sea coastal zone, Western Wadden Sea and Eastern Wadden Sea)

3.3 From pressure to ecosystem component

In the nineties of the previous century RAM methodology was developed (Karman & Schobben 1995, Schobben *et al.* 1996, Jak *et al.* 2000, Karman *et al.* 2001), RAM standing for Risk Assessment for the Marine environment. In the present study the RAM methodology, as described below, was implemented in the prototype model to quantify effects on ecosystem components. We refer to the prototype as CUMULEO-RAM as CUMULEO is the name assigned to the collection of cumulative (of either effects, pressures or effects) tools within IMARES.

3.3.1 Disturbance effect relationships

Effects on species are subdivided in effects on mortality and effects on reproduction. The relationship between a pressure or disturbance and effect are described by simple functions in the present study. The disturbance-effect relationships describe the relation between the intensity of a potential exposure (e.g. frequency of the benthos being disturbed) and the effect on the survival or reproduction on a species. The effect is expressed as a fraction between 0 and 1. Therefore, the function are defined such that when the exposure intensity is zero, there is no effect (0) and when the exposure intensity is maximum, the effect is maximum (1) as well.

Many types of functions can describe the above relationships, i.e. logistic curve, linear relation, etc. An appropriate function type per pressure/impact has been selected, which is applicable for all relevant species. Therefore, for each pressure, only the values of the parameters differ per species. The function has been quantified based on several calibration points, which have been derived from literature information on the sensitivity of the species for that pressure/impact. The variables used in the functions are: y, the effect on survival and/or reproduction (fraction between 0 and 1) and x, the disturbance intensity of the potential exposure. Table 3 shows which disturbance-effect relationships are used to quantify the effects on ecosystem components in the present study. The actual relationships are described in the following sections.

Table 3: Disturbance effect relations used to describe effects for specific user functions are marked with an 'X'

User function	**Random probability function**	**Homogenous probability function**	**Visual disturbance function**
Trawling	X		X
Cockle fishery	X		X
Ensis fishery	X		X
Mussel fishery	X		X
Mussel cultivation		X	X
Lugworm fisheries[b]			X
Lugworm collectingb			X
Shellfish collecting[b]			X
Tiding over on sand flats[b]			X
Smothering (dumping)		X	X
Dredging and aggregation		X	X
Other shipping, offshore platforms, hiking in tidal areas, etc.			X

[b] Parameter abrasion not quantified in present study

In the present study, these relationships are only described for two disturbances: (physical) abrasion and visual disturbance. Obviously, the same approach can be applied to other types of disturbances (e.g., toxicity).

Abrasion

Mortality effects by abrasion are quantified with two different functions, depending on whether the surface within a grid cell is structurally (homogeneously) disturbed or disturbance takes place in a random fashion. If we take trawling as example, when an area is structurally trawled and the area being trawled is equal to the grid cell surface, then the entire area within the grid cell is being disturbed once. If area is trawled randomly, some areas might be disturbed twice (or more), while others are not. For homogenous disturbance the mortality of a species is given by (Karman *et al.* 2001):

$$y = 1 - \left(\left(1 - (x - \lfloor x \rfloor)\right)c^{\lfloor x \rfloor} + (x - \lfloor x \rfloor)c^{(\lfloor x \rfloor + 1)}\right)$$

Where x is the number of times that the entire area of a grid cell is being disturbed in half a year (either winter or summer half year) and c is the fraction of individuals that don't survive a single pass of the disturbing activity (e.g., trawling).

In case of random process, the distribution of the intensity is a binomial process. When the number of samples from a binominal probability distribution increases to infinity, a Poisson distribution is obtained. The latter describes the process of the distribution of the intensity on a grid cell. The chance that a cell is disturbed i times is equal to the fraction of the surface of the cell that is disturbed i times. This fraction is multiplied by the corresponding survival $(1 - c)$. The mortality at a specific exposure level (x) is then obtained by summation of all terms $i = 0$ up until $i = \infty$. In practice, the summation usually converges in less than 12 terms (Karman *et al.* 2001):

$$y = \sum_{i=0}^{i=12} \left(\left(\frac{x^i e^{-x}}{i!}\right)(1 - c)^i\right)$$

The disturbance-effect curve is visualized for both the homogenous and random process for species with a 0.5 survival chance after a single disturbance (Figure 8).

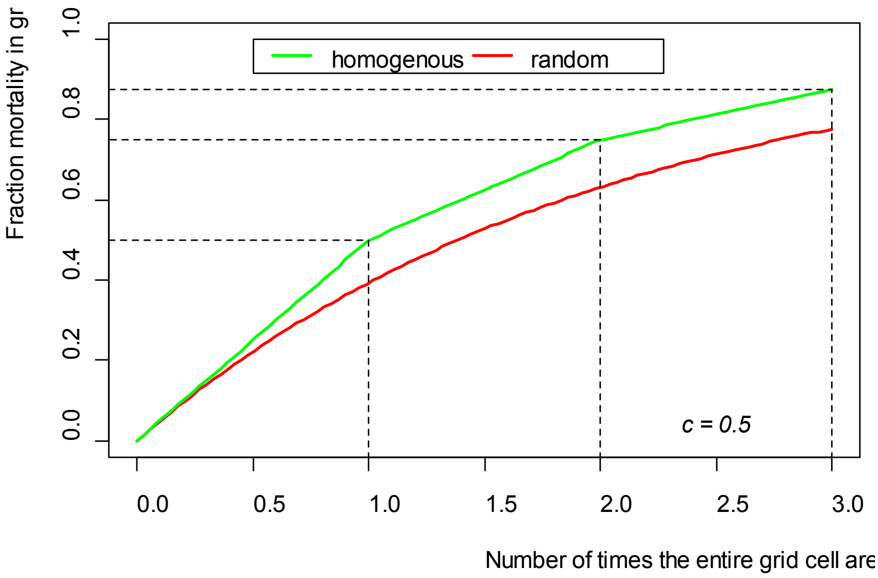

Figure 8: Example of the disturbance-effect relationship for both the homogenous and random process, for species with a 0.5 survival chance (c) for a single disturbance. Disturbance (x) on the x-axis is given as the number of times the entire grid cell area is disturbed. The mortality (y) is given as a fraction between 0 and 1 on the y-axis.

Parameterising abrasion effect relations

In Table 4 overviews are given of the fraction mortality as result of onetime passage of different fishing methods and as a result of a onetime coverage/removal with/of sand or silt of at least 20 cm thickness, reflecting the extraction or deposition of disposed dredged material. The dose-response relationship between fisheries and benthos was described using either random or homogenous probability (see Table 3). The relationship between coverage/removal and mortality was described using a homogenous probabilistic function. No maximum thickness is defined. The magnitude of the effect depends on the thickness of the layer, the composition, the ability to grow or to move out of the layer, and the persistence to oxygen depletion (and accompanied sulphide concentrations). At the longer term decolonisation is important. The importance of seasonality is not clear (Jak *et al.* 2000). The effects of coverage with sand or silt can vary strongly as the fine organic rich silt can go together with oxygen depletion. Besides that, other parameters as temperature and availability of oxygen and the life stage of the organisms are important. The relationship between dredging (or aggregation) and mortality was also described using a homogenous probabilistic function.

The values of the parameters Table 4 were, as far as possible, estimated on the basis of data from the literature, dealing with the sensitivity of the considered species, or otherwise extrapolated from data on related species or biota in general, for the regarded disturbance.

Table 4: Estimates fraction mortality (c), for the selected species, as result of a onetime event

	Fraction mortality *c* (min-max)				
User function	**Heart urchin**	**Baltic tellin**	**Mussel**	**Cockle**	**Ensis**
Beam trawler	0.40 (0.10-0.90)[c]	0.3[d]	0.7[d]	0.3[d]	0.1[c]
Otter trawler	0.25[d]	0.15[d]	0.3[d]	0.1[d]	0.1[c]
Shrimp trawler	0.05[d]	0.01 (0-0.58)[d]	0.05 (0.02-0.59)[d]	0.01[d]	0.015[e]
Ensis fishery	0.28[f]	0.1[g]	0.05[g]	0.05[g]	0.85[h]
Mussel fishery	0.1[d]	0.05[d]	0.6[d]	0.1[d]	0.1[g]
Dumping[i]	0.9 (0.39-0.96)[d]	0.5 (0.21-0.79)[d]	1.0 (0.36-1.00)[d]	1.0 (0.43-1.00)[d]	0.3[g]
Dredging / aggregation	1.0[d]	1.0[d]	1.0[d]	1.0[d]	1.0[g]
Cockle fishery[j]	0.7[d]	0.3[d]	0.01[d]	0.8[d]	0.3[g]
Mussel cultivation	0.1[d]	0.05[d]	0.6[d]	0.1[d]	0.1[g]

[c] Bergman MJN, Santbrink JW (2000) Mortality in megafaunal benthic populations caused by trawl fisheries on the Dutch continental shelf in the North Sea in 1994. ICES Journal of Marine Science 67:1321-1331

[d] Estimation from Jak RG, Kaag NHBM, Schobben HPM, Scholten MCT, Karman CC, Schobben JHM (2000) Kwantitative verstoring-effect relaties voor AMOEBE soorten. Report No. R99/429, TNO-MEP, Den Helder

[e] Estimation based on Rijnsdorp AD, Van Stralen M, Baars R, Van Hal R, Jansen H, Leopold M, Schippers P, Winter E (2006) Rapport Impassing Visserijactiviteiten Comensatiegebied MV2. Report No. C047/06, Wageningen IMARES, IJmuiden

[f] Tuck ID, Bailey N, Harding M, Sangster G, Howell T, Graham N, Breen M (2000) The impact of water jet dredging for razor clams, Ensis spp., in a shallow sandy subtidal environment. Journal of Sea Research 43:65-81

[g] Own estimate

[h] Hauton C, Atkinson RJA, Moore PG (2003) The impact of hydraulic blade dredging on a benthic megafaunal community in the Clyde Sea area, Scotland. Journal of Sea Research 50:45-56

[i] Dumping of dredged material resulting in coverage of at least 20 cm sand or silt, also including sand nourishment

[j] The activity ‘cockle fishery’ included in this assessment involves hand ranking. Because no parameter values could be found in available literature the parameter values presented here are based on mechanical cockle fishery

Visual disturbance

In the presently implemented prototype, it is assumed that visual disturbance affects reproduction. It is reasoned that the both the fraction of the surface (f_s) that is unavailable to a species and the fraction of time (f_t) it is unavailable is directly and linearly proportional to the reduction of reproduction:

$$f_s \cdot f_t \leq 1 \Rightarrow y = f_s \cdot f_t$$

$$f_s \cdot f_t > 1 \Rightarrow y = 1$$

The disturbed surface at a certain moment in time is a simplification to the approach proposed by Smit & Visser (Smit & Visser 1993). In the present study the fraction of the disturbed surface is calculated from the flush distance (*FD*, the minimal distance between a species and the disturbing object causing the bird to flush), the speed of the disturbing object (v), the time required for a species to recover or return after a disturbance (s) and the total surface of the grid cell (S_{cell}) (Figure 8):

$$f_s = \frac{1}{S_{cell}}(\pi \cdot FD^2 + 2 \cdot FD \cdot v \cdot s)$$

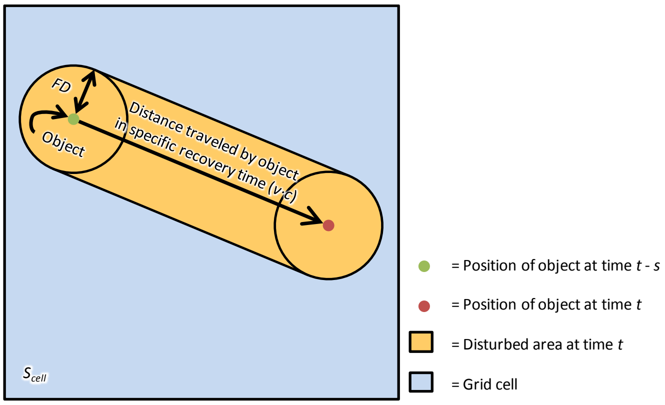

Figure 9: Schematic representation of disturbed area with respect to a grid cell (outer blue square, S_{cell}). The disturbed area (orange) is defined by the speed of the object (v), the flush distance (FD) and the specific recovery time (s)

The fraction of time that an object is calculated from the total number of hours that an object is present (x) divided by the total time (t_{total}) available in the studied period (half a year in this case):

$$f_t = \frac{x}{t_{total}}$$

Parameterising visual disturbance effect relations

Table 5 lists the flush distances (FD) for specific types of disturbances. Most FD values are extracted from (Jak *et al.* 2000). In the present implementation we also distinguished between people and groups of people. As hiking across tidal areas usually done in groups, the pressure would be overestimated, when it would be based on the individual hikers. Therefore, the FD for groups of people is introduced and is assumed to be equal to that of boats. Table 6 shows which activities are associated with which type of disturbance from Table 5. Table 5 also contains the specific recovery times (which is assumed unspecific for different disturbances). Average speeds of the objects are also estimated and listed in Table 6.

Table 5: Estimates of species-related parameters visual disturbance (FD = flush distance)

Type of disturbance	**Parameter**	**Species**	
		Oystercatcher	**Common eider**
Boat	FD (m)	200[k]	400[k]
People	FD (m)	200[k]	100[l]
Group of people	FD (m)	200[m]	400[m]
Offshore construction	FD (m)	100[k]	100[k]
Unspecific	Specific recovery time *s* (h)	0.45[n]	2[o]

Table 6: Estimates of user function-related parameters

User function	**Type of disturbance**	**Average speed (km/h)**
Ferry Services	Boat	18.3
Commercial shipping	Boat	18.52
Recreational shipping	Boat	11.11
Tiding over on sand flats	Boat	0
Gas extraction	Object	0
Hiking in tidal areas	Group of people	3.06
Kite surfing	Boat	28
Seal watching	Boat	9.26
Angling trips	Boat	9.26
Mussel cultivation	Boat	0.8
Mussel seed fishery	Boat	5.56
Mussel seed collector	Boat	0.8
Fishery for Ensis	Boat	0.3
Shellfish collecting	People	0
Beam trawl fishery	Boat	8
Shrimp fishery	Boat	7.5
Otter trawl fishery	Boat	6.5
Cockle collecting	People	0
Lugworm collecting	People	0
Mechanical lugworm extraction	Boat	0.43
Navigational dredging	Boat	0.8
Shell extraction	Boat	0.8
Fyke fishery	Boat	0.8
Gillnet fishery	Boat	0.8
Seine net fishery	Boat	0.8
Coastal defence	Boat	0.8

[k] Estimation from Jak RG, Kaag NHBM, Schobben HPM, Scholten MCT, Karman CC, Schobben JHM (2000) Kwantitative verstoring-effect relaties voor AMOEBE soorten. Report No. R99/429, TNO-MEP, Den Helder

[l] Estimation (expert, C. Smit)

[m] Own estimation based on FD of a boat

[n] Stillman RA, Goss-Custard JD (2002) Seasonal Changes in the Response of Oystercatchers Haematopus ostralegus to Human Disturbance. Journal of Avian Biology 33:358-365

[o] Schwemmer P, Garthe S (2006) Sea ducks and impacts of ship traffic in the Baltic Sea. Journal of Ornithology 147:249

3.3.2 Integration of effects and the derivation of a single population measure

The reproductive rate

As presented previously, for each activity the effect on survival and reproduction is calculated separately. The overall mortality and reproduction effect is now determined by assuming they all act independently. Therefore, the product rule for independent chances is used:

$$y_{total} = 1 - \prod_j (1 - y_j)$$

Where y_{total} is the overall effect on either survival or reproduction and y_j is the effect if each separate activity.

The effects on reproduction and mortality still need to be combined into a single indicator for potential population effects. The net reproductive rate (referred to as reproductive rate from here on) is used for this purpose and is defined as: "the number of adult individuals that are expected to be produced by a just matured juvenile during its entire adult life stage" (Schobben *et al.* 1996). It is calculated by the total number of juveniles that reach the adult life-stage, divided by the total number of adults in a population. It can be seen as an indicator for population growth: if the reproductive rate is less than 1 the population is expected to decline, whereas it is expected to growth if it is larger than 1. Effects of population density and migration are not included, assessment of actual population developments is therefore not possible with the proposed methodology.

