Memo

To
EcoShape BwN HK3.8

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Subject
Inclusion of ecology in the interactive design tool for the Holland Coast

1 Introduction

This document describes the implementation of two ecological indicators, which respectively visualise the impact of nourishments on the benthos population and the impact of coastal changes on the foreshore area that is available for fish. The indicators were developed for the BwN work package HK 3.8. The indicators will be applied in a study (for BwN HK3.8) which evaluates the considered two ecological impacts for different nourishment types. The aim of that study is to define guidelines on ecologically smart nourishments. The considered ecological indicators are included in an interactive tool, which is available for the Holland Coast. This tool was developed within the BwN work package HK4.1 (Deltares, 2012). It is noted that the goal of the current document is to describe the implementation of the indicators and not the impact assessment of nourishment strategies.

A summary of the aims of the related BwN work packages HK3.8 and HK4.1 is given below.

Building with nature HK 3.8
The aim of Building with nature work package HK3.8 is to "Recommend on smart design of sand nourishments to improve the nursery function of the Dutch coast for commercial and non-commercial fish species, to increase harvestable fish population size". For this purpose, an assessment is made of available knowledge on habitat factors (depth, grain size, sediment stability, water temperature, presence of food, etc.) in relation to seasonal patterns, mapping larval settlements habitats and juvenile nursery habitats. Furthermore, additional data on the use of the shallow coastal zone by juvenile fish is collected by executing surveys. The results of this work package will be a set of guidelines on the application of ecologically smart nourishments (for fish population), which will be described in a separate report.

Building with nature HK 4.1
The work package HK4.1 aims at "Developing a strategy for the long-term, sustainable development of the Holland Coast through extrapolation of findings from HK-projects and pilots to the scale of the entire Holland Coast". The strategy will be based on the design philosophy of BwN aimed at maximizing the potentials of the eco-morphodynamic system. The considered coastal management strategies vary between the present management strategy and new strategies that are advised by the Delta commission (2008). The activities are (1) the development of an aggregated morphological model of the Holland Coast enabling the analysis of large scale morphological development, (2) deriving information from geological analogs of sand-engines in order to provide validation material for upscaling of the morphodynamic models, and (3) the development of a habitat - and vegetation model enabling the 'translation' of large scale morphological model forecasts into (ecological) habitat effects and (4) the development of different large scale sand mining - and nourishment scenarios.

2 Explanation of indicators

2.1 General

Two indicators have been developed to evaluate the impact of a nourishment strategy on two aspects of the marine ecology. The first indicator considers the direct impact of individual nourishments on benthic species. The second indicator considers the indirect impact of a nourishment strategy, which is related to the decrease (or increase) of foreshore area that is available for juvenile fish as a result of a progading or retreating coast.

2.2 Indicator 1 : Direct impact of nourishments on the benthic population

The first indicator considers the direct impact of individual nourishments, which is related to the local burial of benthic species under a large amount of sand at the nourishment site. The approach that is used is characterized by the following aspects:

- The restoration of the benthic community can be described by a logistic growth function, with relates population growth to a time-varying carrying capacity.
- The initial impact at the moment of construction of nourishments is assumed to be much larger than the impact on the benthic species after construction of nourishments.
- The type of nourishment (i.e. magnitude of nourishment) is expected to determine the reduction in population and carrying capacity at the time of construction of the nourishment.
- Restoration of the benthic population can be considered independently for separate cells along the coast.

