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# Scaling human pressures to population level impacts in the marine environment

## Implementation of the prototype CUMULEO-RAM model

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## Introduction

### Background

**For centuries the Dutch coastal waters and the North Sea were primarily used for fisheries and shipping, but during the last 20 years the number of uses has increased rapidly. These human uses (such as wind farms, mineral extraction, coastal defences and fisheries) will lead to a decrease in biodiversity and a reduction in ecosystem and mineral resources. Under several European policies and conventions, the EU North Sea member states must establish a sustainable management regime for the marine environment. In addition, a comprehensive system of marine spatial management (also referred to as 'marine spatial planning') is needed to prevent conflicts between the marine environment and economic uses.**

Marine spatial management is best served by common approaches and tools. The ecosystem-based approach was first promoted for fisheries management in the 2002 reform of the EU Common Fisheries Policy. The latest European policy for the EU's marine waters (the Marine Strategy Framework Directive, MSFD) applies the ecosystem-based approach at a broader maritime level. The ecosystem-based approach ensures that the collective pressure of all human activities is kept within limits compatible with the achievement of good environmental status, and in such a way 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. The Dutch government is currently implementing the MSFD.

Crucial for a sustainable management of marine activities is knowledge of the relation between the impact of activities and the marine environment. An important but often difficult aspect is assessing the contribution made by each of the activities to the cumulative effect on the ecosystem.

Despite all the efforts made to publish guidance documents on cumulative effects assessment (CEA), there is still no common

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understanding of how to do this (Karman & Jongbloed, 2008), which is hampering the development of a transparent and widely (globally) accepted approach. In the meantime, environmental impact assessments of projects and plans often attempt to address the issue of cumulative effects, but mainly at a highly qualitative level, and these studies are not comparable with other environmental impact assessments. Two groups of methods and tools can be used to provide a methodological suite for CEA:

- *Scoping and impact identification*, i.e. methods to assist with the identification of how and where a cumulative effect might occur.
- *Evaluation*, i.e. methods to quantify and predict the magnitude and significance of effects, based on their context and intensity.

In the WOT Plan of Work 2010 (*WOT Werkplan 2010* ), the Netherlands Environmental Assessment Agency (PBL) stated the need for a simple and robust model to evaluate the effects of fisheries, eutrophication, wind farms, spatial reservation and sand extraction on the most important ecological indicators. Such a model should provide a reliable source of information on which to base strategic management decisions regarding human activities that affect marine biodiversity. An implementation of the ecosystem modelling suite Ecopath with Ecosim (EwE, www.ecopath.org) (Mackinson & Daskalov, 2007) has been tested as a candidate, but the limits of the EwE implementation for this application appear to have been reached (Van Kooten & Klok, 2011).

## Project goals

Considering all the requirements for such an effects model, it can be questioned whether a single model for this purpose is desirable, or even possible. This is nicely illustrated in Douglas Adams's novel *The Hitchhikers Guide to the Galaxy*, in which a group of hyper-intelligent pan-dimensional beings create the supercomputer Deep Thought to find the Ultimate Answer to the Ultimate Question of Life, the Universe and Everything. 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 we describe a generic methodological framework which can be used to quantify cumulative effects of human activities. In theory, the results could be used to identify where, when and how an activity contributes to an effect. The methodology is demonstrated by implementing a prototype in a case study of the Dutch North Sea Coastal Zone and the Wadden Sea. The results are used to discuss the practical applicability of the method.

The main goals are:

- to develop a prototype of a spatial model to analyse the cumulative effects of human activities on a selection of indicators in a case study;
- to describe the options for future development of the implemented prototype.

## Methods

The basic approach of our cumulative effect assessment (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 fishing causes both benthic 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) and Therivel & Ross (2007), is used for the CEA:

- Scoping phase
  - define spatial and temporal boundaries;
  - identify ecosystem components, pressures and activities.
- Assessment phase
  - describe intensity of activities;
  - assess intensity of pressures;
  - describe sensitivity of ecosystem components;
  - assess the cumulative effects.

## Scoping

Following the general stepwise approach derived from Van der Walt (2005) and Therivel & Ross (2007), the first step of the assessment is scoping to identify the ecosystem components, pressures and activities to be covered by the CEA. First, the spatial and temporal boundaries are defined. Then the eco-

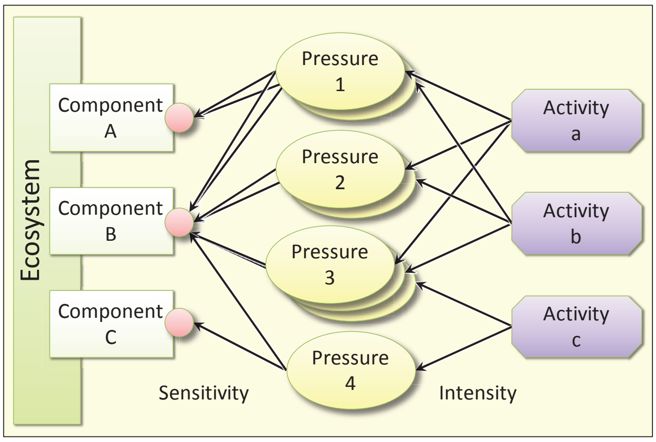


*Figure 1. A generic outline of a cumulative effect assessment (CEA) in which relationships between activities, pressures and ecosystem components/indicators need to be clarified*

system components, pressures and activities are identified. These elements are identified in such a way that the assessment framework links the manageable human activities to the pressures and potential effects they cause in the marine ecosystem.

