Part 2:  
*Global change, Ecosystems and Biodiversity*

Annex 1

**BALANS**  
BALANCING IMPACTS OF HUMAN ACTIVITIES  
IN THE NORTH SEA  
EV/21

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ANNEX 1: SAND AND GRAVEL EXTRACTION DRIVING FORCE
1 MAIN STOCK AND FLOW

1.5 natural rate

DATA: available

- Source: Management Unit of the North Sea Mathematical Models, Royal Belgian Institute of Natural Sciences
- Dataset: According to the expert, the yearly balance of the sedimentary and erosive process is zero. Without further knowledge of the spreading around this value of the year, this parameter has been taken constant and equal to zero.

2 DEMAND FOR EXTRACTION

2.1 total demand

DATA: calculated and verifiable

- Source: FOD Economie, KMO, Middenstand en Energie
- Dataset: Extracted volume of sediment over all types per month over years 1997-2004.

<table>
<thead>
<tr>
<th>MONTH</th>
<th>Volume Extracted in m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>85,017</td>
</tr>
<tr>
<td>February</td>
<td>116,201</td>
</tr>
<tr>
<td>March</td>
<td>154,587</td>
</tr>
<tr>
<td>April</td>
<td>142,275</td>
</tr>
<tr>
<td>May</td>
<td>313,029</td>
</tr>
<tr>
<td>June</td>
<td>291,466</td>
</tr>
<tr>
<td>July</td>
<td>115,560</td>
</tr>
<tr>
<td>August</td>
<td>206,109</td>
</tr>
<tr>
<td>September</td>
<td>150,410</td>
</tr>
<tr>
<td>October</td>
<td>144,673</td>
</tr>
<tr>
<td>November</td>
<td>137,177</td>
</tr>
<tr>
<td>December</td>
<td>95,464</td>
</tr>
</tbody>
</table>

2.3 Fraction
DATA: virtual values estimated from grey literature
- Fine sand: 10%; Medium and coarse sand: 85%; Gravel: 5%

2.6 Quotum over 5 years
DATA: available as one set value = 15,000,000 m³ for 5 years
- Source: Koninklijk besluit van 1 september 2004 betreffende de voorwaarden, de geografische begrenzing en de exploratie en de exploitatie van de minerale en andere niet-levende rijkdommen in de territoriale zee en op het continental plat, O.J. 7 october 2004

3 EXTRACTION

3.1 percentage of overlap
DATA: virtual

3.5 regime of the zones
- Source: virtual
- Dataset:
DEFAULT VALUES:

<table>
<thead>
<tr>
<th>Zone</th>
<th>Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>1</td>
</tr>
<tr>
<td>1b</td>
<td>1</td>
</tr>
<tr>
<td>2a</td>
<td>1</td>
</tr>
<tr>
<td>2b</td>
<td>0</td>
</tr>
<tr>
<td>2c</td>
<td>1</td>
</tr>
<tr>
<td>3a</td>
<td>1</td>
</tr>
<tr>
<td>3b</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

3.7 surface of pockets
The classification scheme used by the geologists differs from the classification scheme of the ‘extractors’. For example the classifications of the Renard Center of Marine Geology, University of Gent is following the Wentworth Scale that have grain fractions that take a median value for a grain type. Whereas, the extractor have a classification system that takes the maximum grain size into account when fulfilling a request for sand extraction by concession holders. To quantify the ‘surface of the pockets’ we have the information of the geologists. This then presents another issue where the grain sizes that are the focus of the extractors and the geologists differ in size scale. For the purpose of this model we have taken the datasets of the geologists and classified them into 3 grain fractions, these being ‘fine sand’, ‘medium-coarse sand’ and ‘gravel’. We currently use the Folk Classification from the geologists that classifies according to percentage silt-clay, sand and gravel.

DATA:
- Source: Renard Center of Marine Geology, University of Gent
- Dataset: Surface area (m²) of 24 pockets; classified by Wentworth Scale

<table>
<thead>
<tr>
<th>ZONE</th>
<th>FS (0-250 mu)</th>
<th>MCS (250-500 mu)</th>
<th>Coarse (&gt;500mu)</th>
<th>Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>0</td>
<td>78351048</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1B</td>
<td>0</td>
<td>26365624</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2A</td>
<td>1175838</td>
<td>9952507</td>
<td>437500</td>
<td></td>
</tr>
<tr>
<td>2B</td>
<td>14097899</td>
<td>22257829</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2C</td>
<td>6670396</td>
<td>97448683</td>
<td>125000</td>
<td></td>
</tr>
<tr>
<td>3A</td>
<td>6722063</td>
<td>788082</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3B</td>
<td>6764903</td>
<td>2625900</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>306693018</td>
<td>687500</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 1. Surface of the grain pockets within extraction zones according to d50 classification. Displayed are the fine sand (<250μm), medium sand (250-500μm) and coarse sand (>500μm) classes. Source: Renard Center of Marine Geology, Ghent University 2006
DATA:
- Source: Renard Center of Marine Geology, University of Gent
- Dataset: Surface area (m²) of 24 pockets; classified by Folk Classification