As mentioned above a logistic growth function with a time varying carrying capacity is used as a basis for the evaluation of the considered indicator. For this purpose, the rate of change of the population as a result of a time-varying carrying capacity from Shephard & Stojkov (2007) was used. The logistic growth function is as follows :

$$\frac{dP}{dt} = rP\left(1 - \left(\frac{P}{K(t)}\right)^{\sigma}\right) \tag{1}$$

With:

P	*population*
t	*time [years]*
r	*growth rate*
K(t)	*time-varying carrying capacity*
σ	*power of logistic growth function*

The time-varying carrying capacity (K(t)) in equation 1 is provided in equation 17 of Shephard & Stojkov (2007). The expression is provided below.

$$K(t) = \frac{K*}{(1+((\frac{K*}{K})^{\sigma}-1)e^{-\sigma\varepsilon t})^{1/\sigma}} \tag{2}$$

With:

*K**	*equilibrium carrying capacity*
ε	*factor for slowly varying population growth (ε<r)*

In order to use the equation for logistic growth (eq. 1) directly in the model it should be translated into an explicit form. Shephard & Stojkov (2007) found such an explicit form for the logistic growth function (see eq. 18 in their paper) which reads as follows:

$$P(t+1)=\frac{K*}{\left[1+\alpha e^{-\varepsilon s\cdot dt}+(\beta-\alpha)e^{-rs\cdot dt}\right]^{1/s}} \quad (3)$$

With:

P(t) *Population before timestep*
P(t+1) *Population after timestep*
dt *timestep between time instance t and t+1 [years]*

$$\alpha=\frac{r}{r-\varepsilon}\left[\left(\frac{K*}{K(t)}\right)^{s}-1\right],\ \beta=\left(\frac{K*}{P(t)}\right)^{s}-1$$

Specific parameters that are required to resolve the considered explicit logistic growth function (eq. 3) should be specified in a special file with input parameters, which contains the initial value of P, the growth rate (r-value) and equilibrium carrying capacity (K*).

The influence of nourishments and structures on the benthic population is included in the model by application of a reduction factor for the population and carrying capacity (r and k-values) at the moment in time that the measure is taken, which is checked throughout the time-loop (see eq. 4 and 5). Typical reduction factors for the r and k values can be provided in a settings file for each of the measures. These reduction factors are only applied at the construction of a measure, as the effect of the construction of nourishments and structures on the ecology is expected to be much larger than throughout its lifetime. It is expected that the type of nourishment (i.e. magnitude of nourishment) is dominant for the reduction in population and carrying capacity at the time of construction of the nourishment as well as for the rate of restoration (r). Therefore typical values can be applied for different nourishment types (e.g. mega, foreshore or beach nourishments). A set of typical reduction-values is currently under development by ecologists, who will also select two or more typical species on the basis of their occurrence and expected species sensitivity to nourishments.

$$P(t)_{red}=P(t)\cdot\left(1-R_{meas}\right) \quad (4)$$

$$K(t)_{red}=K(t)\cdot\left(1-R_{meas}\right) \quad (5)$$

With:

$P(t)_{red}$ *Reduced population as a result of a measure*
$K(t)_{red}$ *Reduced carrying capacity as a result of a measure*
R_{meas} *Reduction factor for a measure*

The influence of coastal measures is assessed separately for alongshore cells, thus assuming that restoration of the benthic population can be considered independently for separate cells along the coast. Consequently, the effects of restoration of the benthic population as a result of colonization by benthos from adjacent cells along the shore are not included. This is a conservative approach, as there may be a faster restoration of the benthic community in reality, but it is considered a small effect compared to the uncertainties in the impact of measures on species and their growth rates. Furthermore, alongshore re-colonization will increase the complexity and input parameters for such a model approach will be difficult to justify scientifically. An overview of the approach used to assess the time development of the benthic population for one species in each of the alongshore coastal grid cells is provided in Figure 1.