Pressures can be selected from existing lists, such as Annex II of the Marine Strategy Framework 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 CEA. An extensive overview of activities is provided in the EU EIA Directive (EC, 1997), adopted by the Kiev Protocol to the Espoo Convention.

Ecosystem components or indicators have a prominent and legitimate role in monitoring, assessing and understanding ecosystem status, the impacts of human activities and the 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 and varied list of potential indicators. Although intended for fisheries management, the framework has a wider applicability and can be used for selecting indicators for ecosystem management. Ecosystem components can also be based on national and international 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) have now been identified and related to each other. The scoping process provides no information about the intensity of the impacts or the sensitivity of the indicators to the selected impacts.

Although the basic elements of the CEA – the activities, pressures and ecosystem components – have now been identified, the elements of space and time, which are the two dimensions through which effects can cumulate (MacDonald 2000), have not yet been defined.

Time can be disregarded in the assessment by assuming that 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, a temporal distribution can be implemented in the assessment, for example by including seasonal differences (Jongbloed *et al.*, 2011-a).

A simple approach to including the spatial dimension in the CEA is described by Halpern *et al.* (2008). They mapped the intensity

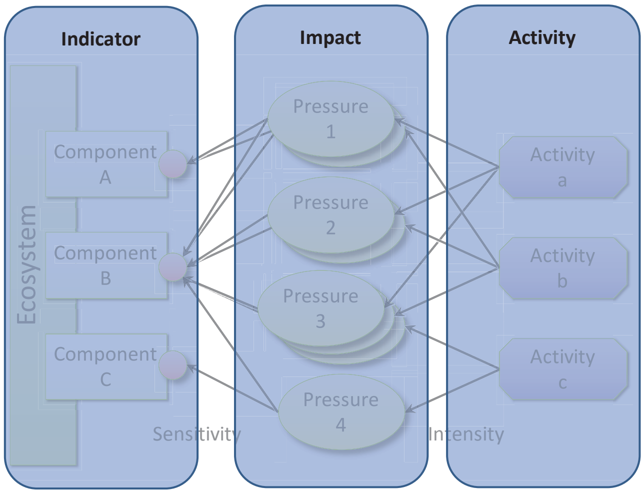


*Figure 2. The scoping process identifies the basic elements for cumulative effects assessment: ecosystem indicators, activities and impacts*

of pressures in geographic cells and included a parameter indicating 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 possible, which could also include the probability of pressures and ecosystem components being present, as implemented by Zacharias & Gregr (2005) for example.

## From activity to pressure

The assessment phase can be broken down into two stages: describing and assessing the intensity of activities and describing and assessing the sensitivity of ecosystem components to the different pressures (Figure 3). Once both the intensity of impacts and the sensitivity of the ecosystem indicators are known, the actual cumulative effects analysis can be carried out.

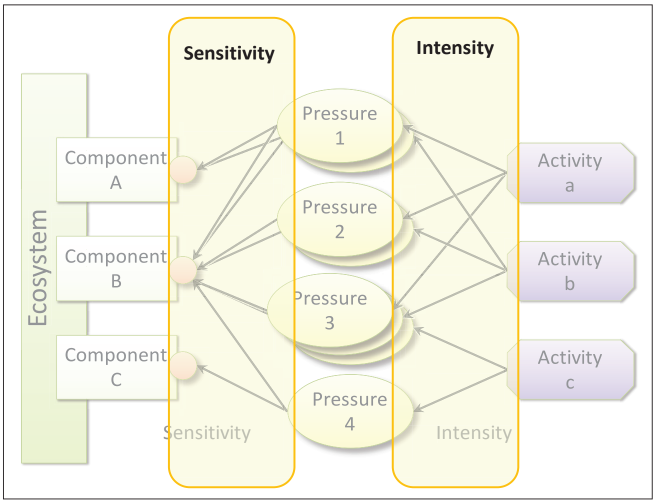


*Figure 3. To assess the effects, the relations between the basic elements (indicator sensitivity and impact intensity) need to be quantified*

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

### From pressure to ecosystem component

The sensitivity of ecosystem components can be described in various ways, either qualitatively (e.g. Connor (2008) and Robinson *et al.* (2008)) or semi-quantitatively (e.g. Zacharias & Gregr (2005) and 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). The limitations of sparse datasets and the complexity of natural systems have compelled conservation scientists to estimate data by expert judgment and other scoring, ranking and rating procedures (Wolman, 2006). Qualitative and semi-quantitative methods therefore rely mainly 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).