Life stages of species are generalized into four stages: pre-juvenile stage (from embryo to juvenile), juvenile stage (individuals that have not yet matured and therefore, cannot reproduce), adult stage (matured individuals that can reproduce) and infertile (senile) stage (Figure 10). The infertile life stage is assumed to be irrelevant for population dynamics as it usually is a small fraction of the entire population. The pre-juvenile stage often plays an important role in population dynamics. However, natural mortality rates are usually high (especially for species that produce large quantities of eggs) but also poorly quantified for this life stage. Therefore, reproduction is defined as the number of individuals that will reach the juvenile stage.

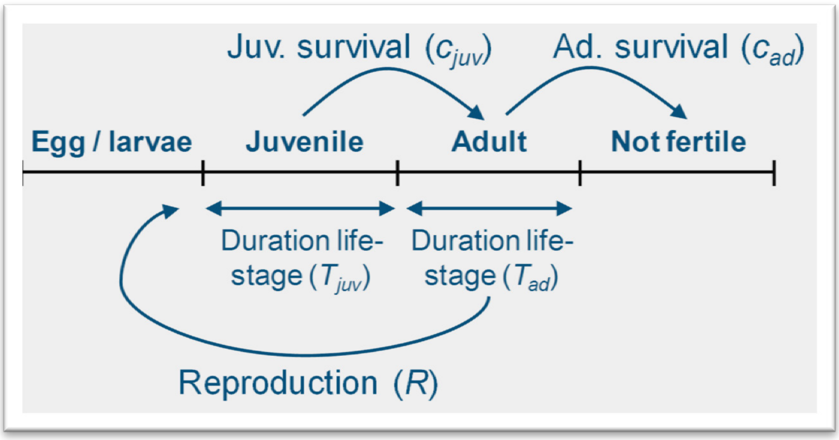

Figure 10: Life stages as distinguished in the calculation of the reproductive rate

It is assumed that within each life stage the mortality and (in case of the adult life stage) reproduction are equal for all individuals. This assumption is incorrect in principle, but necessary as knowledge on the relation between survival/reproduction and age is generally insufficient. When predation is the most important factor in 'natural' mortality then the assumption of constant survival approaches reality. When senility is the most important factor in 'natural' mortality, the survival will decrease with age. As it is intended to set up a generic frame work, and this refinement cannot be quantified for most species, it is omitted from the present implementation.

The number of (eventually mature) individuals that can be produced by a just matured individual depend on the expected lifespan of a mature individual (average duration of the mature life stage), the number of juveniles that are being produced and the survival of juveniles. This can be formalized to the following expression:

$$R_0 = \text{fraction of juveniles reaching adult life stage} \cdot \text{life span of adults} \cdot R$$

Where R_0 is the reproductive rate and R is the reproduction (the number of juvenile individuals produced by an adult per year). The fraction of juveniles that reach the adult life stage depend on the survival for each time step (one year in the present study) and the average duration of the juvenile life stage (in years):

$${c_{juv}}^{T_{juv}}$$

Where c_{juv} is the fraction of juveniles surviving each time step and T_{juv} is the average duration of the juvenile life stage. The life expectancy of adult individuals is described by the integral of adult survival as a function of time:

$$\int_0^{T_{ad}} {c_{ad}}^t$$

Where c_{ad} is the fraction of adults surviving each time step and T_{ad} is the maximum duration of the adult life stage. Even though this function can also be discretized (in other words make survival, c_{ad}, variable with time, rather than constant) differences with the method described here are expected to be marginal. As the discrete approach is more complex, both conceptually and mathematically, the alternative described here was selected. By combining the terms, the reproductive rate (R_0) can now be calculated with:

$$R_0 = {c_{juv}}^{T_{juv}} \cdot R \cdot \int_0^{T_{ad}} {c_{ad}}^t$$

Solving the integral gives the following formulation for the reproductive rate:

$$R_0 = {c_{juv}}^{T_{juv}} \cdot R \cdot \left(\frac{{c_{ad}}^{T_{ad}} - 1}{\ln c_{ad}} \right)$$

As adult survival is held constant, a fraction can still be alive when the species maximum age is reached. In the proposed model it is assumed that this fraction will die immediately (from aging) or become infertile at the maximum age.

The reproductive rate in disturbed situation can now be calculated by incorporating the effects on survival (y_{mort}) and reproduction (y_{repro}) as calculated with the disturbance-effect relationships:

$$R_0 = \left((1 - y_{mort}) \cdot c_{juv}\right)^{T_{juv}} \cdot R \cdot \left(1 - y_{repro}\right)\left(\frac{\left((1 - y_{mort}) \cdot c_{ad}\right)^{T_{ad}} - 1}{\ln\left((1 - y_{mort}) \cdot c_{ad}\right)}\right)$$

Parameterising reproductive rates

Parameters are already derived for a large number of species by (Schobben *et al.* 1996). For each parameter (Reproduction (R), survival (c_{juv} and c_{ad}) and life-span (T_{juv} and T_{ad})) they collected information on minimal, maximal and most likely values. They refer to the latter as the modes. In the undisturbed situation, the reproductive rate is assumed to be 1 (representing a stable population). The parameters are calibrated by (Schobben *et al.* 1996) such that the parameter values are as close to their modes as possible but with the resulting reproductive rate near 1 (accepting only a deviation of less than 0.1%). The parameter values presented by (Schobben *et al.* 1996) for the Baltic tellin and the common mussel gave reproductive rates near 0.9 rather than 1. Therefore, the procedure described by (Schobben *et al.* 1996) is repeated in the present study, to obtain new values for these species.

Ensis was not part of the study by (Schobben *et al.* 1996). Therefore, parameter values were obtained in this study. Due to limited time and budget, it was not possible to collect the minimal, maximal and modes of the parameters. Data was gathered from literature for survival (c_{juv} and c_{ad}) and life-span (T_{juv} and T_{ad}), which were taken as fixed values. The reproduction was estimated from the other parameters by again assuming a reproductive rate of 1. All reproductive rates used in the present study are listed in Table 7.

Table 7: Reproduction (R), survival (c_{juv} and c_{ad}) and life-span (T_{juv} and T_{ad}) parameters derived for reproductive rate calculations

Species	Parameters				
	R	c_{juv}	c_{ad}	T_{juv}	T_{ad}
Common eider	0.363[p]	0.659[p]	0.955[p]	3.592[p]	18.161[p]
Oystercatcher	0.321[p]	0.786[p]	0.925[p]	5.504[p]	31.678[p]
Heart urchin	12.258[p]	0.320[p]	0.602[p]	2.781[p]	8.109[p]
Baltic tellin	2777[q]	0.00369[q]	0.580[q]	1.513[q]	5.192[q]
Common cockle (bed)	308.6[p]	0.02[p]	0.937[p]	1.964[p]	9.408[p]
Common mussel (bed)	5262[q]	$9.347\ 10^{-5}$ [q]	0.612[q]	1[q]	24.180[q]
Ensis	30.93[r]	0.04[s]	0.3[t]	1[u]	3[v]

[p] Schobben HPM, Karman CC, Schobben JHM, Jak RG, Kaag NHBM (1996) Ecologische informatie over RAM-soorten - Schatting van populatiedynamische parameterwaarden. Report No. R96/210, TNO MEP, Den Helder

[q] Based on min, max and modi values from ibid.

[r] Calculated from the other Ensis parameters (c_{juv}, c_{ad}, T_{juv}, T_{ad}) assuming that the replacement value equals 1

[s] Armonies W, Reise K (1999) On the population development of the introduced razor clam *Ensis americanus* near the island of Sylt (North Sea). Helgoländer Meeresunters 52

[t] Freudendahl A, Nielsen M, Jensen T, Jensen K (2010) The introduced clam *Ensis americanus* in the Wadden Sea: field experiment on impact of bird predation and tidal level on survival and growth. Helgoland Marine Research 64:93-100

3.4 Effect assessment output from the prototype

Using the methodology described above, the pressure maps (Annex 2) can be translated into reproductive rate maps. The maps the present case study are shown in Annex 3. These maps give information on potential population effects, but note that they don't include information on habitat suitability. In other words, if the map shows a low reproductive rate (near zero), this means that there is a potential population effect. However, if that specific location is by nature not suitable to support the species, there is no actual effects from the pressures.

Annex 4 shows the relative contributions of each activity to effects on survival and reproduction in pie diagrams. When these diagrams are compared with the pie diagrams in Figure 7, they can be quite different. This is because the pie diagram of the pressures (Figure 7) is not scaled to the sensitivity of the ecosystem components, but the diagrams in Annex 4 are. For instance, from Figure 7 we learn that the intensity/pressure from shrimp fishery is the largest in all the selected areas. However, the Baltic tellin is relatively insensitive for this particular form of fisheries (Table 4), hence the contribution of shrimp fisheries to effects on survival of the Baltic tellin is relatively small (Annex 4).

In the present study, a large amount of output is generated (Annex 3 and 4) for each species separately. When the model is to be used for management decision support, effort should go into aggregating the results into a single figure, which is easy to interpret.

3.5 Quality check on software

In the process of implementing the proposed methodology, the 'WOT Natuur & Milieu' checklist for achieving an A status of simulation models is followed as much as possible. In the present form, the implemented model should be considered a prototype. Therefore, the status checklist will not be audited and the actual A status cannot be achieved in the present stage of development. Part of the A status involves proper documentation of the principles underpinning the model and a description of the model's domain, which is described in the previous and remainder of the text. This chapter will only describe the software testing.

The described methodology has been implemented in R (The R Foundation for Statistical Computing 2009). A major advantage of R is that is free and widely used. As a consequence many libraries with statistical (and other) functions are developed and available for R and many scientists are familiar with the scripting language. Unfortunately, it has some downsides as well. R performs relatively slow when iterative loops are involved. Fortunately, for many of the matrix calculations in R, loop-structures can be avoided. Furthermore, the prototype did not show any issues with speed. The critical step with respect to speed in the prototype is the writing of output. When run locally from a hard drive on a notebook calculations are performed within seconds. When run from a network, speed becomes variable depending on the available bandwidth of the network. In the latter case, running the script can take up to several minutes.

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[u] *Ensis americanus* reaches maturity at the end of its first life year Cardoso J, Witte JI, Van der Veer HW (2009) Reproductive investment of the American razor clam *Ensis americanus* in the Dutch Wadden Sea. Journal of Sea Research 61:295-298

[v] Ensis rarely gets older than 4 years old Beukema JJ, Dekker R (1995) Dynamics and growth of a recent invader into European coastal waters - the American razor clam, *Ensis directus*. Journal of Marine Biological Association of the United Kingdom 75:351-362

Another point of attention in R is the scope of variables. In R it is not necessary to declare variables. In other words you don't need to let the code know what the type (e.g. integer or a floating point) of variables is. Therefore, R cannot distinguish between local and global variables, which could lead to all sorts of problems. Of course, care was taken to avoid such problems. Unfortunately, there was no time in the present project to let a colleague check the entire code line by line, in order to eliminate such issues. However, a limited quality test was performed as follows.
The model principles where implemented by a colleague in Microsoft Excel (Microsoft Corporation 2010b) for a single spatial grid cell and compared with the results generated with the R script. This way, it was possible to compare the results of the two implementations for a small random subset of spatial grid cells. This was carried for a selected grid cell where most of the assessed activities take place and 10 randomly selected grid cells. When the relative survival and mortality and reproductive rate calculated by the two implementations are compared for those grid cells, the results are equal to each other up to at least 5 digits for all selected grid cells. As the model is presently only developed to up to the prototype stage, the quality check described above should suffice.

3.6 Workshop

On 30th of November 2010 a workshop was organised by IMARES mainly to discuss and evaluate the methodology and implemented prototype. Several IMARES experts (Martin Baptist, Floris Groenendijk, Chris Klok, Tobias van Kooten, Erik Meesters, John Schobben, Pepijn de Vries, Jan Tjalling van der Wal) in the field of modelling and ecology attended this workshop. PBL was represented by Rick Wortelboer at the workshop.

The outcome of the workshop will not be presented in this section as they are fully integrated in the discussion, conclusions and recommendations of this report. Minutes of the workshop were provided to the attendees (in Dutch).

4 Discussion

4.1 Spatial and time issues

In the present implementation, a spatial resolution of approximately 1 by 1 nautical mile is selected to scale pressures, but also to calculate the reproductive rate. In order to estimate actual population effects on such resolution would be challenging as populations (of birds) are larger than the area of a grid cell in the model. In addition, migration takes place between grid cells, which is not implemented in the prototype. For benthos the spatial resolution might be sufficient to estimate population effects as benthos is more stationary. However, during the reproduction cycle, gametes move freely through the water column.

The spatial resolution of pressure intensity may depend on the type of pressure. In the present approach it is required to scale each pressure to the same resolution. This may result in losing spatial details for some pressures and suggesting unrealistically high resolution for others. Standardisation on data acquisition and resolution is therefore advisable.

Depending on the underpinning management questions needed to be answered, the half year distinction made in the present case study might not be sufficient. The methodology presented here can be easily adjusted to specify more time periods for the pressure maps. However, the number of assumptions needed to generate such maps will increase, resulting in higher uncertainties. Also, it would be better to distinguish between the biology of different seasons. For instance, in the present study effects on reproduction in the winter season are calculated, while birds generally don't reproduce (or reproduce elsewhere) during this season. Introducing such adjustments is possible but increases the complexity of the model. Currently, the tool only assesses effects on reproduction and survival within the study area. For some species the population are also affected by events outside this area. Further research is required to what extend pressures in the study area affect reproduction and survival for species that are only present a limited period of time in this area.

4.2 Processes

In the prototype visual disturbance is assumed to have a linear relation with the effect on reproduction of birds. In reality the relationship between visual disturbance and reproduction is much more complex and not always completely known. The assumption of a linear relationship is probably worst-case but could be refined if sufficient knowledge is available. Furthermore, other indirect effects are likely to be more important for birds, for instance, the reduction of the food supply by abrasion. Food-web interactions are not incorporated in the proposed methodology (i.e., there are no links between the ecosystem components in Figure 1). As for some species, such as the common eider, habitat suitability directly links with food (prey) availability. Ideally prey densities are modelled, including pressures on those prey species. However, this will make the model more and more complex, reducing its transparency. As a simplification, habitat suitability maps could be used as a proxy for food availability.

In the implemented prototype, the reproductive rate is always one in the undisturbed situation. Effects on reproduction and survival are quantified between 0 and 1 in the present case study. As a result, the reproductive rate is always 1 or less, indicating a stable are declining population. In the present setup it is not possible for population to increase. This is no problem if s need to be compared relatively, but it will become a problem when the calculated impact needs to be translated to actual and realistic effects on the population. The question is whether the generic methodology presented here should be used to quantify actual effects on populations. But if it is, more complex properties such as population density dependence should be added.

Furthermore, in the current implementation the reproductive rate does not explicitly describe the pre-juvenile life stage (egg/larvae) (Figure 10). Effects during this life stage are implicitly included as effects on reproduction. If sufficient data and knowledge on the processes is available, a more complex model, included in the egg/larval stage could be used instead.

In the present case study effects on reproduction and survival are cumulated by assuming effects from each pressure is an independent chance. It is therefore a monofactorial approach. This can best be illustrated with an example. Let's assume that a cockle bed is disturbed once by a beam trawler and then once by an otter trawler. After a disturbance of a beam trawler 30% of the cockles will survive and 90% in the case of an otter trawler (Table 4). When the survival of the cockles from both the beam and the otter trawler are independent 90% of the 30% which is 27% will survive the combination of events. However, if the beam trawler specifically kills those individuals that are also more sensitive for the otter trawler the survival of the combined events might be higher than 27%. On the other hand if, the individuals that are less sensitive for the otter trawler are killed specifically by the beam trawler, the survival of the combined events might be less than 27%. Such covariant dependencies are difficult to quantify and therefore generally unknown for the large number of combinations of pressures. Although independent action is probably the most realistic assumption it is not necessarily worst case as shown with the previous example.

The implementation assumes a generic life-cycle (Figure 10) which can be used for vertebrates (e.g., birds, fish and marine mammals), but also invertebrates (such as molluscs). It is unsuitable for floral organisms (due to their vegetative reproduction).

4.3 Parameters

As indicated before, one of the strengths of the presented methodology is the reducibility of the parameters. In the present study most parameters originate from (Jak *et al.* 2000). Although they report all underpinning literature, the literature is not linked to individual parameter values. To improve the reducibility, a database should be set up containing all parameter values and metadata such as the source.