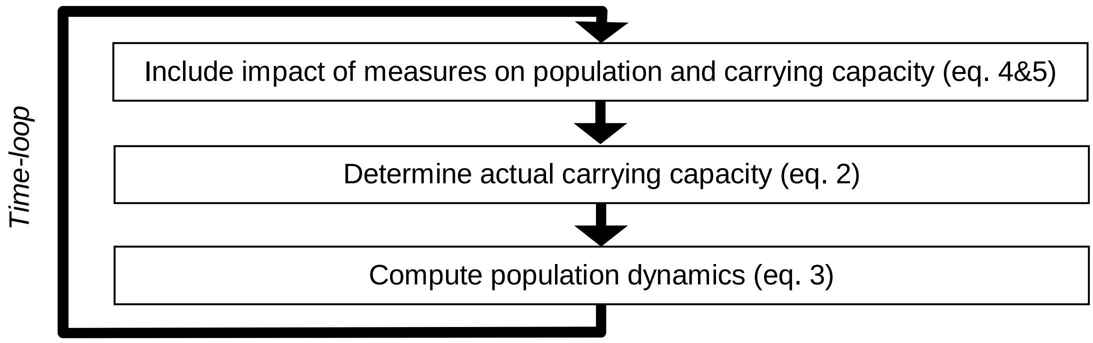

Figure 1: Approach used to assess time development of the benthic population for one species in a grid cell

2.3 Indicator 2 : Indirect impact of nourishments on the foreshore area

The second indicator considers the indirect impact of a nourishment strategy, which is related to the change of the foreshore area as a result of a prograding or retreating coast. The actual foreshore area is considered a proxy for the available space for juvenile fish along the coast (so called nursery function for juvenile fish). For example, a reduction in the foreshore area as a result of continuous nourishments along the coast may have a negative impact on the nursery function of the coast.

In order to evaluate this indicator it was assumed that the area at each depth contour reduces equally to the reduction of the foreshore area in time. The available foreshore area along the Dutch coast up to the NAP-20m contour was estimated in a very simple way by using an average width of the foreshore for the whole of the Holland coast of about 10 km (referred to as shorewidth). The relative reduction in the available foreshore width (ψ) is then evaluated over time for each of the grid cells along the coast with formula 6.

$$\psi(x,t) = \frac{B_{ref}(x) - \Delta B(x,t)}{B_{ref}(x)} \qquad (6)$$

With:

B_{ref}	*Reference width of the foreshore [m] (default = 10 km)*
ΔB	*Coastline change [m]*
ψ	*Relative change of foreshore area*
x	*Alongshore distance [m]*

3 Changes to the code

The changes that were made to the code of the Interactive Tool for the Holland Coast (ITHK) were made in the postprocessing directory and added to ‘postprocessing\indicators\eco\’. The functions that were added are the following:

- *ITHK_ind_ecology_benthos.m*
  The Ecorules2.m function computes the impact on indicator 1. It uses information on the measures (nourishments and structures) that are constructed on the coast, as well as information on the relative impact of measures on the benthic population (i.e. reduction factors for the population, carrying capacity and typical growth rates). These ecological impact parameters are read from a settings file (‘eco_input.txt’) for a pre-selected number of relevant benthic species. A read routine (‘ITHK_ind_ecology_benthos_read.m’) automatically reads the relevant parameters from the settings file (‘ITHK_ind_ecology_benthos_input.txt’). The results of this routine are passed on through the ITHK code and used later on by the ‘ITHK_KMLbarplot.m’ to generate KML files that can be presented in the ITHK java interface.
- *ITHK_ind_foreshore_juvenilefish.m*
  The Shorewidth.m function computes the impact on indicator 2 (indirect impact of nourishment on the foreshore area). It computes a relative change of the foreshore width for each alongshore grid cell on the basis of the computed coastline displacement and a reference width of the foreshore. By default a reference width of 10km is used.
- *ITHK_KMLbarplot.m*
  This function writes the computed impact on the indicators that was generated by the ‘ITHK_ind_ecology_benthos.m’ and ‘ITHK_ind_foreshore_juvenilefish.m’ to a KML file. These files can be presented in the ITHK web interface or directly in Google Earth.
- *ITHK_ind_ecology_benthos_input*
  This settings-file contains the ecological parameters used for the evaluation of the direct impact of nourishments on the local benthic population. It includes a growth rate of the species (r), an equilibrium carrying capacity (k_s), an initial population (p0) and reduction factors for different types of measures on the coast, like beach nourishments, revetments etc. A variable number of species can be used by adding multiple blocks with above parameters. One such input parameters block read like:

```
*
* species 1
* species name:  polychaetes
*
r                          = 3
k_s                        = 100
p0                         = 100
k_beach_nourishment        = 50
k_foreshore_nourishment    = 80
k_mega_nourishment         = 95
k_revetment                = 5
k_groyne                   = 10
k_others                   = 10
```