When combining all the individual effects, similar endpoints should be used. If the CEA is not based on a single uniform endpoint, such as mortality, an additional step should be included in the assessment to derive one single endpoint. Jak *et al.* (2000) and Karman *et al.* (2009) describe a method for integrating the effects of potential exposures which combines mortality with reproduction to derive a single population measure. As a final step, all effects are combined to assess the cumulative effects.

## Results

### Scoping

Much of the dataset used in the present study was compiled for a project (*Nadere Effect Analyse or NEA*) to assess the combined or cumulative impact of human activities on two marine protected areas in the north of the Netherlands (Jongbloed *et al.*, 2011-a). These areas (the Wadden Sea and the North Sea Coastal Zone) are both part of the European Natura 2000 network. They contain significant numbers of various bird species, mammals such as seals and harbour porpoise, a few fish species, and habitats such as submerged sandbank (H1110) and intertidal mud and sand flats (H1140). For practical reasons, the same areas (the Natura 2000 parts of the North Sea Coastal Zone and the Dutch Wadden Sea) were used in the present study.

A list of human activities having a possible impact on the conservation targets was available from the same NEA cumulative effect study (Jongbloed *et al.*, 2011-a) and previous work on the Natura 2000 areas of the North Sea Coastal Zone and the Wadden Sea (effect studies of individual activities: Jonker & Menken (2008), Slijkerman *et al.* (2008a), Slijkerman *et al.* (2008b), Slijkerman *et al.* (2008c) and Jongbloed *et al.* (2011-b). These studies also gathered information on 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 and emergence conditions. To make mapping of 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). For our purposes, presence is a prerequisite and thus a good proxy for visual disturbance. Abrasion is linked to food availability, turbidity and physical changes to the sea bed. This choice was also guided by the availability of reliable datasets on several types of fishery, which are important human activities affecting presence and abrasion.

The fisheries datasets, mainly on shrimp fisheries and beam trawl (Euro-cutter, up to 300 hp), set the geographical resolution to 2 min. longitude by 1 min. latitude (roughly equivalent to 1 x 1 nautical mile, at the latitude of the Netherlands). This is the standard resolution used by the Vessel Monitoring System (VMS), which is the source of the underlying data feeding into these datasets. Analysis has shown that this is an appropriate resolution for presenting this type of data (Rijnsdorp *et al.*, 1998, Piet & Quirijns, 2009). 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 two-hourly intervals. The system does not log the state of the fishing vessel (fishing, steaming, berthed etc.). This information is deduced from the speed of a vessel, which is discernibly lower while actively fishing than when steaming to a destination. The available dataset only contained aggregated data for vessels that were actively fishing. Information with respect to the pressures is stored per grid cell and used to calculate effects per grid cell.

For the prototype we decided to perform the analyses for two periods: a six-month summer period from April to September and a six-month winter period from October to March. This choice is a compromise, because the fisheries datasets were available as quarterly data and could readily be aggregated to this level, considerably reducing the need to make estimates or assumptions about the levels of each activity. Moreover, attempting to add finer temporal detail was judged to be unwise considering the geographical accuracy of some datasets. A drawback of the chosen temporal split is that it does not necessarily fit well with the timing of life cycle events in the ecosystem element included in the study. However, as this timing is different for each species, the effort required to refit the timescale to each species (or species group) would be enormous and also requires more and better data than is presently available. This problem of data quantity and quality applies not only to the species, but also to most human activities. For the present study the six-monthly subdivision was what we had to work with.

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

The selected human activities numbered 26 in total and are listed in De Vries *et al* (2011). The presence and abrasion of each of these activities (if present) was determined, mapped and aggregated to the same level as the fisheries datasets.

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

## 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 was compiled from fishery datasets on shrimp, beam trawl and otter trawl fisheries originating from a database containing Vessel Monitoring System (VMS) records. These datasets included both the presence of fishing vessels (hours actively fishing) and abrasion (fraction of cell area disturbed). Abrasion was assessed on the basis of a representative width of the deployed fishing gear, which means that the abrasion resulting from otter trawling was not included in the calculations because this type of fishing net does not have a fixed width. Otter trawling is not a large fishery within the study area and so these activities will have a very small impact in relation to other types of fishing. In addition to these larger fisheries, the data on the fishery for Ensis is also based on VMS records.

For all other human activities, some additional data, and in some cases assumptions, were required to enable the use of available Geographic Information System (GIS) maps to award numbers for presence and/or abrasion to the final cumulative dataset.

Ferry services provide a straightforward example of the process. As ferries do not cause abrasion, only their presence was considered for this activity. A GIS map of shipping routes in the study area was available, including the routes used by ferries. Information on the number of departures and the time each trip takes was obtained from the websites of the ferry companies operating in the area. As many services operate less frequently in the winter period than in the summer period, these data were combined and the total number or hours of presence during summer/winter for each ferry route were calculated. The final step in completing the VMS grid was to determine the relative length of ferry routes for each VMS cell and allocating to each VSM cell the number of hours of presence of ferries based on the relative length (Figure 4).