The parameters used to calculate the reproductive rate (R, c_{juv}, c_{ad}, T_{juv}, T_{ad}) are calibrated under the assumption that in an undisturbed situation the population is stable and hence the reproductive rate is equal to 1. This might not be true, in fact under ideal (undisturbed) conditions, populations will probably grow until they reach a density dependent limit. In order to parameterise the reproductive rate literature data is used which is usually based on field data which are never ideal or optimal conditions. Scaling all reproductive rates to 1 makes relative comparison of effects from pressures easier, but estimating actual effects on populations more complicated.

4.4 Possibilities of linking with MSDF descriptors

The Annex I of the MSDF lists in total 11 descriptors for determining a good environmental status. At the time of the present work, the descriptors were qualitative and not highly specific, making it difficult to implement them in the present prototype. This was therefore not attempted. However, the presently developed prototype addresses some aspects of the descriptors. Sea floor integrity, for instance, is assessed by the present prototype by determining the potential effect (expressed as the reproductive rate) of abrasion on benthic species. However, the MSDF only allows activities that do not adversely affect the benthic community. The present prototype calculates potential effect levels without stating whether the benthic community is adversely affected by these effects. The simplest fix for this problem would be defining a 'safe' effect threshold. However, it would be difficult to make an objective definition of the threshold. Many of the other descriptors deal with the same issue in that they define pressure intensities which do not adversely affect the ecosystem.

Other descriptors, for example those in relation to biodiversity and the food-web, in most of the cases require information on interaction between species. This is not implemented in the presently proposed approach, as discussed in the 'Processes' section of the discussion.

5 Conclusions

The implemented prototype CUMULEO-RAM model is a tool to scale impacts from activities to population relevant indicators, although actual population size and distribution cannot be determined with the prototype. Focus for future work should therefore be expansion of the human activities and pressures and not so much to attempt to incorporate population dynamics. The latter should be modelled separately when more detailed answers are necessary.

The strength of the presented approach lies in the transparency of the methodology, assumptions and parameterisation. Therefore it is an approach that can be relatively easily understood and can be used to deduce. It combines spatial data to get insight in effects on survival and reproduction. It's simplicity makes adjustments and extensions uncomplicated. It's visual aspects combined with the speed of the calculations makes it a powerful tool to support discussions with experts: does the model produce results experts would anticipate? As a result the approach is also useful to guide or focus future research.

The implemented prototype currently assesses potential population effects. The methodology would become much more powerful if it is combined with habitat suitability maps: actual effects can only occur if pressures are located in suitable habitats. For birds, distinction between resting, reproduction and forage habitat should be made.

6 Recommendations

The following recommendations are made to improve the implemented CUMULEO-RAM prototype:

- Obtain/develop habitat suitability maps in order to combine with reproductive rate maps.
- Explore alternatives for the reproductive rate.
- Testing of the model,
    - Compare combination of reproductive rate and habitat suitability maps with actual presence maps of species;
    - Show applicability of the model in a project in which model input and output are combined with expert opinion.
- Expand with more species, in order to obtain a more complete overview on for instance biodiversity.
- Expand with additional human activities,
    - Military training activities;
    - Tidal power generation;
    - Fossil fuel power generation;
    - ….
- Expand with additional pressures,
    - Toxic pressure;
    - Acoustic disturbance;
    - Thermal pressure (e.g., from heat discharges);
    - Changes in substrate;
    - …
- Perform uncertainty/sensitivity analysis with the model, including at least the uncertainty resulting from the parameters, but also that of the underpinning assumptions if possible.
- Refine time scale (from half a year to a quarter of a year for instance) where possible and necessary.
- Create a database with all parameter values linked with their source, to improve reducibility.
- Study the possibilities of aggregating the results into a single indicator for management decision support.
- Focus on MSDF descriptors of good environmental status.

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Annex 1 Fact sheets on cumulative pressure calculations

The cumulative calculations were based on the data and knowledge available within IMARES relating to the various fishing activities (VMS registrations). In standard analyses and the maps presented with them, this is represented as a series of adjacent areas (grid cells). These grid cells measure 2 minutes longitude by 1 minute latitude, approximately 1 nautical mile by 1 nautical mile. The surface of each grid cell is not constant: the further north the cells are (towards the poles), the smaller they become. The distance between the longitudes is reduced to zero at the pole and is greatest at the Equator.

At this spatial scale (1 by 1 nautical mile = 1,852 x 1,852 km), optimal use is made of the data as known about the various fisheries. For all other activities, the results are also given in these grid cells.

For all the assessed activities, a compromise is thus made between the necessity of being able to make such an assessment and its limited accuracy. This limited accuracy is partly inherent to the way in which the data is provided. For example, the waterways are known as lines (one dimensional), but it is physically impossible for shipping to navigate such a narrow waterway.

For each activity, based on the available map material and a minimum number of records, a picture of the distribution of the presence (hours) and abrasion is created. The attribution of the hours or disturbed seabed surfaces is only done as the last step, in order not to risk the available precision too early in the process.

On the other hand, by up scaling to a spatial scale of 1 by 1 nautical mile, for most activities their exact location is not critical. The details are naturally lost in the up scaling.

Activity:	**Ferry services**
Basic material (map):	Waterways dataset as supplied for the NEA study
Disturbance type:	Presence
Values applied:	Distance according to available GIS datasets Length of journey according to shipping company websites Number of sailings per season according to timetables on shipping company websites
Background to the values applied & assumptions:	
The expected time that a ferry will stay in the area is known based on the planned duration of the crossing. The number of crossings is known from the timetable. The length of the route and the ferry's journey time helps assess the speed. By calculating with an average speed, the length of time that a ferry is in the area is slightly longer than in reality. This is because part of the total duration of the crossing involves slow manoeuvring in the harbour on arrival and departure. The calculation is therefore slightly conservative in the sense that it tends towards an overestimation. The total presence of a ferry in the area is attributed to the calculation areas (cells or grids) based on the share that each cell has in the total ferry route.	

The summer or winter ratio is also known from the timetables.	
Sources:	Voortoets Waddenzee [Preliminary assessment Wadden Sea] (RWS 2008.054) table 2.18 and the shipping companies' websites: http://www.teso.nl/; http://www.rederij-doeksen.nl/; http://www.wpd.nl/

Activity:	**Commercial shipping**
Basic material (map):	Waterways dataset as supplied for the NEA study With extension of the waterway sections in the NSCZ beyond the outer boundary thereof (direction based on the direction of the waterway).
Disturbance type:	Presence/Visual disturbance
Values applied:	The smallest waterways have been given use intensities for commercial shipping for 5 ships on a yearly basis, other small waterways 10 or 25 respectively. Of the busier waterways, the 1000 to 2500 category is the most common. The highest intensity is attributed to the waterways near the port of Den Helder with 10000 to 15000 ship movements on a yearly basis. The summer/winter ratio has been set at 60%/40%.
Background to the values applied & assumptions:	
In the attribution of intensity of shipping movements to the available waterways, use is made of the WATIS map (from 2001 = image material) and the distinguishing possibilities in various waterway classes. When attributing intensity, particularly with respect to categories for which the WATIS map showed values between 50 and 750, a slightly higher value was attributed. Thus in this map, any growth of shipping is compensated in the cumulative calculations. The other place where significant growth occurred is the entrance to the port of Den Helder from the North Sea, where there has been a huge increase in shipping movements (particularly of supply ships for the offshore oil and gas industry) since the production date of the WATIS map. Some of the growth in transhipment and economic value since 2001 to the present day is not the result of more ship movements, but due to an increase in the average size of the ships. The increase in ship movements is smaller than that of transhipment and/or economic values. In attributing the presence, a typical speed of 10 knots (18.52 km/h) is assumed. This is reasonable for these ships based on the known speed of similar sized ferry boats with a speed of 9.9 knots. Although most of the ships can reach higher speeds, when approaching ports and/or navigating difficult waterways like the bending channels of the Wadden Sea, such speeds will not be feasible. In combination with the route length in a cell and the number of ship movements on that route, the number of hours that ships will be present in the cell can be calculated. When attributing the number of ship movements based on the WATIS map, the available routes are also taken into account. This means that the number of ships on both sides of a division or merger of waterways must be logically related to each other. The ratio used, i.e. 60% in the summer six month period versus 40% in the winter six month period of the figures on a yearly basis is based on the assumption that for the Wadden islands, the summer period is slightly busier due to the presence of tourists requiring more supplies.	
Sources:	WATIS map (volume 2001) of shipping densities as published in the RIKZ Werkdocument RIKZ/AB/2004.612, Menselijke belasting Waddenzeegebied door scheepvaart en atmosferische depositie [Human impact Wadden Sea area by shipping and atmospheric deposition], Bellert *et al.* 2004 RWS map Scheepsvaardichtheid NCP [Shipping density NCP] (production year 2001, volume data 1999/2000)

	Transhipment data (development in recent years) for the ports of Den Helder, Harlingen and Delfzijl/Eemshaven as included in Voortoets Waddenzee, RWS 2008.054, fig. 2.5

Activity:	**Recreational shipping**
Basic material (map):	Waterways dataset as supplied for the NEA study With extension of the waterway sections in the NSCZ beyond the outer boundary thereof.
Disturbance type:	Presence/Visual disturbance
Values applied:	The smallest waterways have been given use intensities for commercial shipping of 5 ships on a yearly basis, other small waterways 25. Of the busier waterways, the category of 2500 is the most common. The categories 1000 and 5000 are also frequent. The summer/winter period ratio is set at 75%/25%.
Background to the values applied & assumptions:	
When attributing the intensity of ship movements to the available waterways, use is made of the WATIS map (of 2001 = image material) and the distinguishing possibilities in various waterway categories. When attributing intensity, particularly with respect to categories for which the WATIS map gives a value of around 1700, a clearly higher value is attributed, i.e. 2500. Thus in this map any growth in shipping is compensated in the cumulative calculations. The fact that the recreation shipping has increased since 2001 is also documented based on Lock counts. When attributing the presence, a typical speed of 6 knots (11.11 km/h) is assumed. This assumption is reasonable for these ships in relation to the speeds of ferry boats and commercial shipping. Many of the ships are technically capable of reaching higher speeds, but due to the relatively low effective speeds used, the presence on the water is overestimated. In practice, it is probable that more time is actually spent in marinas. In combination with the route length in a cell and the number of ship movements on that route, the number of hours that ships will be present in the cell can be calculated. When attributing the number of ship movements based on the WATIS map, the available routes are also taken into account. This means that the number of ships on both sides of a division or merger of waterways must be logically related to each other. The ratio used, i.e. 60% summer six month period versus 40% winter six month period of the figures on a yearly basis is based on the assumption that for the Wadden islands, the summer period is slightly busier due to the presence of tourists requiring more supplies.	
Sources:	WATIS map (volume 2001) of shipping densities as published in the RIKZ Werkdocument RIKZ/AB/2004.612, Menselijke belasting Waddenzeegebied door scheepvaart en atmosferische depositie [Human impact Wadden Sea area by shipping and atmospheric deposition], Bellert *et al*. 2004 RWS map Scheepsvaardichtheid NCP [Shipping density NCP] (production year 2001, volume data 1999/2000) Waddenzee.nl Sluistellingen recreatievaart http://www.Wadden Sea.nl/Feiten_en_Figures.1901.0.html

Activity:	**Tiding over on sand flats**
Basic material (map):	Locations (names) of popular moorage locations for ships.
Disturbance type:	Presence/Visual disturbance, abrasion
Values applied:	Total number of moored ships (2400) is estimated on basis of statistics from the Voortoets Waddenzee and then based on a ranking attributed to the available locations.

	The presence at a moorage location is set at 12 hours. The abrasion is set at 50 m^2, corresponding with ship dimensions of approx. 5 by 10 metres. Summer/winter ratio 85/15%.
Background to the values applied & assumptions:	
A list is available of the six popular moorage locations: Richel, Oostpunt Terschelling, Engelsmanplaat, Oost Schiermonnikoog, Oerd and Simonszand. A central location is placed on the map for each of these locations; around these points an area is defined with a radius of 1 km as tidal flat area. The available statistics from the Voortoets Waddenzee are for various sub areas and from several organisations, including LNV, SBB, Fryske Gêa, BBZ and Wadvaarders collected in 2005/2006. The numbers and characteristics of the observations vary considerably from many and big ships or only a few, mainly smaller ships. The calculation value of 2400 has been chosen as a reasonable compromise. An estimate of the popularity of the areas from the statistics and the current availability means that in the cumulation some of the popular places in the statistics only have a few moorages. Richel is currently closed all year round pursuant to Art. 20 and Simonszand from 15 May to 1 September. These places only have a few moorages. Based on the ranking, the following distribution of moorages over the locations was produced.	

Moorage location	Percentage
Richel	5%
Oostpunt Terschelling	24%
Engelsmanplaat	29%
Oost Schiermonnikoog	19%
Oerd	14%
Simonszand	10%

Sources:	Voortoets Waddenzee (RWS 2008.054) Tables paragraph 4.1

Activity:	**Gas extraction**
Basic material (map):	Platform dataset as supplied for the NEA study.
Disturbance type:	Presence/Visual disturbance
Values applied:	Platform is present all year round: 8760 hours/year. Summer/winter ratio 50/50%.
Background to the values applied & assumptions:	
-	
Sources:	RWS, GIS data supplied on DVD

Activity:	**Hiking in tidal areas**
Basic material (map):	Mudflat routes dataset as supplied for the NEA study
Disturbance type:	Presence/Visual disturbance
Values applied:	Total number of hikers in tidal areas is derived from the statistics available from Waddensee.nl. Number of participants and size of groups are also derived from this information. The duration and distance walked during a trip is also derived from Waddensee.nl. Summer/winter ratio 95/5%.
Background to the values applied & assumptions:	
Based on the reported statistics and popular routes, times can be derived for the length of a mudflat hike. The calculation uses the planned number of walks advertised by the various organisers on their websites. This also takes into account an attribution according to the region/route on which the walkers will be active. For each trip, the average number of participants per trip and the organiser are taken into account. In the end calculation, the value for disturbance due to the presence of the mudflat walkers is adjusted	

downwards. The reason for this adjustment is that the disturbance of a group of mudflat hikers is overestimated if these are considered as a series of individuals who perform their activity spread out over the mudflat. Members of a group tend to walk close to the other members. In this group factor (based on 10), by using a disruption distance of 500 m for the group (rather than 250 m for one person), a major underestimate can be avoided. In essence, a group of mudflat hikers is now assessed at a similar level to a group of tourists on a boat or seal trip. The trips advertised for 2010 give a distribution of this activity over the summer and winter period of 90/10. For the calculation, these values have been adjusted to 95/5 based on the assumption that the number of participants per trip in October (the month in which most 'winter trips' are planned) is clearly lower than during the high season in summer.	
Sources:	http://www.Wadden Sea.nl/Feiten_en_Figures.1901.0.html http://www.Wadden Sea.nl/Wadlooproutes.190.0.html Websites of : Dykstra`s Wadlooptochten, FryskeWaedrinners, Stichting UithuizerWad, Stichting Wadloopcentrum Pieterburen, Wadgidsengroup Noord Nederland, Wadloopcentrum Fryslân, Wadlooporganisation Arenicola

Activity:	**Kite surfing**
Basic material (map):	Originally supplied GIS datasets with kite surfing areas and location (spot), including supplementary data received later (for the NEA study).
Disturbance type:	Presence/Visual disturbance
Values applied:	Number of surfers present on a 'normal day' in the season: 10 Idem outside the season: 2 Number of hours that a surfer is active in a day: 4 Number of days a week that kite surfers are active: 3 (2 days at weekend 2 and 1 other weekday).
Background to the values applied & assumptions:	
According to the website of the Nederlandse Kitesurfvereniging [Netherlands Kite Surfing Association], there are 10000 active kite surfers in the Netherlands. These numbers are not further linked to certain locations, nor are there any other indications on which to assess the popularity of certain spots in the WS/NSCZ. For this reason, all locations are treated the same. The values used for the calculation are described above. These values seem to be realistic in relation to other use categories and incidental observations of kite surfers present at certain locations. By introducing a difference between a 'normal day' during the season (summer six months) and outside the season, a differentiation between these periods automatically occurs.	
Sources:	Website Nederlandse Kitesurfvereniging: http://www.nederlandsekitesurfvereniging.nl/