4 Example case

4.1 Introduction

In this section a typical example is shown of the results for both ecological indicators that are described in Section 2.2 and 2.3. First, the Holland coast model in the ITHK is described concisely in Section 4.2. Section 4.3 then describes the reference scenarios, for which the results are presented in Section 4.4.

4.2 Holland coast model

The ITHK includes a UNIBEST coastline model that has been setup for the Holland coast (from Hoek van Holland to Den Helder). Structures were included at Scheveningen and IJmuiden to represent the harbour moles at these locations. The model has a length of 118 km and includes 113 cross-shore profile rays for which the sediment transport was computed. An overview of the longshore sediment transport is in the model is provided in Figure 2.

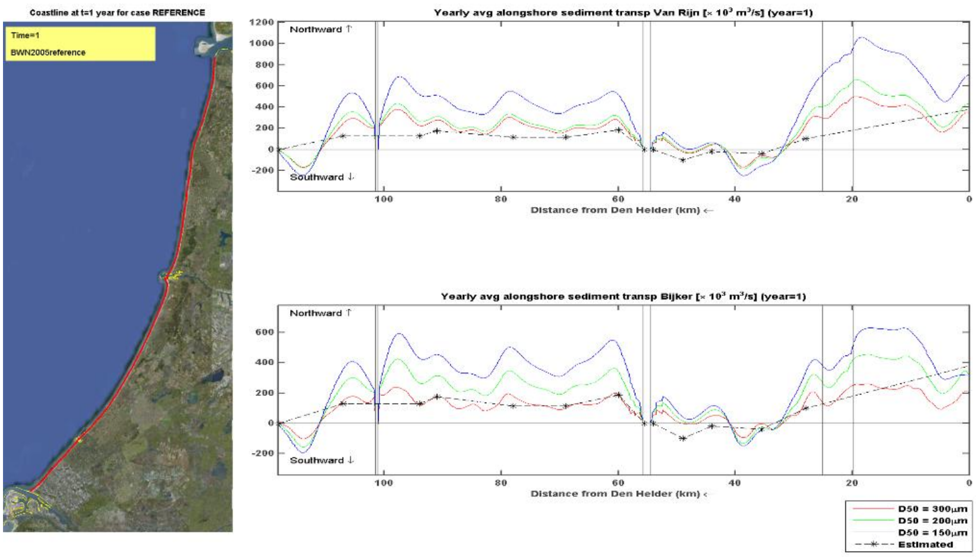

Figure 2: Computed sediment transport for 3 sediment diameters (D50=150, 200 and 300 μm) and two sediment transport formulae (Top: Van Rijn, 2004, Bottom: Bijker, 1977) (Deltares, 2010)

A detailed description of this tool is provided in the memo 'Evaluation of nourishment strategies Cycle 1 : HK4.1: Long-term sustainable strategies for the Holland Coast' (Deltares,2010).

4.3 Test case

4.3.1 Test description

First a general test case was performed which checks the performance of the indicator that visualises the direct impact of nourishments on the benthic population. For this purpose, a model simulation with a period of 20 years was performed. Within the modelled timeframe, a number of measures was implemented:

- Continuous nourishment north of Scheveningen
- Revetment just north of Ter Heijde

Furthermore, the initial benthic population (P_0 of 100) is much smaller than the carrying capacity (K* of 1200) of the system. Consequently, an increase in the population is expected for areas without nourishments or coastal structures.