*Table 1. 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 |

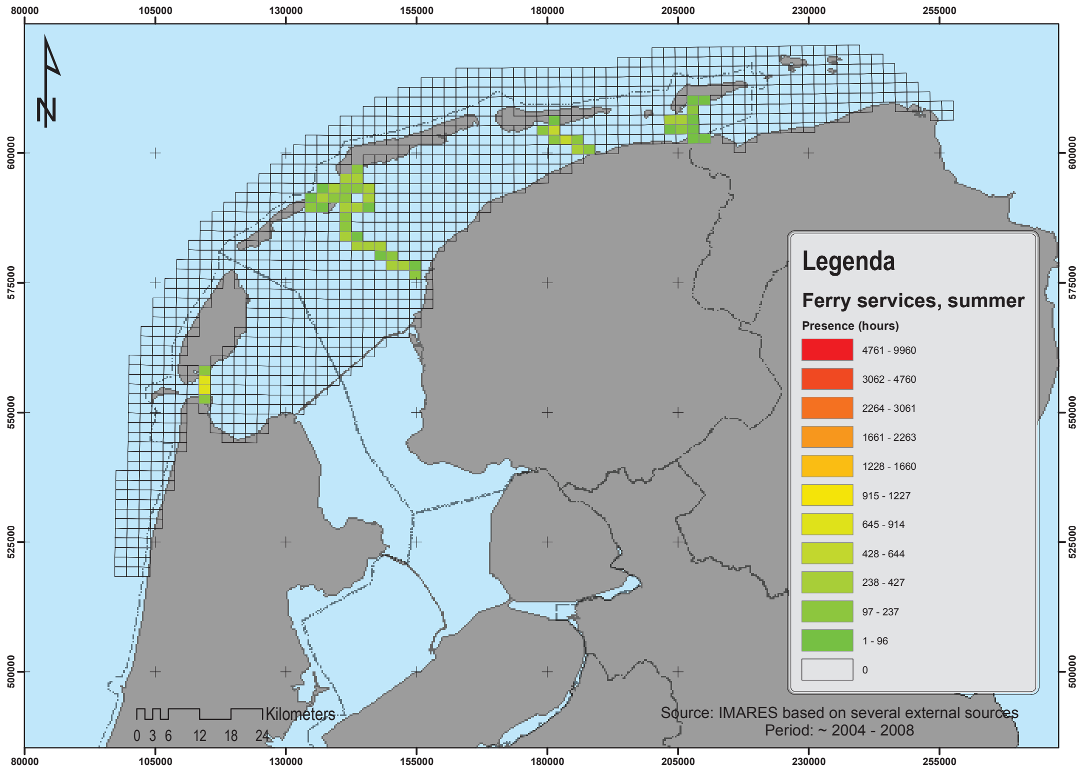


*Figure 4. Map showing presence (hours) of ferry services to be included in the cumulative pressure*

The environmental pressure of cockle collecting is a more complicated to quantity. There are no recorded maps of where this takes place and how intensive 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. These are found in the mid-tidal range, preferably where the sediment has a heightened silt content. This area can be identified from maps on emergence time and sediment type. Additionally, some areas are out of bounds because of legal restrictions or conditions imposed by the licensing authority. Also known are the number of licensed cockle collectors, how much time they spent and how much area is actually disturbed on an annual basis. Cockle collecting ceases almost completely during the months January to March as the flesh weight becomes too low during that period. All these data were combined to produce a map of both presence and abrasion by cockle collecting. The abrasion pressure of cockle collecting was assigned to the VMS cells according to the proportion of the area affected (Figure 5). A series of fact sheets documenting the basic maps used and the assumptions is available in Annex 1 of De Vries *et al* (2011).

All cumulative calculations were performed by combining GIS calculations (ESRI) and database manipulations (Microsoft Corporation, 2010a). The final dataset consists of four separate tables (summer/winter and presence/abrasion), with a row for each VMS cell and a column for each activity. These data can be used to make maps showing cumulative pressure, calculate statistics and prepare graphs. Several subdivisions of the area can be used to group VMS cell into larger units. A relevant subdivision is 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 was used to present the results: North Sea Coastal Zone, Western Wadden Sea and Eastern Wadden Sea (the eastern part is quieter than the western part) (Figure 6 and Figure 7). Pressure maps of individual activities are presented in Annex 2 of De Vries *et al* (2011).

## From pressure to ecosystem component

The RAM methodology was used to quantify the effects on ecosystem components. RAM stands for Risk Assessment for the Marine environment, a method developed in the 1990s (Karman & Schobben, 1995, Schobben *et al.*, 1996, Jak *et al.*, 2000, Karman *et al.*, 2001). In the present study the RAM methodology was implemented in the prototype model CUMULEO-RAM (CUMULEO is the name assigned to the collection of tools for measuring cumulative pressures or effects used by IMARES).