Activity:	**Seal watching**
Basic material (map):	Waterways, exposure time of tidal flats (sublitoral), Seal sites
Disturbance type:	Presence/Visual disturbance
Values applied:	300 trips per organiser, average trip length 2 hours. Total number of organisers: 22. Summer/winter ratio: 70% / 30%
Background to the values applied & assumptions:	
Based on information from the Voortoets, the limiting conditions under which seal trips may be organised are clear: seals may not be approached too close causing them to escape into the water; the escape route into the water may not be obstructed (or risk being obstructed); passengers on board may not make any noise or sudden movements. The period in which the seals may be observed during the trip is around 20 minutes. The length of the activity is around 2 hours. In the closed Blauwe Balg area near Terschelling, 4	

permit holders may organise a total of 800 trips (per year). An online search for organisers was also conducted (n=9) and data collected such as the port from which they operate, how many trips they offer, how long they last and when these are planned. Other organisers (n=5) have no (advertised) planning or the ability to deploy extra ships if there is enough demand. In order to compensate for this and for any unknown organisers, extra organisers were added for the home ports (n=8), based on an estimate of the potential market size. For each port (8) from which seal trips are organised, a region was determined which was covered by this port, based on the range of the ship during the total duration of the activity minus the observation period and the location of the destination of the seal sites.	
Sources:	Voortoets Waddenzee (RWS 2008.054) Organisers" websites: (with calendar/planning) http://www.sikkema.nl/zeehond/html/afvaart.htm http://www.dageraad.nu/robben.aspx http://www.sportvissentexel.nl/pages/robbentocht.htm http://www.robbenboot.nl/nederlands/afvaarten.php http://www.rondvaartmakkum.nl/agenda.html http://www.zeestertx35.nl/index.php; http://www.dezeeleeft.nl/ http://silverwind.lauwersland.nl (without calendar/planning): http://www.janrotgans.com http://www.bruinvis.nl/ http://www.terschellingrondvaart.nl/ http://www.waddencruises.nl/

Activity:	**Angling trips**
Basic material (map):	Waterways, exposure time of tidal flats (sublitoral)
Disturbance type:	Presence/Visual disturbance
Values applied:	4000 departures on a yearly basis for a total of 19 organisers, average trip duration 8 hours. Summer/winter ratio: 70% / 30%
Background to the values applied & assumptions:	
Waddensee.nl offers statistics about this activity for 2005. There is also information in the Voortoets Visserij Waddenzee. Online search also conducted. This showed that no angling takes place in the North Sea Coastal Zone. Organisers of the sport mainly operated from Den Helder and give a sailing time to the 1st fishing place of between one and one and a half hours, which is thus outside the research area. For the Wadden Sea, some organisers (n=10) publish a timetable. There are also sites which offer ships, but do not indicate the number of sailings or the duration of the trips. Information was also collected about the port from which they operate, how many trips they organise, how long they last and when they are planned. Other organisers (n=5) have no (advertised) planning or ability to deploy extra ships when demand requires. Based on a similar consideration as applied to the organisers of seal trips, 9 fictional organisers were added (presence of both market and supply). For each port (4: Den Oever, Oudeschild, Den Helder, Harlingen), a region was determined which was covered by this port, based on the range of the ship (ca. 25 km.) and available routes.	
Sources:	Waddenzee.nl http://www.Wadden Sea.nl/sportvissen.252.0.html Voortoets Visserij Waddenzee (IMARES, C093_08)

	Organisers' websites: (with calendar/planning) http://www.sportvissentexel.nl/pages/prijzen.htm http://www.dageraad.nu/opstappen.aspx http://www.swrw.nl/ http://www.sportvisserij-stella.nl/ http://www.degrootrecreatie.nl/sportvissen/ http://www.wad-anders.info/sleepnetvissen.html http://www.maria-hendrika.nl/ http://www.wuta.nl/ http://www.goedkoop-sportvissen.nl/sportvissen.html http://www.hendrik-karssen.nl/start.html http://www.makreelvissen.nl/prijzen.html http://www.sportvisserijmercure.nl/ http://www.ms-tender.nl/ (no calendar/planning): http://zeevissen.startpagina.nl/ http://www.sportvisserij_Waddenzee.nl

Activity:	**Mussel cultivation**
Basic material (map):	Mussel cultivation dataset as supplied for the NEA study.
Disturbance type:	Presence/Visual disturbance, abrasion
Values applied:	Presence: 74 hours in the summer and 10 hours in the winter per mussel bed. Abrasion: 66% of the surface of the mussel bed in a VMS grid cell is calculated as disturbed surface.
Background to the values applied & assumptions:	
The presence of ship and fishermen on a mussel bed is established on the basis of the data collected by the PB Nieuwe Mosselpercelen, which indicates the month in which certain work is carried out, how much time this involves, etc. This results in the number of hours per mussel bed as included under Values applied. The total number of mussel beds is established at 494. It also emerges that of the allocated beds, around 50% are also considered suitable for mussels; the rest is overhead. On this basis, it was decided to include 66% of the mussel bed for abrasion. This is then the relevant area plus a margin for going 'over the edge' by fishing.	
Sources:	PB Mosselpercelen [PB Mussel Beds] (Fisheries Directorate, September 2005)

Activity:	**Mussel seed collector**
Basic material (map):	Mussel seed collector dataset as supplied for the NEA study.
Disturbance type:	Presence/Visual disturbance
Values applied:	Presence is 21 days in the summer and 6 days in the winter, with 9 hours in an active day for an mussel seed collector surface of 50 ha.
Background to the values applied & assumptions:	
In report C088/09, table 4 gives a brief overview of the actions and activities for an mussel seed collector of a 50 ha mussel bed, using a long-line or tube system. These values are also used here, applying 9 hours for an active day.	
Sources:	Ecologische analyse van potentiële locaties voor mosselzaadinvang (MZI) in Nederlandse kustwateren, [Ecological analysis of potential locations for mussel seed collection (MZI) in Dutch coastal waters], R.H. Jongbloed, A.C. Smaal, C.J. Smit, M. Poelman, A.G. Brinkman, N.M.J.A. Dankers, I.G. de Mesel & J.A. van Franeker, Report C088/09, IMARES Den Helder, 7 October, 2009

Activity:	**Mussel seed fishery**
Basic material (map):	Edited Blackbox data Mussel seed fishing (approved by PO Mosselcultuur [PB Mussel Culture]).
Disturbance type:	Presence/Visual disturbance, abrasion
Values applied:	Presence: Fished hours based on the blackbox data scaled up to the VMS grid cells. Abrasion: 1 hour of fishing results in 42225 m^2 disturbed seabed. This activity only takes place in the six summer months.
Background to the values applied & assumptions:	
The analysis used the (detailed) blackbox data as collected for the mussel seed fishing. Approval for this was requested and obtained from the owner of PO Mosselcultuur. The same years 2006-2008 as analysed for the other fishing types were used. The actual hours fished was determined in a VMS grid cell. These hours were converted to the disturbed seabed area based on the following data: a blackbox registration counts as 'fishing' with speeds between 1.3 and 7 knots; for the calculation, the value 3 knots was used. When fishing, per ship 4 mussel trawl nets were used, each 1.90 m. wide.	
Sources:	Database with blackbox registrations from the mussel seed fisheries with relevant documentation. Data management was carried out by IMARES, permission to use the data was requested from the owner: PO Mosselcultuur

Activity:	**Fisheries for Ensis**
Basic material (map):	VMS grid (2 min Lon by 1 min Lat, approx 1 x 1 nautical mile).
Disturbance type:	Presence/Visual disturbance, abrasion
Values applied:	Presence: Fished hours based on VMS registrations abrasion: 1 hour fishing results in 300 m^2 disturbed seabed Summer ratio.
Background to the values applied & assumptions:	
The analysis used the VMS registrations of this type of fishing. See also Trawler fishing Factsheet for more information (below). The period studied is 2006-2008. These hours are converted into the disturbed seabed area based on the following data: the width of the vessel used is 1 metre, the maximum distance travelled during 1 hour's fishing is 300 metres, in accordance with values included in the Voortoets Visserij NSCZ.	
Sources:	VMS registration database (Min. LNV, IMARES) SAS processing scripts for VMS registrations (IMARES) Voortoets visserij effecten Noordzeekustzone, Kwalitatieve analyse van visserijeffecten op Natura 2000 instandhoudingsdoelen t.b.v. het Beheerplan Noordzeekustzone [Preliminary assessment fishing effects North Sea coastal zone; qualitative analysis of fishing effects on Natura 2000 conservation targets for the North Sea Coastal Zone Management Plan] (LNV Helpdeskvraag 08-46), DME Slijkerman, JE Tamis, OG Bos, HM van Overzee, RG Jak, Report C090/08, IMARES, Den Helder, 24 November 2008

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Activity:	**Beam trawl fishery (Eurobeamer to 300 hp engine power).**
Basic material (map):	VMS grid (2 min Lon by 1 min Lat, ca. 1 x 1 nautical mile).
Disturbance type:	Presence/Visual disturbance, abrasion
Values applied:	Number of VSM registrations per (grid) cell. Length of time per registration is 2 hours, as long active fishing at the time of registration. Vessel width is 2 x 4 m trawler (both sides of the ship). Exact summer/winter ratio is known based on the quarterly statistics.
Background to the values applied & assumptions:	
In compliance with EU regulations, nearly all fishing vessels have equipment which regularly records the	

following data: identity of the ship, date, time, speed and course. The standard frequency with which this is recorded is 1 x 2 hours, whereby the time of registration is not known – not affected. For some time, IMARES has been making maps and presenting analyses with a spatial resolution of around 1 by 1 nautical mile. With the current registration frequency, this is a good compromise between making a spatial distinction and the reliability of the data. The data used are supplied in basic data files, whereby the individual ships are no longer recognisable. For the analysis, the data of both summer quarters (Q2 = April-June and Q3 = July/Sep) are attributed to the summer six month period and those of Q1 (Jan-Mar) and Q4 (Oct-Dec) to the winter six months. The decision as to whether a VMS registration is included as 'fishing' is based on the speed with which the ship is travelling at that moment. Speeds between 3 and 6 knots (nautical miles per hour) are included as 'fishing' in the map material. The vessel breadth to be used (4 metres for trawlers in this power category) is also standardised and is considered representative for this segment of the fishing fleet. For the NEA cumulation calculations, it was decided to use the relatively accurate grid on which the VMS registrations is known as the basis of the calculation. The various types of fishing are important activitys which are also fairly well known. This is seen as the 'hard' basis of the analysis. (Map material is also available for shrimp fishing and otter trawling based on VMS registrations). The VMS registrations used are from the years 2006 to 2008 inclusive. They thus form a combination of three years, with regard to fishing activities. The presence of an active trawler fisherman is directly derived from the number of VMS registrations in a cell. For the calculation of the disturbed seabed area, a speed of 4.2 knots (rounded to 8 km/h) is also used, meaning that 1 VMS registration results in 2 hours * 8 km/h * 2 nets * 4 m wide = 228000 m2 or 22.8 ha. A cell has a surface of around 343 ha. The abrasion is expressed as relative measure compared with the total surface area of the cell. In the numbers used here, this relative measure for abrasion (disturbed seabed area/ cell area) amounts to 1 by 15 VMS registrations in a cell. This analysis only refers to the part of the fishing fleet which fishes with a maximum engine power of 300 hp. These so-called beam trawlers may operate in the Wadden Sea and the North Sea Coastal Zone. According to EU regulations and current Dutch legislation, bigger ships (over 300 hp) must fish further offshore and are not therefore considered to be active in the study area. The presence of these big fishing vessels is limited to their presence as a sailing ship and thus belongs to the assessment of commercial shipping. N.B. Here a cell area is considered to be around 343 ha because although the exact area per cell is known, it is not universally the same. Due to the shape of the globe, these cells become smaller the further north one goes.	
Sources:	VMS registration database (Min. LNV, IMARES) SAS processing scripts for VMS registrations (IMARES)

Activity:	**Shrimp fishery (Eurobeamer to 300 hp engine power).**
Basic material (map):	VMS grid (2 min Lon by 1 min Lat, ca. 1 x 1 nautical mile).
Disturbance type:	Presence/Visual disturbance and abrasion
Values applied:	Largely the same as trawler fishing (see relevant sheet).
Background to the values applied & assumptions:	
The speed at which shrimp fishermen are considered to be actively fishing based on the VMS registration is between 3 and 4 knots. To calculate the disturbed seabed area, a speed of 6.5 km/h (within this range) is used. The typical width of shrimpers is 2 x 9 m. (both sides of the ship).	

For further information, see trawler fishing.	
Sources:	VMS registration database (Min. LNV, IMARES) SAS processing scripts for VMS registrations (IMARES)

Activity:	**Otter trawl fishery (Eurobeamers, to 300 hp engine power).**
Basic material (map):	VMS grid (2min Lon by 1 min Lat, ca. 1 x 1 nautical mile).
Disturbance type:	Presence/Visual disturbance (No assessment of abrasion, see background).
Values applied:	Largely the same as trawler fishing (see relevant sheet).
Background to the values applied & assumptions:	
The active fishing presence of otter trawlers is based on the VMS registrations and the speed at the moment of registration. The 'fishing' range is between 3 and 5 knots. To calculate the disturbed seabed area caused by this fishing, a value is determined of 3.9 knots (geometric average of the marginal values) for the calculation, i.e. rounded to 7.5 km/h. However it is not possible to properly establish the extent of the abrasion caused by otter trawlers. The width covered by this net depends on many factors, including the position of the trawls, the planned catch, speed and possible depth of the water. It is not therefore possible to establish a typical value for the calculation.	
Sources:	VMS registration database (Min. LNV, IMARES) SAS processing scripts for VMS registrations (IMARES)

Activity:	**Shellfish collecting (for own use)**
Basic material (map):	Dyke wall dataset as supplied for the NEA study Exposure time of tidal flats dataset as supplied for the NEA study
Disturbance type:	Presence/Visual disturbance and abrasion
Values applied:	Shellfish collection (mainly) takes place within 750 metres of a dyke, in tidal flat areas with an exposure time of 50% (of the tidal cycle). Summer: period 1 searcher/day per 4 km. dyke length for 7 days/week Winter: only for 2 day/week Disturbed seabed area 25 m2 per searcher/collector Visit duration 1.5 hours per searcher/collector Disruption distance per 250 m (individual walker/mudflat walker)
Background to the values applied & assumptions:	
Based on the features with which the activity Collecting Shellfish is described in the NEA concept reports, a data set is constructed using GIS and available map material specifically for this use. Due to the limiting condition of availability, it has been decided to refer to dykes (dyke walls) which are usually easy to access by car (or bicycle). The searchers are generally private individuals looking for shellfish for their own use and who normally do so at low tide and thus at a safe distance from the dyke (escape possibility). This safe distance is estimated at 750 m. No hard facts are known about the extent of this activity. The final calculation is based on the assumption that in the summer season there will be 1 active searcher per day per suitable length of dyke. In the winter season, the number falls to only 2 days a week (=weekend). This then produces a summer/winter ratio of around 80/20%. The GIS analysis produces numerous areas with a circumference (instead of dyke length); this value (in metres/8000) is multiplied by 26 (number of weeks per six month period) and with either the visit duration of 1.5 hours or the turned over surface per visit 25 m^2) for presence or abrasion. For the end result for abrasion, this must be divided by the total cell area within which the activity falls. The values presented here have been adjusted on the basis of the probable extent (=considerably smaller) of this activity compared with the Ground Baiting activity, about which more is known. The original version clearly overestimated the extent.	