4.3.2 Results

This section shows the results of the test case for the indicator that visualises the direct impact of nourishments on the benthic population. The computed impact on the indicators (for each grid cell and time step) was aggregated to a smaller number of 60 alongshore coastal cells with a length of about 2 km and 20 output time steps for the purpose of presentation on the map.

The model results show that the benthic population at the location of the nourishment and revetment has decreased considerably because of the measures (see Figure 3). In fact, the population drops to zero for areas with a continuous nourishment or revetment. Gradually, eco indicators showed that the benthic population (P) at other sections increased except for those sections which are influenced by a nourishment or revetment.

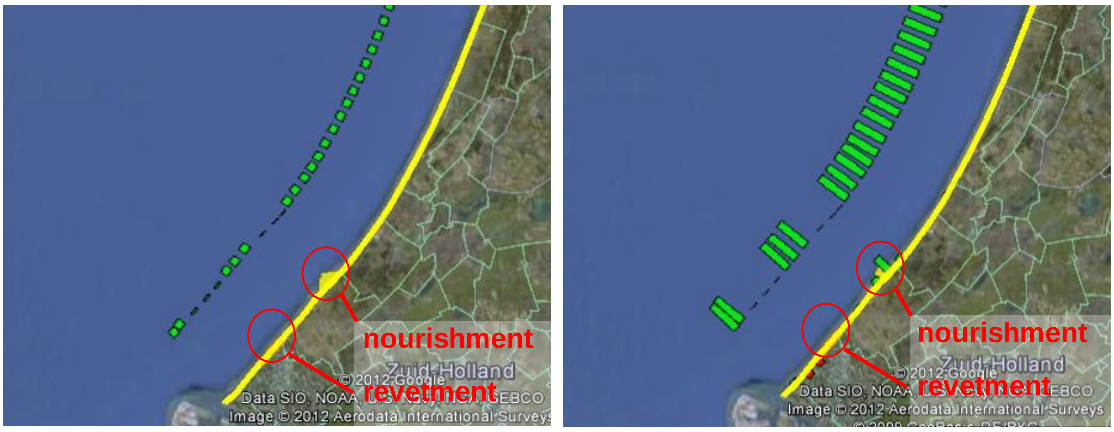

Figure 3: Ecological indicator for the impact of coastal measures on the benthic population (bars shown at 10 km offshore) and the current coastline (yellow line) after one year (left panel) and seven years (right panel).

The development of the benthic population is plotted over time in Figure 4. The graph shows a coastal cell without measures (green line), with a nourishment (blue line) and with a revetment (pink line). At the undisturbed section, the benthic population gradually grows towards the equilibrium carrying capacity (K* =1200). While a continuous measure may decimate the local benthic population over time.

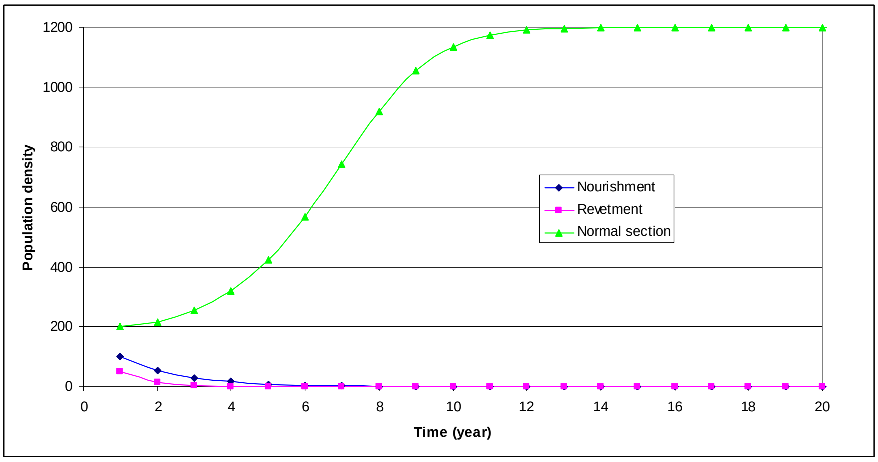

Figure 4: Benthic population over time for three coastal sections. The blue line shows the benthic population at a section with a continuous nourishment. The pink line shows the time-development for a section with a revetment, while the green line indicates the development of the benthic population for a section without any measures.