### *Disturbance–effect relationships*

In the RAM methodology, effects on species are subdivided into effects on mortality and effects on reproduction. In the present study the relationship between a pressure or disturbance and an effect are described by simple functions. The disturbance-effect relationships describe the relation between the intensity of a

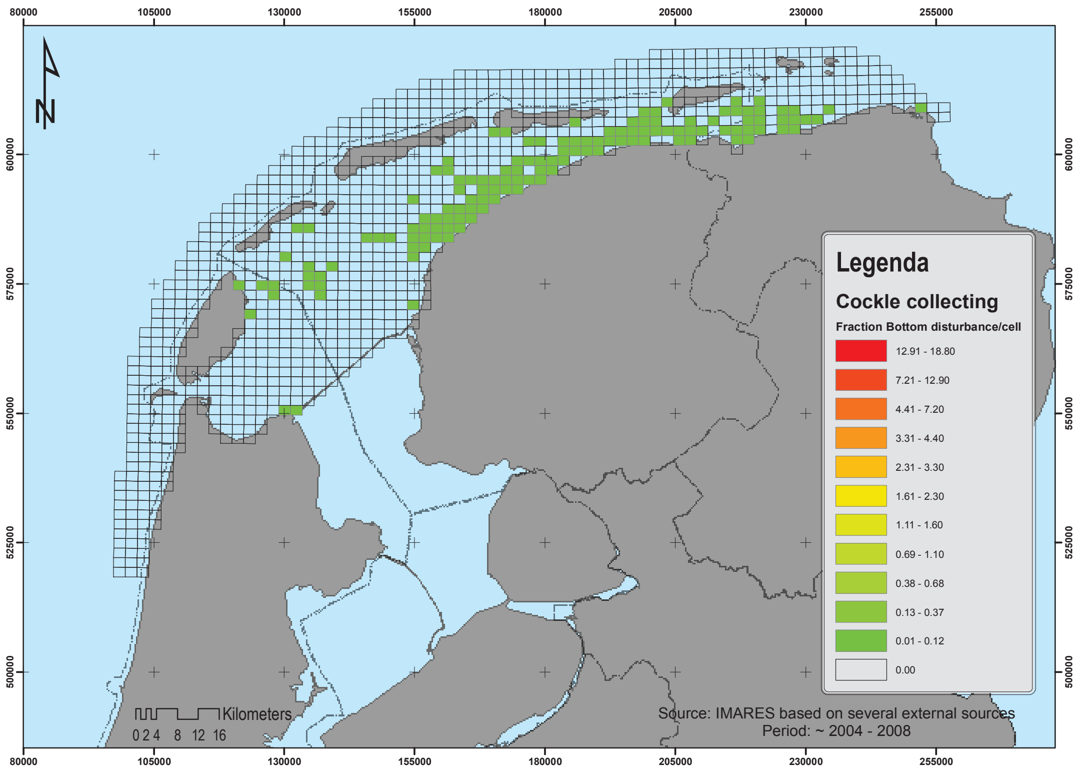


*Figure 5. Map showing abrasion (fraction of cell abraded) by cockle collecting to be included in the cumulative pressure*