If there are more people involved in collecting shellfish in the area, this is not critical for the current estimate, as long as these people mainly operate (very) close to the dyke. Their activity is then not markedly distinguishable from any cyclists and walkers who might be present on the dyke, and who are not taken into account here.	
Sources:	Verstoringsafstanden [Disturbance distances]: Jak *et al.* (2000, TNO-MEP) NEA report about collecting shellfish

Activity:	**Cockle collecting**
Basic material (map):	Data sets about sludge levels, exposure time of tidal flats, exclusively for 'fishing involving abrasion' and Article 20 areas, as supplied for the NEA study. Supplemented with the exception 'island-1st channel' as included in the permit granted for 2008-2009.
Disturbance type:	Presence/Visual disturbance and abrasion
Values applied:	Presence: 52000 hours on a yearly basis abrasion: 150 ha on yearly basis Summer/winter ratio: 66%/37%
Background to the values applied & assumptions:	
The area that is suitable for manual cockle fishing is determined on the basis of information from the PB Handkokkelen, the permit for 2008-2009 and C047/08. It thus becomes clear that a high density of cockles is desirable, that cockles prefer sludge-rich locations and occur in the highest densities in tidal areas with low exposure times of 40% to 60%. In the GIS, this is interpreted as areas with sediment type sludge in combination with the 25-75% low exposure times. This area is then subject to numerous exclusions such as 'fishing involving abrasion', Article 20 areas and the areas which are excluded in the permit between the islands and the 1st channel (PDF maps, belonging to the permit). Per tide cycle, fishing takes place for 3 hours (2 hours in outgoing tide and 1 hour in incoming tide). According to the sources mentioned, there are 31 active manual cockle fishermen, the maximum amount of cockles which may be harvested is 1050000 kg (meat weight). In the period 1995-2006, an average 210000 kg was harvested (20%). The catch per 'half tide' is around 300 kg gross. The meat percentage varies from 10-22%. Based on a meat percentage of 15%, a half tide produces 45 kg cockle meat. In order to achieve the maximum permitted amount, around 1450 man weeks are involved (over 58000 hours). Another estimate is constructed as follows: 30 manual cockle fishermen are least active in late winter and early spring; in this period the cockles are thin and yield the least meat. That results in around 40 weeks of activity on a yearly basis, i.e. 1200 man weeks (48000 hours), with a ratio 2/3 summer, 1/3 winter. The estimate used is the mid value between both estimates. The estimate is conservative in that it is based on harvesting the maximum permitted quantity, of which historically only 20% is harvested. According to the various sources, the maximum permitted surface of 300 ha on a yearly basis is not achieved; at most 150 ha is fished on a yearly basis. This value is spread over the available area.	
Sources:	Handkokkelactiviteiten in de Waddenzee, Antwoord op een aantal vragen van de Provincie Fryslân [Manual cockle activities in the Wadden Sea. Answers to various questions from the Province of Friesland], A. G. Brinkman, B.J. Ens, J. Jansen, M.F. Leopold, Report C047/08, IMARES Texel, 19 June 2008 PB Handkokkelen Vergunning Handkokkelen 2008-2008 [Manual cockle fishery permit 2008-2008]

Activity:	**Lugworm collecting**
Basic material (map):	Dyke wall dataset as supplied for the NEA study Tidal flat dataset as supplied for the NEA study
Disturbance type:	Presence/Visual disturbance and abrasion
Values applied:	Presence: 62000 hours on a yearly basis Abrasion: 65 ha on a yearly basis Summer/winter ratio 75%/25%
Background to the values applied & assumptions:	
The sources mentioned clearly show that with regard to geographical distribution, ground baiting is very similar to collecting shellfish as an activity. Access is important, so near dykes. Because this is an economic activity and the baiters are experienced in the area, their range is further from the dyke; a distance of 1000 metres was therefore chosen. This takes into account the fact that it is hard work and that the catch must also be transported. In GIS, based on these characteristics, a suitable area for ground baiting has been identified. Based on the data with respect to the size of the market (100 tons per year) , the number of lugworms a professional fisher can catch (around 1000), the number of tides required to collect such a quantity (around 15500) can be estimated. In a workable number of hours of 4 per tide (approx. in accordance with manual cockle fishing), this results in an estimate of around 62000 hours on a yearly basis. Based on an average worm density of 24/m^2 (Balgzand, '85-'07), an area of 65 ha must be turned over, possibly more because the catch efficiency is not 100%. However, this is compensated if the cockle fisher knows the best areas to find. No numbers of active professional cockle fisherman are known, but based on the required number of tides and the assumption of 5 workable tides per week and 40 workable weeks per year, there could be between 75 and 80 active professional cockle fisherman. The summer/winter ratio has been established at 75%/25%. This takes into account the fact that demand and the appeal of ground baiting is considerably greater in summer, partly because higher demand also means a better price. Moreover, additional care needs to be taken in winter due to strong wind and/or cold water, which can result in (too) dangerous conditions.	
Sources:	Voortoets visserij Waddenzee [Preliminary assessment Wadden Sea fisheries] (C093/08) Voortoets visserij Noordzeekustzone [Preliminary assessment North Sea Coastal Zone] (C090/08) Oplegdocument aanpassingen Voortoets visserij Waddenzee [Implementation document adjustments Preliminary assessment Wadden Sea fisheries] (10-06-2009) Oplegdocument aanvullingen voortoets [Implementation document preliminary assessment] WZ 9-7.doc Rapport Wadpierenvisserij [Mudflat worm fishery report] (Leopold & Bos, C013/09) Raad voor de Waddenzee, Advies Waddenzeevisserij [Council for the Wadden sea, Advice Wadden Sea Fisheries] (Dec. 2007)

Activity:	**Otter trawl fishery (Eurobeamer, to 300 hp engine power).**
Basic material (map):	VMS grid (2 min Lon by 1 min Lat, approx. 1 x 1 nautical mile).
Disturbance type:	Presence/Visual disturbance (no assessment of abrasion, see background).
Values applied:	Largely the same as for trawl fisheries (see relevant description).
Background to the values applied & assumptions:	
The active fishing presence of otter trawlers is determined on the basis of the VMS registrations and the speed at the moment of registration. The 'fishing' range for the speed is 3 to 5 knots. In order to calculate	

the disturbed seabed area caused by this fishing, a value is determined to be able to calculate of 3.9 knots (geometric average of the marginal values), or rounded to 7.5 km/h. However it is not possible to properly establish the extent of abrasion caused by otter trawlers. The width covered by this net depends on many factors, including the position of the trawls, the planned catch, speed and possible depth of the water. It is not therefore possible to establish a typical value for the calculation.	
Sources:	VMS registration database (Min. LNV, IMARES) SAS processing scripts for VMS registrations (IMARES)

Activity:	**Mechanical lugworm extraction**
Basic material (map):	Permit areas for mechanical lugworm harvesting as supplied for the NEA.
Disturbance type:	Presence/Visual disturbance, abrasion
Values applied:	Presence: 3600 hours on a yearly basis Abrasion: 94.5 ha on a yearly basis Summer/winter ratio: 60%/40%
Background to the values applied & assumptions:	
There are currently two companies with a permit to mechanically harvest lugworms. Each has a permit for a certain area. The location of these areas is known and supplied as a GIS file. Based on data from the permits and relevant assessments, both the presence and the abrasion can be established for both permit holders. Arenicola: Operates all year round, 2 trawls per tide at low water, trawl lengths of 200 to 500 metres, with a width of 1.2 metres and a speed of 2-4 metres/minute. A trawl length of 400 metres was used, which produces a disturbed area of 1000 m2 per tide. Based on a speed of 3 metres/minute, this takes 5 hours. The PB also mentions an estimated total area of disturbed seabed of 27 ha, which translates into 270 tides x 5 hours and is a presence of 1250 hours on a yearly basis. Balgzand: Operates all year round, 5 trawls per tide at high water, max. length 450 metres. The PB gives a disturbed seabed area per tide of max. 2700 m^2, which corresponds to a trawl width of 1.2 metres. The trawl speed is not given, but based on a value of 4 metres/minute, 5 trawls take over 9 hours work, per tide cycle. As given in the PB, an estimate is made of maximum 67.5 ha disturbed seabed area on a yearly basis. That translated into 250 tides active fishing per year and is thus 2350 hours. The fact that the dredgers are usually left unmanned on the mudflat was not taken into account in the presence, nor was the fact that the crew comes and goes in other ships. This has partly already been included with regard to commercial shipping.	
Sources:	PB Lugworm harvesting Balgzand PB Mechanical lugworm harvesting Arenicola Draft decision Duinker Draft decision Rotgans

Activity:	**Coastal defence (Sand suppletion)**
Basic material (map):	Data sets over recently (5 years) implemented suppletions and suppletions planned for the next 5 years, as supplied for the NEA study
Disturbance type:	Presence/Visual disturbance and abrasion
Values applied:	Based on data available in the GIS, lengths and volumes (x million m3) of

	sand to be suppleted are known. In combination with the additional data, a potential presence and abrasion can be determined. See Background below for further details. The sand suppletion activity is only attributed to the summer six month period, when the weather conditions are most suitable.
Background to the values applied & assumptions:	
In Noord-Nederland (study area), a maximum of 30 km along the coast is suppleted on a yearly basis. In combination with a realistic cycle of 1-1.5 hours extraction, 1 hour sailing, 1 hour compression or rainbowing and 1 hour return journey, plus hopper capacity of (min. 10 000 m3) with planned suppletion volumes, a time can be calculated per kilometre of 40 hours rainbowing and 80 hours sailing. The sub activity extraction was not taken into account because this takes place outside the NSCZ. Each sub area where suppletion has taken place (past 5 years) or is expected to take place (next 5 years) is known and is attributed a quantity of sand suppletion per summer period based on the local length over which suppletion can take place and the total year effort (30 km) which is available. For example, the suppletion site Ameland beach is around 13 km long, although there is a total of 93 km which can be suppleted. The rainbowing activity for Ameland beach is then given a total hour presence of 13/93 of 30 km * 40 hours = 168 hours. The same for abrasion area, the total area over which suppletion can be carried out is 4999 ha and 93 km long, but of which a max. 30 km is actually suppleted on a yearly basis. This area is thus 527 metres wide. Per square metre 'potential' sand suppletion area, there is therefore an average of 0.32 (30/93) m2 abrasion. These values are summarised per grid cell for the end assessment and finally divided for the surface of this grid cell. The sand suppletion activity is only carried out in the summer period due to the considerably better weather conditions during this period.	
Sources:	E-mail correspondence with internal expert IMARES (M. Baptist and external expert) about realistic cycle when carrying out suppletion work and hopper capacity.

NEA N2000 – Cumulation : North Sea Coastal Zone and Wadden Sea	
Activity:	**Shell extraction**
Basic material (map):	Permit areas for shell harvesting as supplied for the NEA, supplemented with data sets about water depth and seal sites.
Disturbance type:	Presence/Visual disturbance, abrasion
Values applied:	Presence: 9500 hours on a yearly basis Abrasion: 1250 ha on a yearly basis Summer/winter ratio: 50%/50%
Background to the values applied & assumptions:	
For the geographic distribution of shell harvesting, the following limiting conditions are also respected: no harvesting at less than 1500 metres from seal breeding, resting and nursing areas; harvesting only takes place in the deeper channels, at least 5 metres (below NAP, here a minimum of 5 metres). The supplied numbers are considered to correspond with the actual harvesting of around 150000 m^3 per year. However, the maximum permitted quantity is 180000 m^3. The supplied values have been upgraded. It also appears in current practice that several licensed areas are not used. In order to show possible wider distribution of shell harvesting over the licensed area as a whole, the distribution over the sub areas has been slightly adjusted. The limiting condition that a maximum of 50% of the harvested amount may come from Wadden Sea is hereby respected. The effective ratio NSCZ/WS is 60%/40%.	
Sources:	Spreadsheet with data supplied by Arcadis, among others based on the PB Schelpenwinning [PB Shell harvesting].

Activity:	Dredging (navigation channels)
Basic material (map):	Data sets with dredging locations and deposit locations as supplied for the NEA study, supplemented with several missing locations.
Disturbance type:	Presence/Visual disturbance, abrasion
Values applied:	Presence: 6900 hours on a yearly basis abrasion: 3700 ha on a yearly basis Only in winter
Background to the values applied & assumptions:	
For the geographical distribution, the normal dredging and deposit locations are used from the supplied data sets. As the overview received includes several dredging or deposit locations which were not yet in these data sets, these have been added. To determine the time involved in this activity, a processing capacity of 1000 m^3/hour is assumed for dredging and 2000 m^3/hour for depositing. Dredging needs to be more precise than depositing, so will take more time. Depositing can also be done by 'klappen', which is very fast. To determine the disturbed seabed area, an average dredging depth of 1 metre is assumed. For depositing, a layer thickness of 0.25 metre is assumed. In table 5.3 of the PB shell harvesting, this is the lower boundary of the layer thickness, whereby 'Only a few fast crawling and good diggers survive'. There is more abrasion as a result of depositing than dredging, due to the above assumptions, but also because considerably greater volumes are involved in depositing. With regard to dredging, only the locations within the Natura 2000 areas were studied; with regard to depositing, the volumes originating from the various ports were also taken into account. The given dredging volumes which can be linked to a clear location are included there, and the same applies to the volumes to be deposited. The dredged volumes for 'navigation channels' in the Wadden Sea district are divided over all the remaining dredging locations, in proportion to their surface. The depositing of this volume of dredged material is equally divided over all the remaining deposit locations.	
Sources:	Spreadsheet with data supplied by Arcadis, among others based on the various permits granted.

Activity:	Gillnet fishery
Basic material (map):	Exposure time of tidal flats as supplied for the NEA, supplemented with map material regarding water depth.
Disturbance type:	Presence/Visual disturbance
Values applied:	Presence: 6000 hours on a yearly basis Summer/winter ratio: 90%/10%
Background to the values applied & assumptions:	
Gillnet fishing usually takes place on tidal flats and along plate edges. In GIS, this is determined as a combination of the area with a low tide duration < 25% and the sublittoral area with a water depth of less than 5 metres. The tidal basin Eems-Dollard is excluded, as is the Eastern Wadden Sea, with the exception of the Eilanderbalg tidal basin (= near the Eastern point of Schiermonnikoog and Simonszand). All Article 20 areas are also excluded. It was decided to exclude all Art. 20 areas because of the big overlap in closure times, particularly in summer. Based on 5 hours gillnet/24 hours over 5 days/week for 8 active fishermen, because the active period runs from April to October, this calculation produces over 6000 hours' presence on a yearly basis. The summer/winter ratio is also derived from this. The values 5 hours /24 hours and 5 days/week are higher than the inspector's values. This is to	

compensate for gillnet fishing by recreational fishermen. The inspector did not take this into account because these permits will be abolished as of 2011. However, because the other activities mainly relate to the period 2006-2008, it is better to take this into account. Time is also attributed to the sub activity 'looking for fish'.	
Sources:	e-mail LNV inspector for the Wadden Sea district, whose answer has been discussed with colleagues

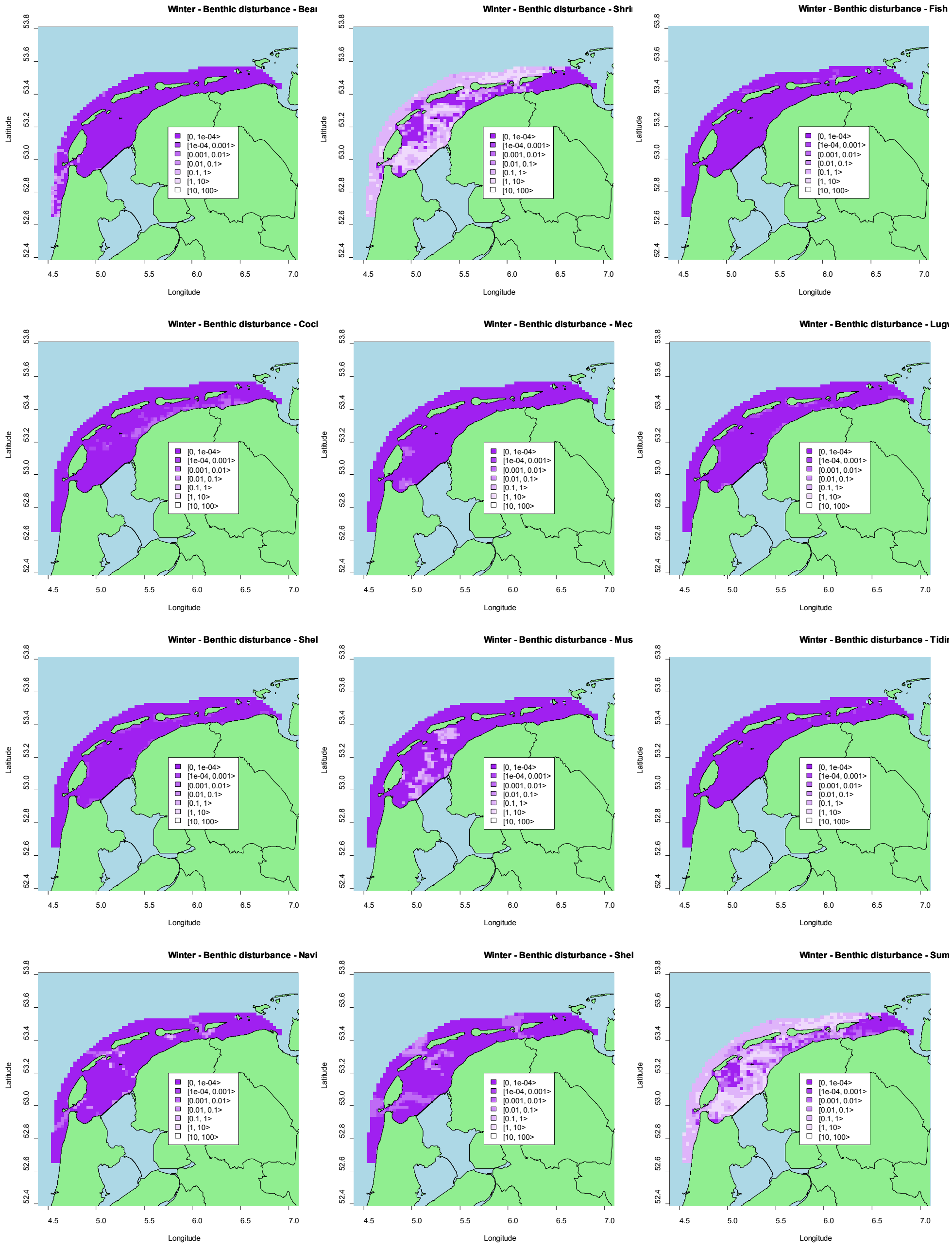
Activity:	**Seine net fishery**
Basic material (map):	Exposure time of tidal flats as supplied for the NEA, supplemented with map material relating to water depth.
Disturbance type:	Presence/Visual disturbance
Values applied:	Presence: 7500 hours on a yearly basis Summer/winter ratio: 90%/10%
Background to the values applied & assumptions:	
The characteristics of seine fishing have strong similarities to gillnet fishing. The exclusions and the active period are the same. With regard to use of space, there is a preference for shallow areas (watersheds). In GIS, this is indicated as an area with a low exposure >75% and the area in the North Sea Coastal Zone that is less than 5 metres deep (and situated along the beach) The following values are used: 5 hours seine fishing/24 hours over 5 days/week for 10 active fishermen. This results in a total of 7500 hours on a yearly basis op.	
Sources:	e-mail LNV inspector for the Wadden Sea district, whose answer has been discussed with colleagues