On the basis of this test case it is concluded that the implemented indicators perform as expected.

4.4 Reference scenarios

4.4.1 Description of scenarios

It is also worthwhile to evaluate also the effects for somewhat more realistic test scenarios than the test-case that was described in the previous section. This section therefore provides an overview of typical results for the reference scenarios of the coast, which are summarised here:

1. *Autonomous*
   Autonomous development without measures
2. *Minimal consolidation: Continuous nourishments*
   Minimal consolidation of the coast at coastal settlements with 5 million m^3/yr of continuous nourishments.
3. *Minimal consolidation: Five yearly nourishments*
   Minimal consolidation of the coast at coastal settlements with 2.5 million m^3/yr of nourishments with an interval of 5 years.
4. *Seaward*
   Seaward extension of the coast with sand engines of 20Mm3 and a return interval of 10 years at 5 locations along the coast (Vlugtenburg, Katwijk, Zandvoort, Egmond and at the Hondsbossche zeewering).
5. *Revetments*
   Revetments protecting the coastal settlements (no additional nourishments)

The model simulations cover a period of 95 years until the year 2100. A moderate sea level rise (2 mm/yr) is included for all scenarios by means of an additional coastal retreat that was computed for a profile with an average slope of 1:500. A moderately fast and a slow recovering species of benthos are included in the model (with growth rates of 1 and 3). It is noted that the aim of these scenarios is to evaluate indicators values and not the actual coastal changes.

4.4.2 Results

This section presents the results of the model run for the reference scenarios (Figure 5a to Figure 5e). The Figures show the coastline position as a yellow line on the coast and the change in coastline position with red and green bars (which improve the visibility of the coastline changes). In offshore waters the indicators for Benthos (green bars) and juvenile fish are presented (blue bars). The blue bar, in fact, presents the relative change in foreshore area, which is considered a proxy for the nursery area that is available for juvenile fish.

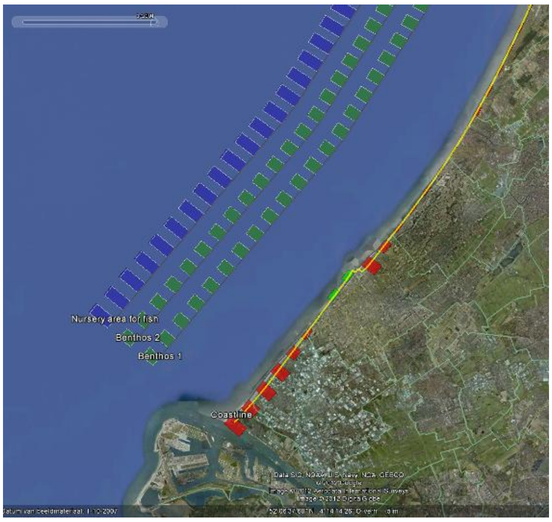

Figure 5a: Coastal development and coastal indicators for reference scenario 1 (Autonomous).

Figure 5a shows considerable erosion along the coast. Consequently, the foreshore area increases slightly, which results in a slightly larger area for juvenile fish (blue bars) than initially (grey box). There is no impact on Benthos found, as there are no measures taken in this scenario.