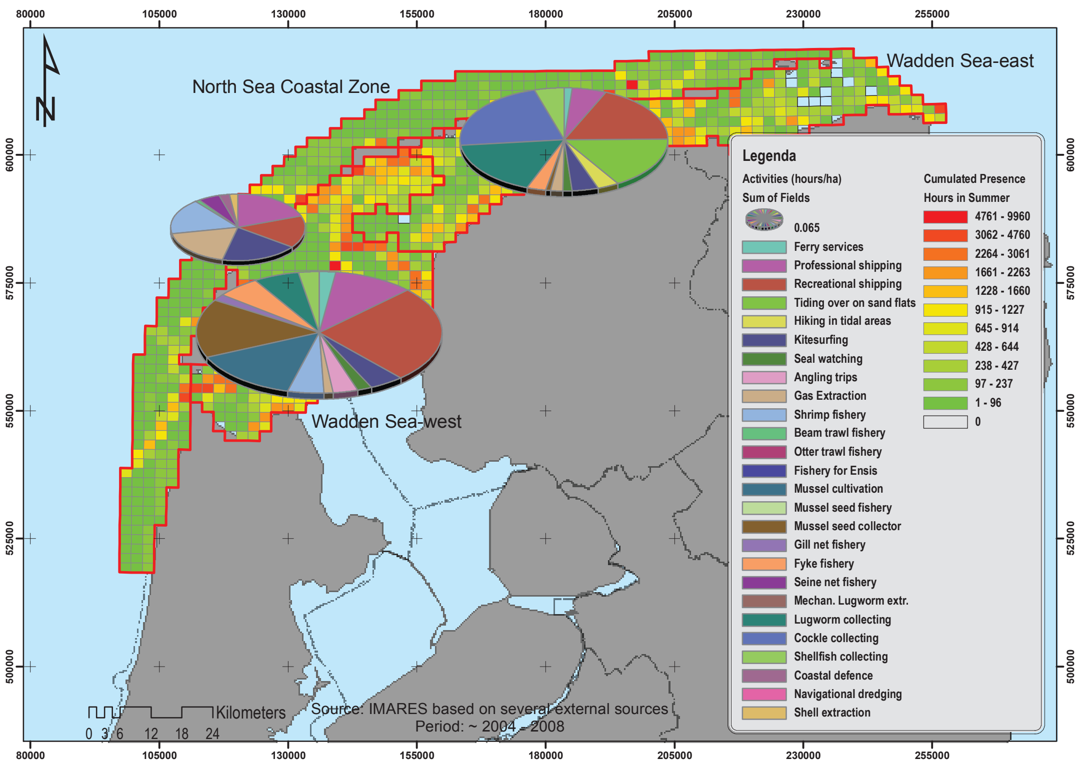


*Figure 6. Map showing summer presence by cell and contribution per activity; pie diagrams show contributions by activities to pressure for the three defined areas (North Sea Coastal Zone, Western Wadden Sea and Eastern Wadden Sea)*

potential exposure (e.g., frequency of disturbance to benthos) and the effect on the survival or reproduction of a species. The effect is expressed as a fraction between 0 and 1. The functions are defined such that when the exposure intensity is zero there is no effect (0), and when the exposure intensity is at the maximum the effect is also maximum (1).

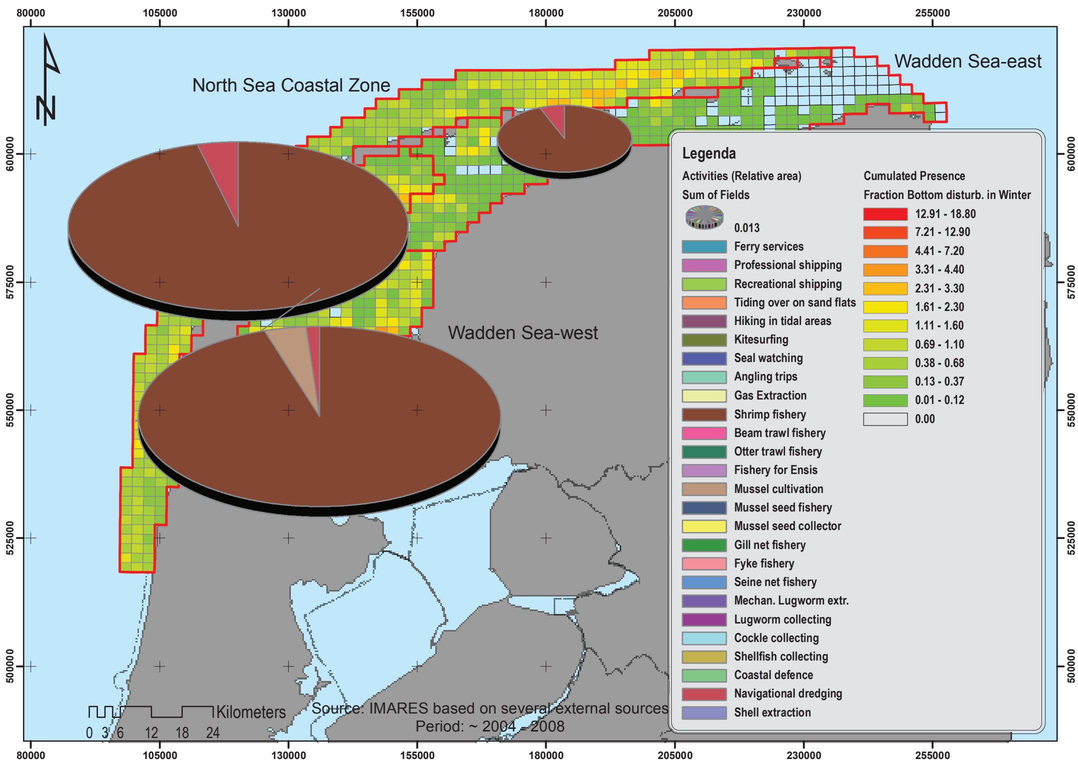


*Figure 7. Map showing winter abrasion and contribution per activity; pie diagrams show contributions by activities to pressure for the three defined areas (North Sea Coastal Zone, Western Wadden Sea and Eastern Wadden Sea)*

Many types of functions can describe the above relationships, such as a logistic curve, linear relation, etc. For each pressure/impact we selected an appropriate function type that is applicable to all relevant species. This means that for each pressure, only the values of the parameters differ between species. The functions were quantified using several calibration points derived from the literature on the sensitivity of the species to the pressure/impact.

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*

The mortality effects by abrasion were quantified by two different functions, depending on whether the surface within a grid cell is structurally (homogeneously) disturbed or disturbance takes place in a random fashion. For both types of distributions, disturbance–effect relationships from Karman *et al*. (2001) were used. A detailed description of the relationships and their parameterisation is given in De Vries *et al* (2011).