Activity:	**Fyke fishery**
Basic material (map):	Locations of discharge sluices, locks, ports and dykes and dams as supplied for the NEA
Disturbance type:	Presence/Visual disturbance
Values applied:	Presence: 4500 hours on a yearly basis Summer/winter ratio: 60%/40%
Background to the values applied & assumptions:	
In spatial terms, fyke fishing mainly takes place near inlets and outlets such as discharge sluices, locks, ports and near dykes and dams. These locations all contribute over 95% of fyke fishing. Fyke fishing on the free grounds in the Wadden Sea is therefore not taken into account, as their location is unknown. In GIS, the locations of discharge sluices, locks and ports as points are known. Around each of these points, a circle-shaped area with a radius of 500 m is used as available for fyke fishing. For dykes and dams, use is made of the stone wall data set with a buffer distance of 100 m. As it is unsuitable for fyke fishing, Pollendam is not taken into account. Fyke fishing is done all year round, as long as there is no ice. The most intensive period is from August to November. In 2009, a ban on eel fishing was introduced from September to November. On this basis, the summer/winter ratio has been established at 60%/40%. Active fishermen are engaged for between 8 and 16 hours per week in sailing, placing and replacing the fykes. There are around 20 fyke fishermen, some of whom are full time. The inspector estimates that this totals 4500 hours' presence on a yearly basis.	
Sources:	e-mail LNV inspector for the Wadden Sea district, whose answer has been discussed with colleagues

Annex 2 Pressure maps per activity and totals

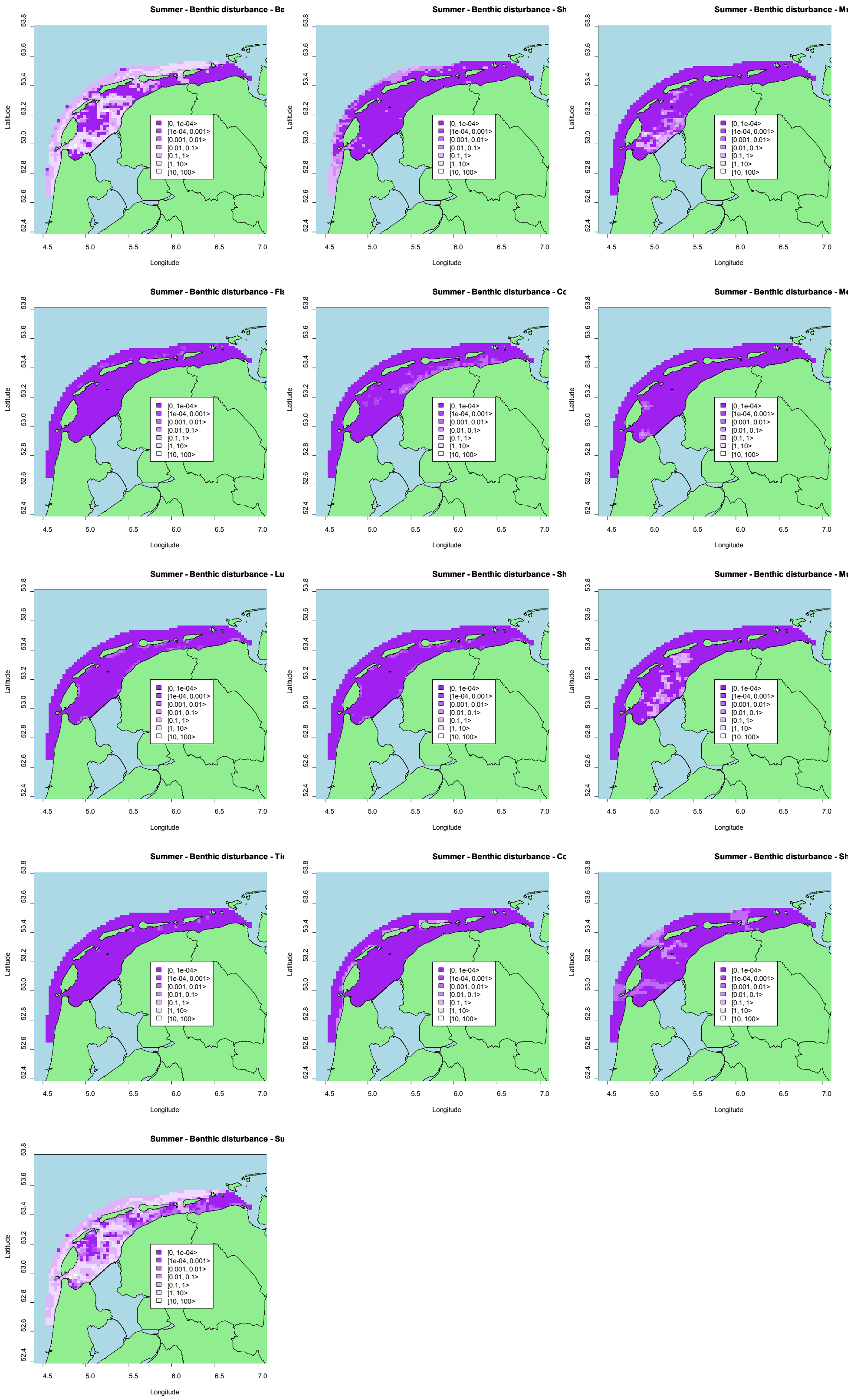
Abrasion in the winter half year

Units in legend are number of times the entire grid cell area is disturbed in half a year.



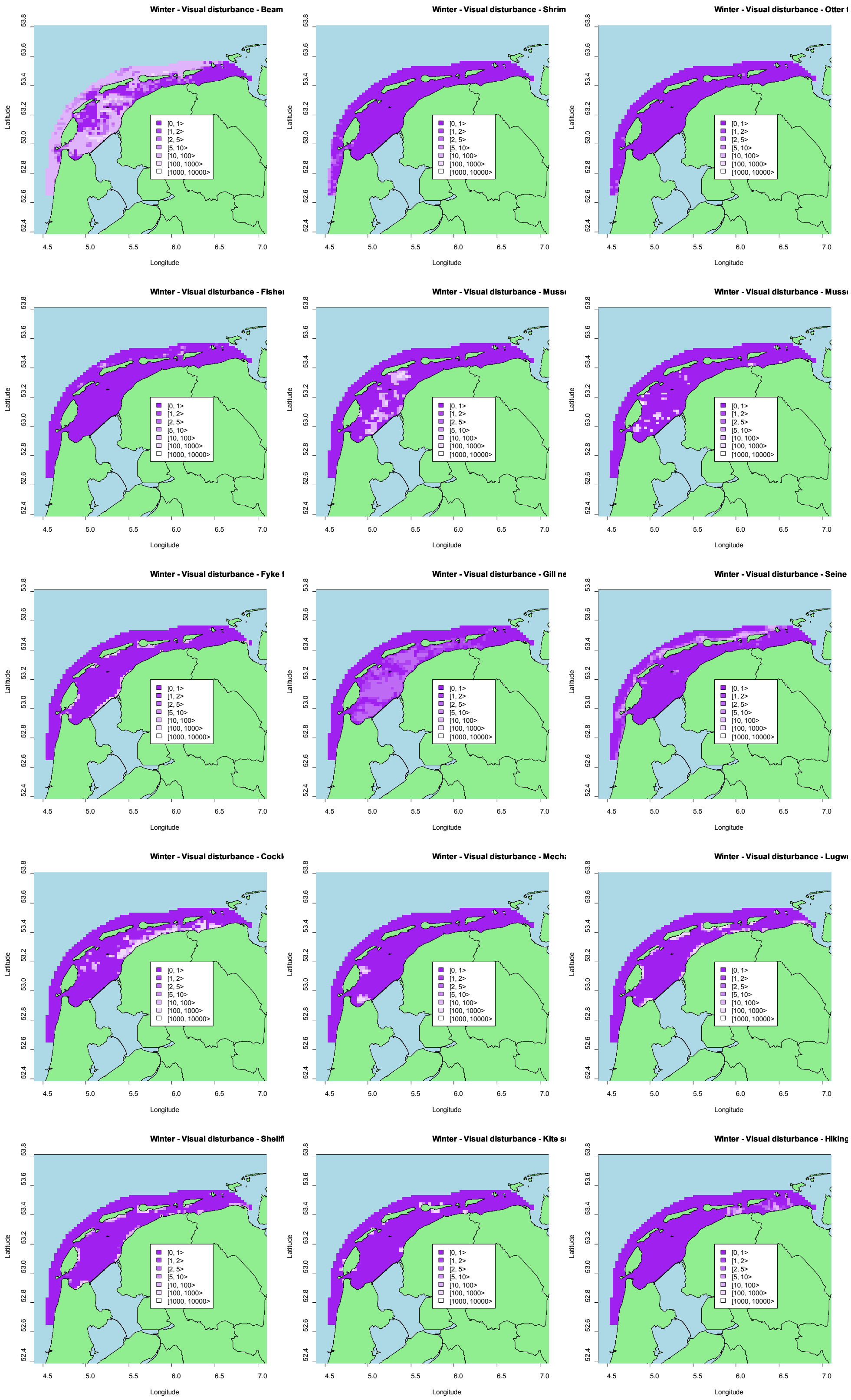
Abrasion in the summer half year

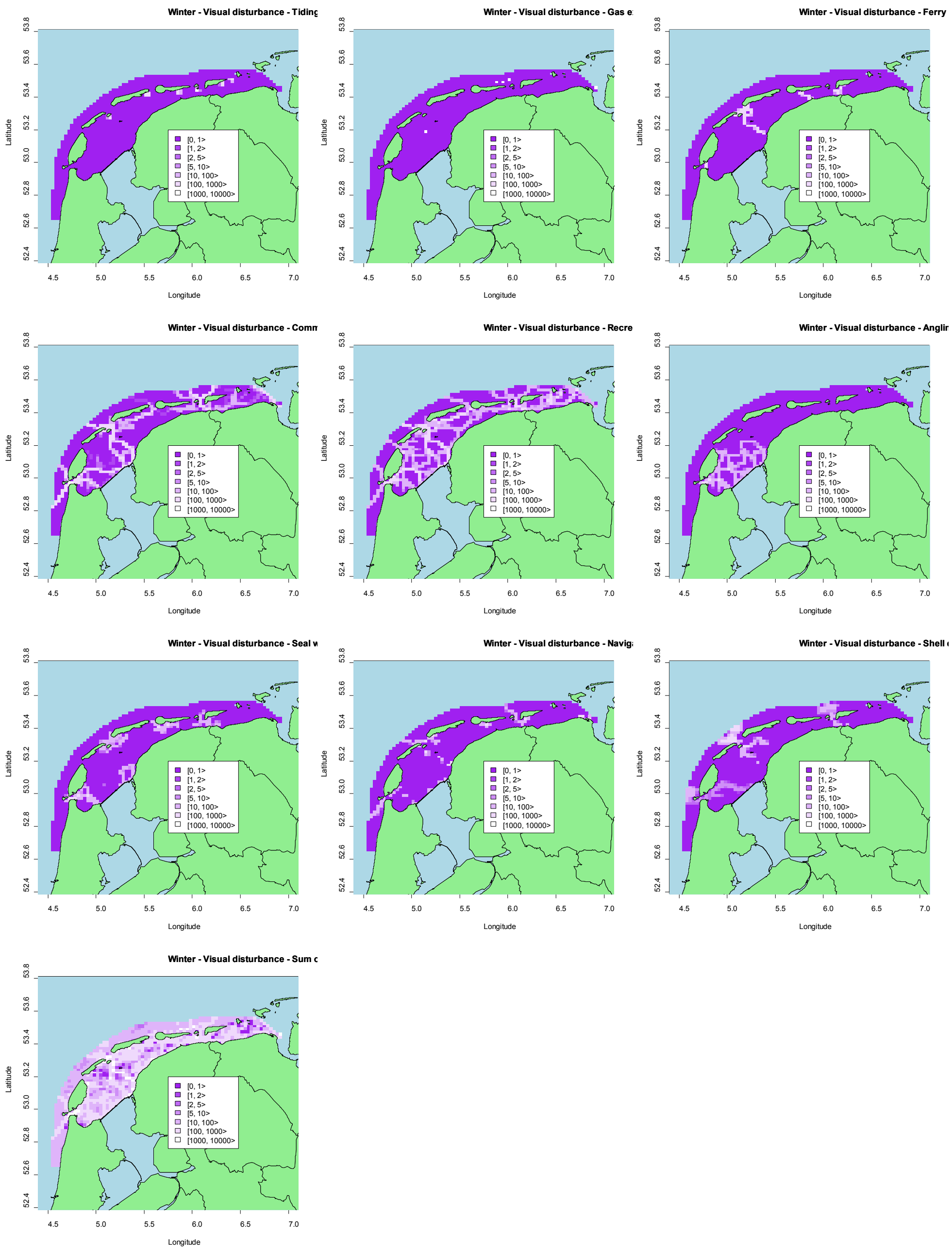
Units in legend are number of times the entire grid cell area is disturbed in half a year.