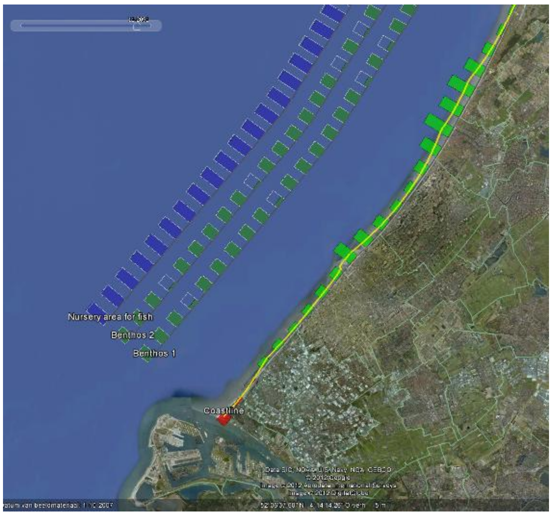

Figure 5b: Coastal development and coastal indicators for reference scenario 2 (Minimal consolidation: Continuous nourishments).

The impact of a continuous (i.e. yearly) nourishment (Figure 5b) on the benthic population, in Scenario 2, was found to be considerable at the location of the nourishments even though the volumes are relatively small. The relative coastline changes are not that large that they affect the nursery area significantly.

Figure 5c: Coastal development and coastal indicators for reference scenario 3 (Minimal consolidation: Five yearly nourishments). Moments in time before and after a nourishment took place.

The nourishments with a regular interval of five years (Figure 5c) also shows that the benthic population is influenced locally at the nourishment sites. Furthermore, it shows that the population of moderate to quickly recovering species may restore within five years. The slower species with a growth rate of 1 does, however, hardly recover in the period between nourishments.

Figure 5d: Coastal development and coastal indicators for reference scenario 4 (Seaward). Moments in time before and after a nourishment took place.

The coastal development for a seaward scenario (Figure 5d) showed that the coast can be build out considerably in such a period. The impact on the benthic species is very large directly after the placement of a nourishment, but species do have time to recover in the ten year period between the nourishments. Furthermore, it shows that there is a noticeable reduction of the foreshore area (blue bars) because of the build out of the coast.

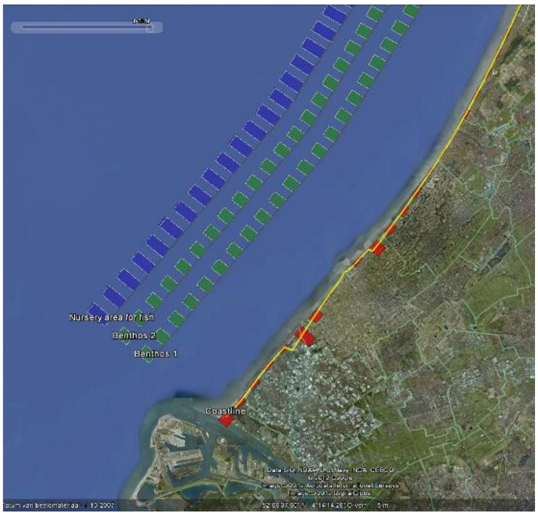

Figure 5e: Coastal development and coastal indicators for reference scenario 5 (Revetments).

The scenario with revetments (Figure 5e) shows a small impact on the considered indicators as there are no nourishments.

5 Conclusions

The implementation of two ecological coastal indicators is described in this document. The considered coastal indicators are (1) the direct impact of nourishments on the local benthic population and (2) the indirect impact of coastal changes on the nursery area that is available for juvenile fish.

A theoretical description of the method of valuing of these indicators is provided. An application for a test case then showed the proper functioning of the implemented changes.

Version	Date	Author	Initials	Review	Initials	Approval	Initials
1.0 (Draft)	June 2012	B.J.A. Huisman Q. ye K.E. v.d. Wolfshaar	[signature]	Arjen Luijendijk	[signature]	KlaasJan Bos	[signature]

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