### *Visual disturbance*

In the prototype implementation it is assumed that visual disturbance affects reproduction. It is reasoned that both the fraction of the surface that is unavailable to a species and the fraction of time it is unavailable are directly and linearly proportional to the reduction in reproduction. The disturbed surface at a certain moment in time is a simplification of the approach proposed by Smit & Visser (1993). In the present study the disturbed surface fraction was calculated from the flush distance (*FD*, the shortest distance between a species and the disturbing object at which the bird flushes), the speed of the disturbing object (*v*), the specific recovery time (*s*, the time required for a species to recover or return after a disturbance) and the total surface of the grid cell ($S_{cell}$) (Figure 8).
A detailed description of the visual disturbance effect relation and its parameterisation is given in De Vries *et al* (2011).

### *Integration of effects and the derivation of a single population measure: the net reproductive rate*

The effect on survival and reproduction was calculated separately for each activity. The overall mortality and reproduction effect was determined by assuming that the effects of each activity occur independently of each other.

The effects on reproduction and mortality still need to be combined into a single indicator for potential population effects. The net reproductive rate (from here on referred to as 'reproductive rate') was 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 dividing the total number of

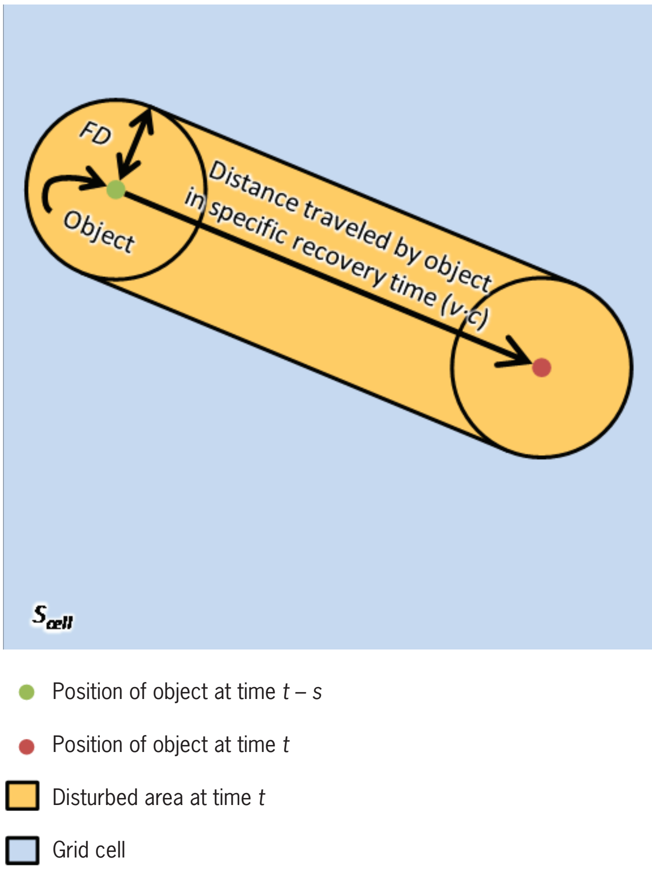


*Figure 8. Schematic representation of disturbed area within a grid cell (outer blue square, Scell); the disturbed area (orange) is defined by the speed of the object (v), the flush distance (FD) and the specific recovery time (s)*

juveniles that reach the adult stage by the total number of adults in a population. It can be seen as an indicator for population growth: if the reproductive value is less than 1 the population is expected to decline, whereas if it is larger than 1 it is expected to growth. The effects of population density and migration are not included. An assessment of actual population size and distribution is therefore not possible with the proposed methodology.

The life stages of species were generalised into four stages: pre-juvenile stage (from embryo to juvenile), juvenile stage (individuals that are not yet mature and therefore cannot reproduce), adult stage (mature individuals that can reproduce) and infertile (senile) stage (Figure 9). The infertile life stage was assumed to be irrelevant for population dynamics as these individuals usually make up just a small fraction of the entire population. The pre-juvenile stage often plays an important role in population dynamics, but natural mortality rates are usually high (especially for species that produce large quantities of eggs). However, as the mortality rates for this life stage are poorly quantified, reproduction was defined as the number of individuals that will reach the juvenile stage. This means that the effects during the pre-juvenile life stage are implicitly included as effects on reproduction.

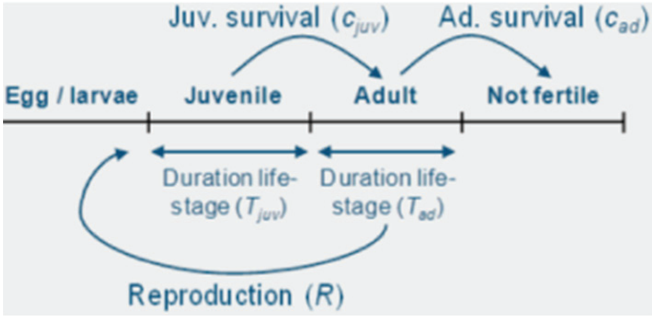


*Figure 9. Life stages used in the calculation of the reproductive value*

The reproductive value was calculated from the survival and lifespan of both juvenile and adult individuals and the reproduction. The underlying assumptions, derivation and parameterisation are described in De Vries *et al.* (2011).