Visual disturbance in the winter half year

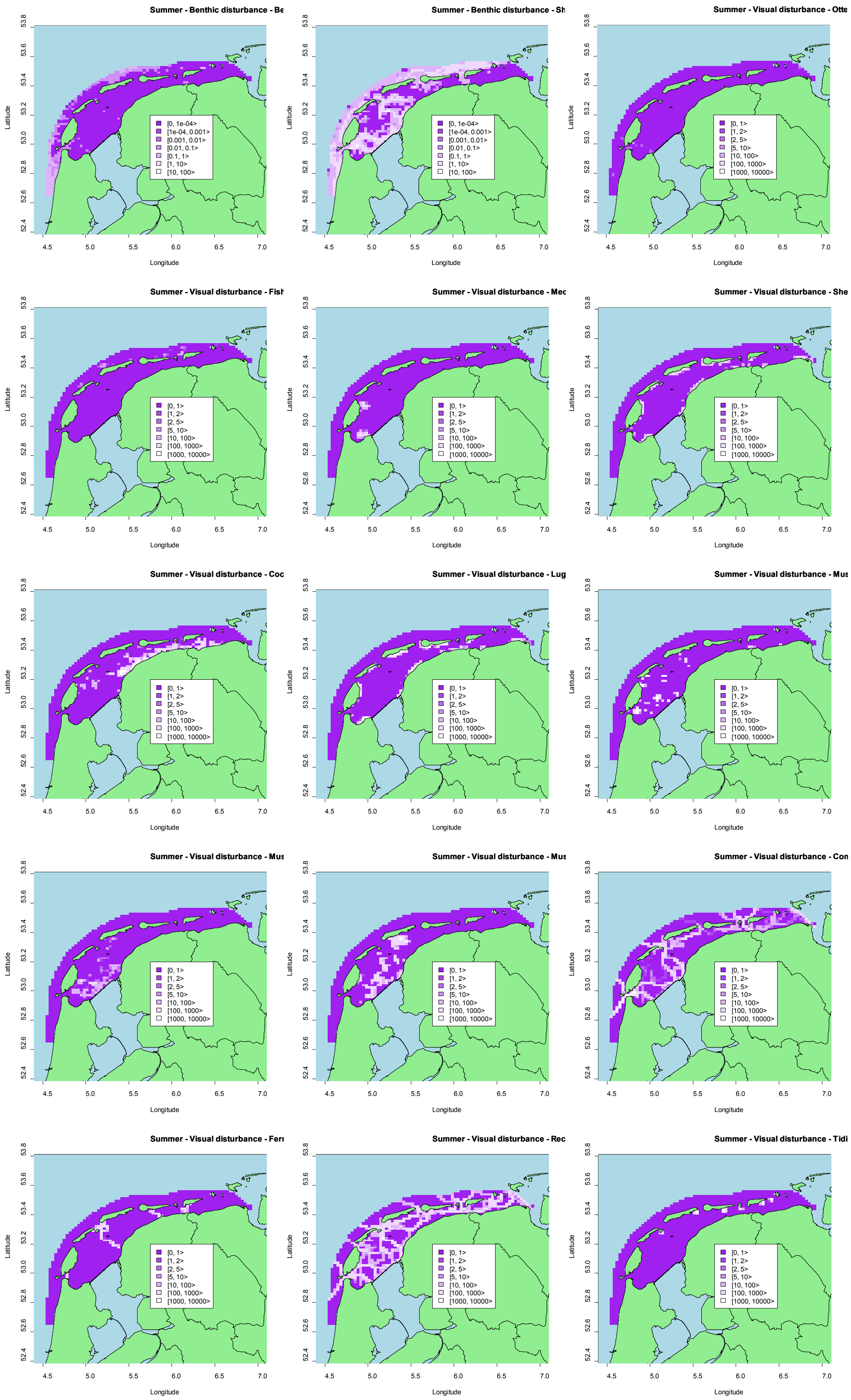
Units in legend are the total number of hours an object is present in a grid cell.

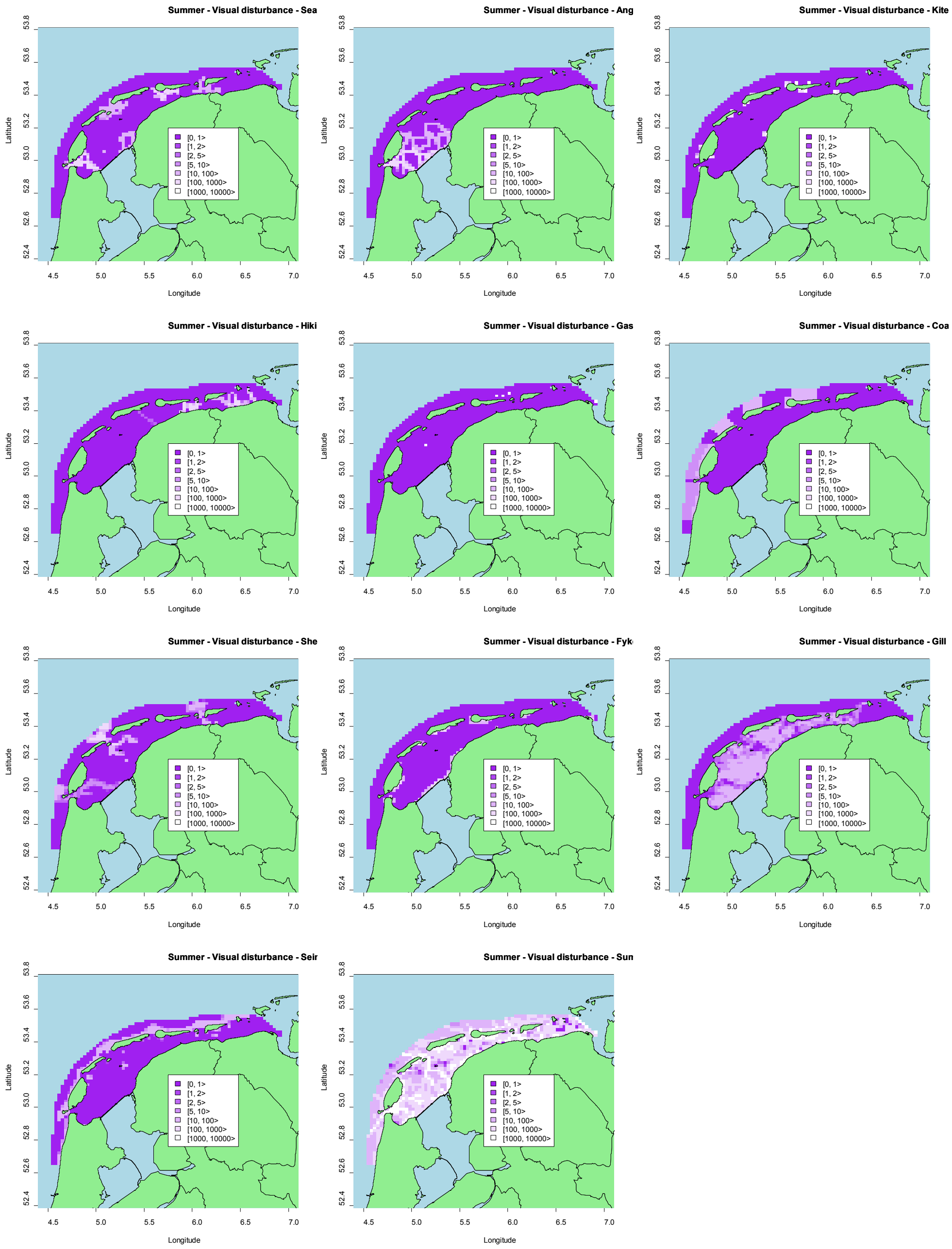



Winter - Visual disturbance - Tiding
Winter - Visual disturbance - Gas e
Winter - Visual disturbance - Ferry
Winter - Visual disturbance - Comm
Winter - Visual disturbance - Recre
Winter - Visual disturbance - Anglir
Winter - Visual disturbance - Seal w
Winter - Visual disturbance - Navig
Winter - Visual disturbance - Shell
Winter - Visual disturbance - Sum c
Latitude
Longitude
[0, 1>
[1, 2>
[2, 5>
[5, 10>
[10, 100>
[100, 1000>
[1000, 10000>

Visual disturbance in the summer half year

Units in legend are the total number of hours an object is present in a grid cell.

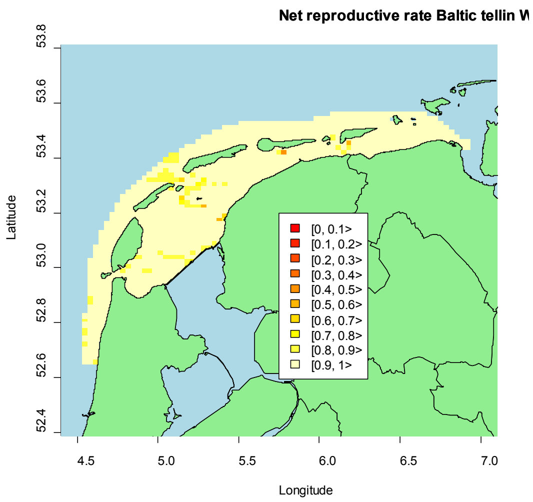


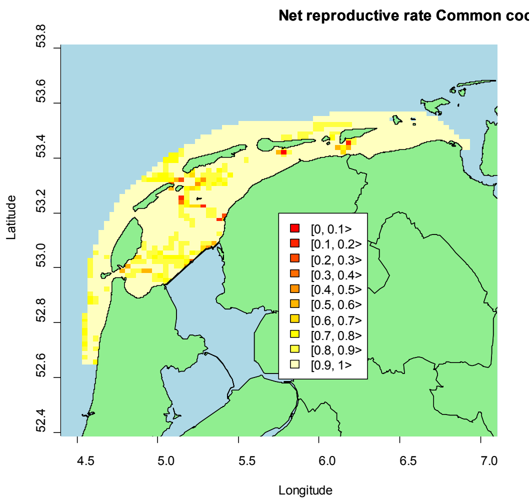

Summer - Visual disturbance - Sea
Summer - Visual disturbance - Ang
Summer - Visual disturbance - Kite
Summer - Visual disturbance - Hiki
Summer - Visual disturbance - Gas
Summer - Visual disturbance - Coa
Summer - Visual disturbance - She
Summer - Visual disturbance - Fyk
Summer - Visual disturbance - Gill
Summer - Visual disturbance - Sei
Summer - Visual disturbance - Sun
[0, 1>
[1, 2>
[2, 5>
[5, 10>
[10, 100>
[100, 1000>
[1000, 10000>
Latitude
Longitude

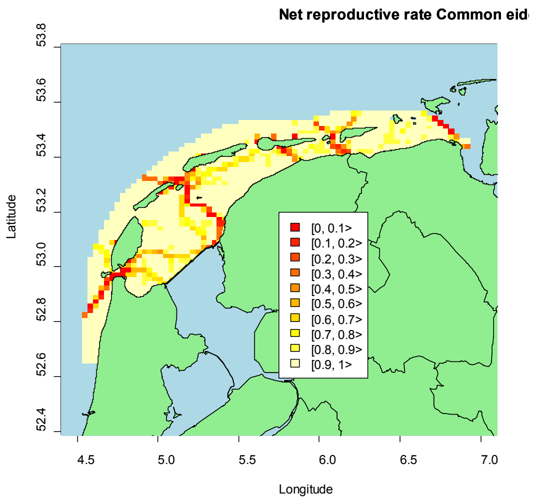
Annex 3 Maps of calculated reproductive rates

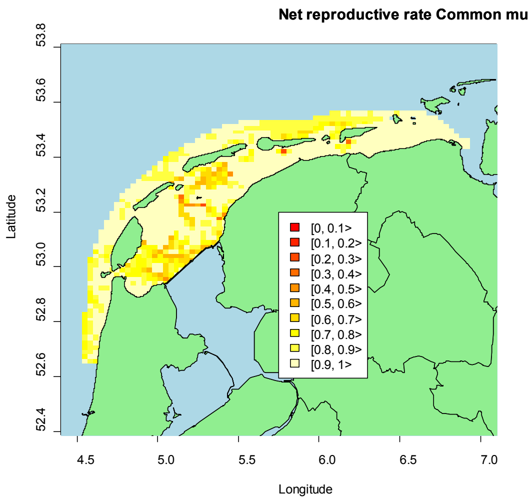
Illustrations below are generated wit R. Scaling of grid cells is not highly accurate but sufficient for intended interpretation.

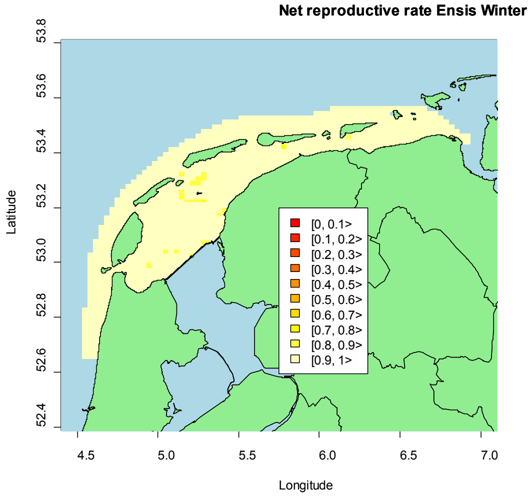
Results for winter half year

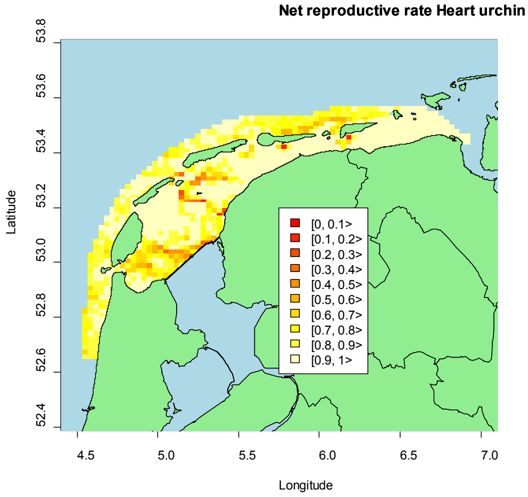


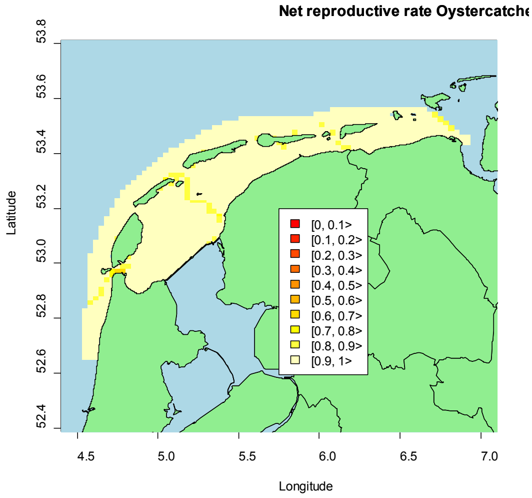




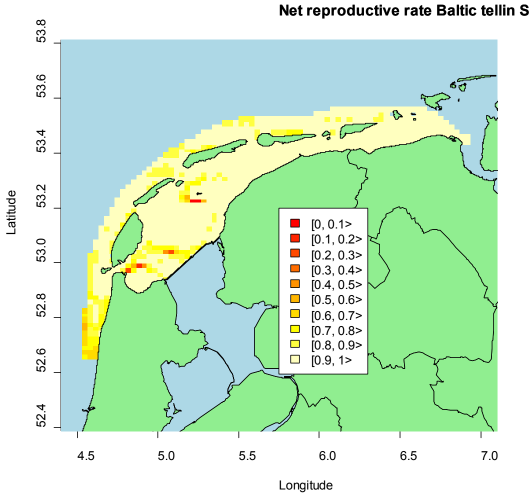


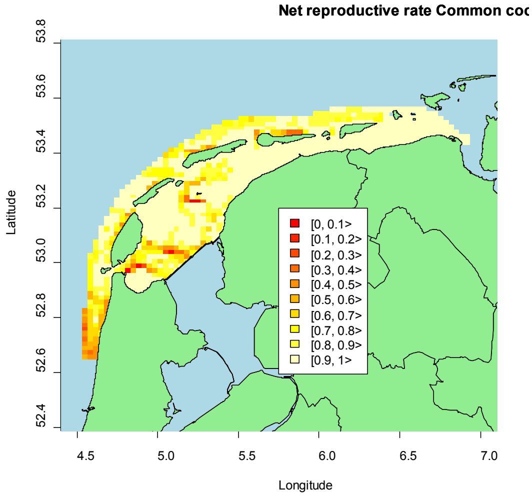

Net reproductive rate Ensis Winter
Latitude
Longitude
[0, 0.1>
[0.1, 0.2>
[0.2, 0.3>
[0.3, 0.4>
[0.4, 0.5>
[0.5, 0.6>
[0.6, 0.7>
[0.7, 0.8>
[0.8, 0.9>
[0.9, 1>

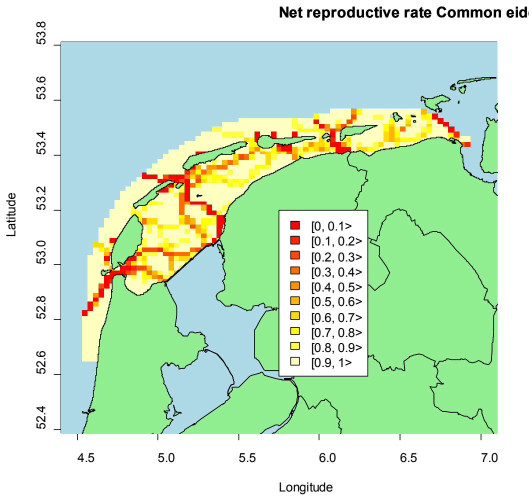

Net reproductive rate Heart urchin
Latitude
Longitude
[0, 0.1>
[0.1, 0.2>
[0.2, 0.3>
[0.3, 0.4>
[0.4, 0.5>
[0.5, 0.6>
[0.6, 0.7>
[0.7, 0.8>
[0.8, 0.9>
[0.9, 1>

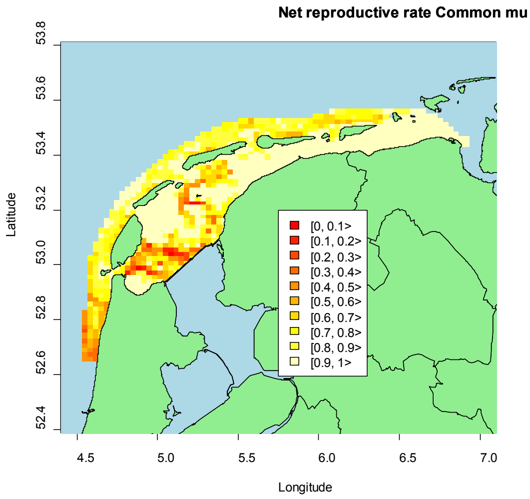

Net reproductive rate Oystercatche
Latitude
Longitude
[0, 0.1>
[0.1, 0.2>
[0.2, 0.3>
[0.3, 0.4>
[0.4, 0.5>
[0.5, 0.6>
[0.6, 0.7>
[0.7, 0.8>
[0.8, 0.9>
[0.9, 1>

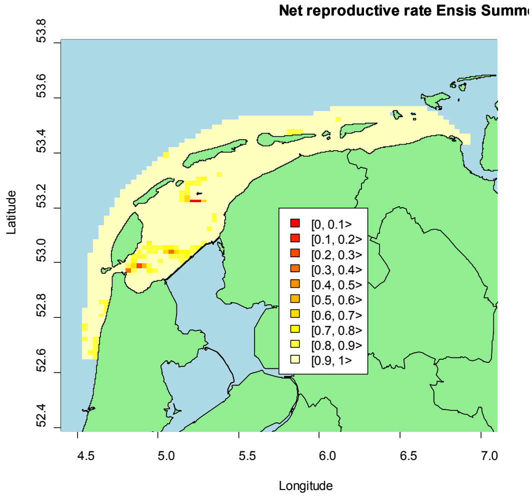
Results for summer half year

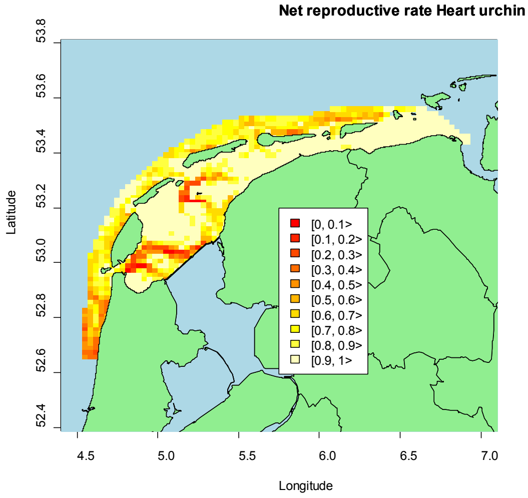


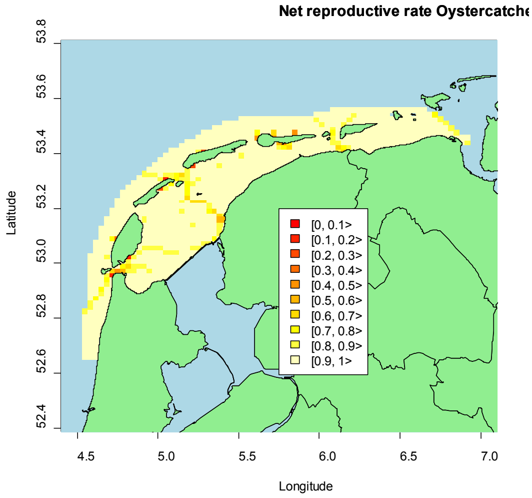






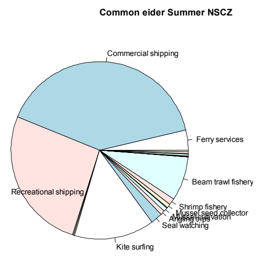

Net reproductive rate Ensis Summ
Latitude
Longitude
[0, 0.1>
[0.1, 0.2>
[0.2, 0.3>
[0.3, 0.4>
[0.4, 0.5>
[0.5, 0.6>
[0.6, 0.7>
[0.7, 0.8>
[0.8, 0.9>
[0.9, 1>

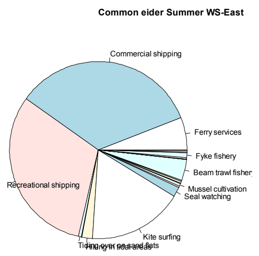

Net reproductive rate Heart urchin
Latitude
Longitude
[0, 0.1>
[0.1, 0.2>
[0.2, 0.3>
[0.3, 0.4>
[0.4, 0.5>
[0.5, 0.6>
[0.6, 0.7>
[0.7, 0.8>
[0.8, 0.9>
[0.9, 1>

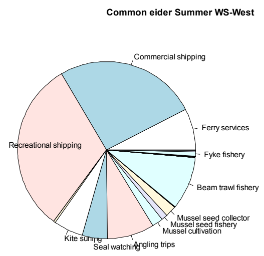

Net reproductive rate Oystercatche
Latitude
Longitude
[0, 0.1>
[0.1, 0.2>
[0.2, 0.3>
[0.3, 0.4>
[0.4, 0.5>
[0.5, 0.6>
[0.6, 0.7>
[0.7, 0.8>
[0.8, 0.9>
[0.9, 1>

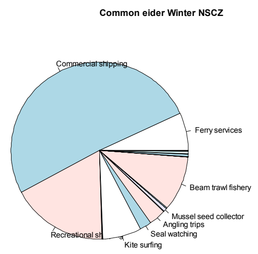
Annex 4 Contribution of activities to effects on survival and reproduction

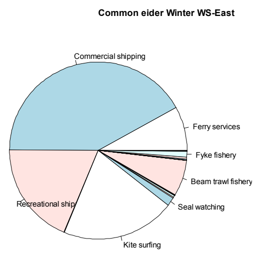
Pie diagrams show contributions of activities to effects on survival (oystercatcher and common eider) and mortality (all other species). Only contributions larger than 0.5% are labelled in the diagrams. Contributions are specified per half year: summer and winter; and per region: western Wadden Sea (WS-West), eastern Wadden Sea (WS-East) and North Sea Coastal Zone (NSCZ). Please note that the diagrams only reflect potential effects as the overlap of pressures with habitats is not determined in present study.

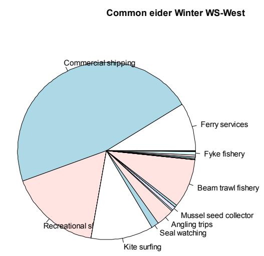

Common eider Summer NSCZ
Commercial shipping
Ferry services
Beam trawl fishery
Recreational shipping
Shrimp fishery
Seal watching
Kite surfing

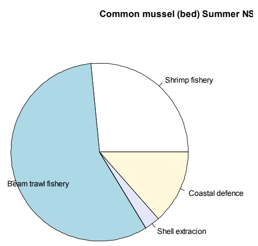

Common eider Summer WS-East
Commercial shipping
Ferry services
Fyke fishery
Recreational shipping
Mussel cultivation
Seal watching
Kite surfing

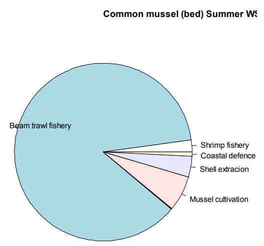

Common eider Summer WS-West
Commercial shipping
Ferry services
Recreational shipping
Fyke fishery
Beam trawl fishery
Mussel seed collector
Mussel seed fishery
Mussel cultivation
Angling trips

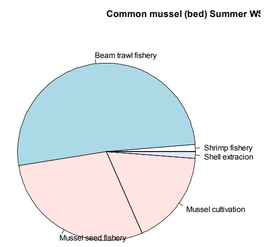

Common eider Winter NSCZ
Commercial shipping
Ferry services
Beam trawl fishery
Mussel seed collector
Angling trips
Seal watching
Kite surfing

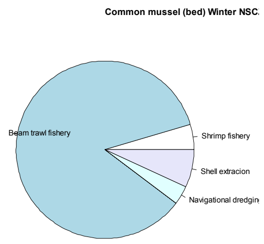

Common eider Winter WS-East
Commercial shipping
Ferry services
Fyke fishery
Beam trawl fishery
Seal watching
Kite surfing

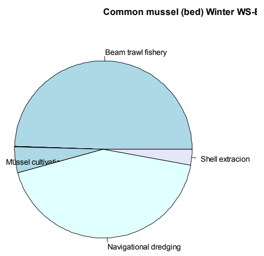

Common eider Winter WS-West
Commercial shipping
Ferry services
Fyke fishery
Beam trawl fishery
Mussel seed collector
Angling trips
Seal watching
Kite surfing

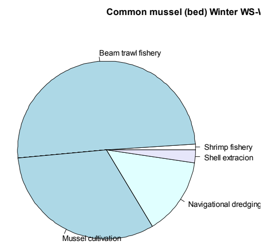

Shrimp fishery
Beam trawl fishery
Coastal defence
Shell extracion

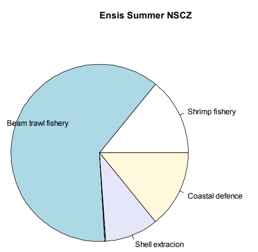

Beam trawl fishery
Shrimp fishery
Coastal defence
Shell extracion
Mussel cultivation

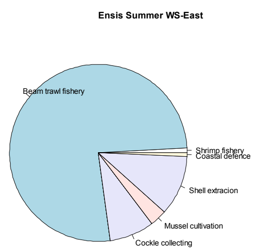

Beam trawl fishery
Shrimp fishery
Shell extracion
Mussel cultivation
Mussel seed fishery

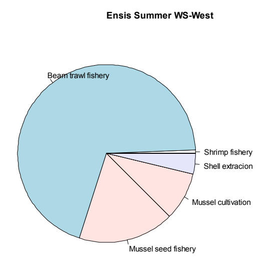

Beam trawl fishery
Shrimp fishery
Shell extracion


Beam trawl fishery
Shell extracion
Navigational dredging


Beam trawl fishery
Shrimp fishery
Shell extracion
Mussel cultivation


Ensis Summer NSCZ
Shrimp fishery
Beam trawl fishery
Coastal defence
Shell extracion


Ensis Summer WS-East
Beam trawl fishery
Shell extracion
Mussel cultivation
Cockle collecting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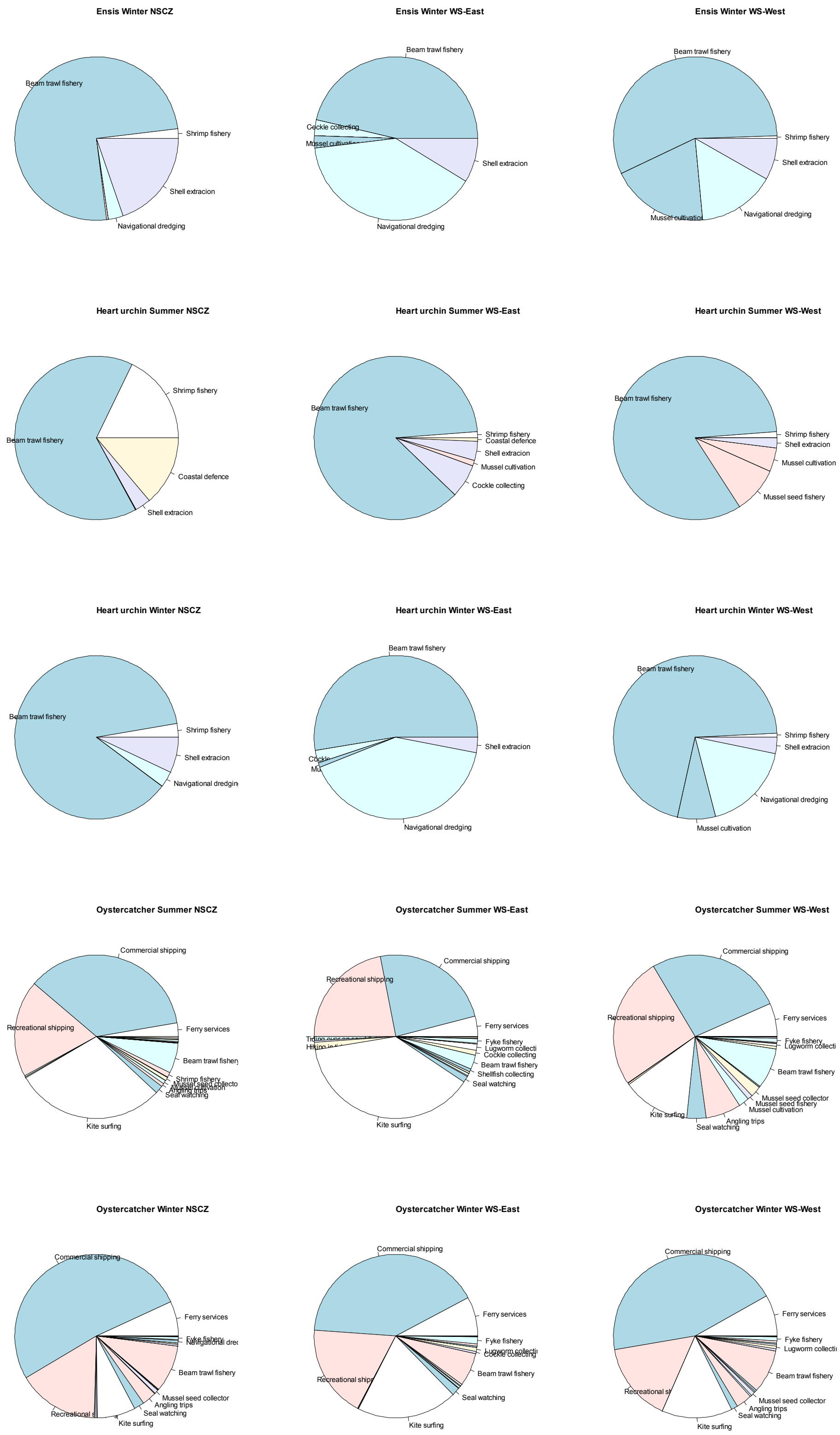
Beam trawl fishery
Shrimp fishery
Shell extracion
Mussel cultivation
Mussel seed fishery


Ensis Winter NSCZ
Beam trawl fishery
Shrimp fishery
Shell extracion
Navigational dredging
Ensis Winter WS-East
Beam trawl fishery
Cockle collecting
Mussel cultivation
Shell extracion
Navigational dredging
Ensis Winter WS-West
Beam trawl fishery
Shrimp fishery
Shell extracion
Navigational dredging
Mussel cultivation
Heart urchin Summer NSCZ
Shrimp fishery
Beam trawl fishery
Coastal defence
Shell extracion
Heart urchin Summer WS-East
Beam trawl fishery
Shrimp fishery
Coastal defence
Shell extracion
Mussel cultivation
Cockle collecting
Heart urchin Summer WS-West
Beam trawl fishery
Shrimp fishery
Shell extracion
Mussel cultivation
Mussel seed fishery
Heart urchin Winter NSCZ
Beam trawl fishery
Shrimp fishery
Shell extracion
Heart urchin Winter WS-East
Beam trawl fishery
Shell extracion
Navigational dredging
Heart urchin Winter WS-West
Beam trawl fishery
Shrimp fishery
Shell extracion
Navigational dredging
Mussel cultivation
Oystercatcher Summer NSCZ
Commercial shipping
Recreational shipping
Ferry services
Shrimp fishery
Seal watching
Kite surfing
Oystercatcher Summer WS-East
Commercial shipping
Recreational shipping
Ferry services
Fyke fishery
Cockle collecting
Beam trawl fishery
Shellfish collecting
Seal watching
Kite surfing
Oystercatcher Summer WS-West
Commercial shipping
Recreational shipping
Ferry services
Fyke fishery
Beam trawl fishery
Mussel seed collector
Mussel seed fishery
Mussel cultivation
Angling trips
Seal watching
Kite surfing
Oystercatcher Winter NSCZ
Commercial shipping
Ferry services
Beam trawl fishery
Mussel seed collector
Angling trips
Seal watching
Kite surfing
Oystercatcher Winter WS-East
Commercial shipping
Ferry services
Fyke fishery
Beam trawl fishery
Seal watching
Kite surfing
Oystercatcher Winter WS-West
Commercial shipping
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Fyke fishery
Beam trawl fishery
Mussel seed collector
Angling trips
Seal watching
Kite surfing

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2009

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2012

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