## Effect assessment output from the prototype

The RAM methodology can be used to translate the pressure maps into reproductive value maps. Figure 10 shows the reproductive value map for the common cockle in the summer as an example. All other reproductive value maps for the case

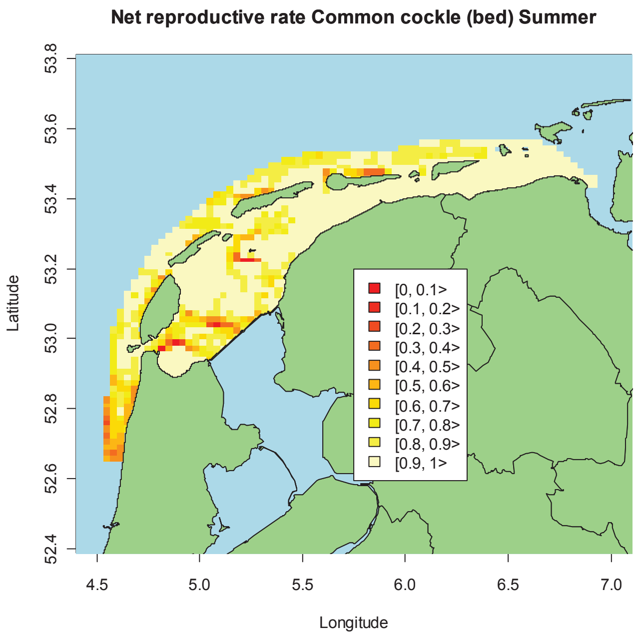


*Figure 10. Calculated map of reproductive values for the common cockle in the summer, an example of output generated in the present case study*

study are reported in Annex 3 of De Vries *et al*. (2011). These maps give information on potential population effects, but they do not include information on habitat suitability. In other words, if the map shows a low reproductive value (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, the pressures have no actual effect. Therefore, the methodology would be much more powerful if it was combined with habitat suitability maps.

Annex 4 of De Vries *et al*. (2011) contains pie diagrams showing the relative contributions made by each activity to the effects on survival and reproduction. These diagrams can be quite different from the pressure pie diagrams in Figure 7, because these pressure pie diagrams are not scaled to the sensitivity of the ecosystem components, whereas the diagrams in De Vries *et al*. (2011) are. For instance, from Figure 7 we learn that the intensity/pressure of the shrimp fishery is the largest in all the selected areas. However, the Baltic tellin is relatively insensitive to this particular form of fishing, and so the contribution made by shrimp fisheries to the effects on the survival of the Baltic tellin is relatively small.

## Discussion

The spatial resolution used in the present study might not be suitable for translating the results into actual population effects because the spatial extents of the 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 six-month periods might need to be refined, depending on the type of strategic management decision required. Neither does the current model include impacts outside the study area, which might also affect actual populations (for migratory species). Such effects should be studied in the future.

Some processes are simplified in the implemented prototype. Important simplifications to keep in mind are: the assumption of a linear relation between disturbance fraction (temporal and spatial) and reproductive effort; populations are assumed to be stable in the undisturbed situation (in other words, the reproductive value equals 1 in the situation without human activities); interactions between species are currently not included; the cumulative effects from different pressures are determined by assuming that the effect of each pressure is independent of the others; and the generic life-cycle defined for calculating the reproductive value (Figure 9) is not suitable for some types of organisms (such as plants).

## Conclusions

The implemented prototype CUMULEO-RAM model is a tool for scaling impacts from activities to population relevant indicators, although actual population size and distribution cannot be determined with the prototype. Future work should therefore focus more on expanding the human activities and pressures and less on attempting to incorporate population dynamics. The latter should be modelled separately when more detailed results are needed.

The strength of the presented approach lies in the transparency of the methodology, assumptions and parameterisation, making it relatively easy to understand. It combines spatial data to get insights into effects on survival and reproduction. Its simplicity makes adjustments and extensions uncomplicated. Its visual aspects combined with the speed of the calculations make 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 for guiding or specifying future research.

## Recommendations

The implemented prototype currently assesses potential population effects. The methodology would be much more powerful if combined with habitat suitability maps, as actual effects can only occur if pressures are located in suitable habitats. For birds, a distinction should be made between resting, reproduction and forage habitat. We therefore recommend working on combining reproductive value maps with habitat suitability maps in order to estimate actual effects. Further study should also focus on alternatives for the reproductive value and testing the model. This could include a sensitivity and/or uncertainty analysis. The tools should also be expanded to include more human activities, pressures and species (ecosystem components). The transparency of the model could also be improved by setting up a database with all parameters linked to their source.

Although the focus in the present study was not to link with the Marine Strategy Framework Directive descriptors for a good environmental status, it is desirable to investigate such possibilities in the future.

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