<table>
<thead>
<tr>
<th>ZONE</th>
<th>gmS+mS</th>
<th>gS+S</th>
<th>sG</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>1773229</td>
<td>76247515</td>
<td>330305</td>
</tr>
<tr>
<td>1B</td>
<td>0</td>
<td>26365623</td>
<td>0</td>
</tr>
<tr>
<td>2A</td>
<td>0</td>
<td>11565844</td>
<td>0</td>
</tr>
<tr>
<td>2B</td>
<td>0</td>
<td>36355728</td>
<td>0</td>
</tr>
<tr>
<td>2C</td>
<td>0</td>
<td>104244079</td>
<td>0</td>
</tr>
<tr>
<td>3A</td>
<td>359517</td>
<td>7150628</td>
<td>0</td>
</tr>
<tr>
<td>3B</td>
<td>3968809</td>
<td>5421994</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>307318017</td>
<td>62500</td>
</tr>
</tbody>
</table>
Fig. 2. Surface of the grain pockets within extraction zones according to Folk classification. Displayed are the mS-gmS, S-gS and sG classes. Source: Renard Center of Marine Geology, Ghent University 2006

3.8 extraction depth of gear
DATA:
   • Source: Reimerswaal, personal communication
   • Dataset: available as one set value = 0.5m

3.9 sum of surfaces
DATA:
   • Source: Renard Center of Marine Geology, University of Gent
   • Dataset: see annex section 3.7
3.11 surface to be extracted per zone and type

**DEFINITION:** With this variable, we distribute the monthly demand for a given grain size over the zones. When the first zone is closed (either by policy or because the critical depth is reached) we go to the next one, in order of increasing distance of the zones to the shore. It is a “virtual” surface as it does not take into account the actual extraction depth.

**EQUATION:**

\[
\begin{align*}
\text{Surface\_to\_be\_extracted\_per\_zone\_and\_type}\_\text{[Zone1a,Fine\_Sand]} &= \text{IF} & ((\text{Critical\_depth\_flag}\_\text{[Zone3a,Fine\_Sand]} + \\
& \text{Critical\_depth\_flag}\_\text{[Zone3b,Fine\_Sand]} + \\
& \text{Critical\_depth\_flag}\_\text{[Zone2a,Fine\_Sand]} + \\
& \text{Critical\_depth\_flag}\_\text{[Zone2b,Fine\_Sand]} + \\
& \text{Critical\_depth\_flag}\_\text{[Zone1b,Fine\_Sand]})) = 0 \text{ AND} & \text{Critical\_depth\_flag}\_\text{[Zone1a,Fine\_Sand]} = 1) \\
& \text{THEN} & \text{To\_be\_extracted\_nominal\_surface\_per\_type}\_\text{[Fine\_Sand]} \\
& \text{ELSE} & (0)
\end{align*}
\]

\[
\begin{align*}
\text{Surface\_to\_be\_extracted\_per\_zone\_and\_type}\_\text{[Zone1a,Medium\_Coarse\_Sand]} &= \text{IF} & ((\text{Critical\_depth\_flag}\_\text{[Zone3a,Medium\_Coarse\_Sand]} + \\
& \text{Critical\_depth\_flag}\_\text{[Zone3b,Medium\_Coarse\_Sand]} + \\
& \text{Critical\_depth\_flag}\_\text{[Zone2a,Medium\_Coarse\_Sand]} + \\
& \text{Critical\_depth\_flag}\_\text{[Zone2b,Medium\_Coarse\_Sand]} + \\
& \text{Critical\_depth\_flag}\_\text{[Zone1b,Medium\_Coarse\_Sand]})) = 0 \text{ AND} & \text{Critical\_depth\_flag}\_\text{[Zone1a,Medium\_Coarse\_Sand]} = 1) \\
& \text{THEN} & \text{To\_be\_extracted\_nominal\_surface\_per\_type}\_\text{[Medium\_Coarse\_Sand]} \\
& \text{ELSE} & (0)
\end{align*}
\]

\[
\begin{align*}
\text{Surface\_to\_be\_extracted\_per\_zone\_and\_type}\_\text{[Zone1a,Gravel]} &= \text{IF} & ((\text{Critical\_depth\_flag}\_\text{[Zone3a,Gravel]} + \\
& \text{Critical\_depth\_flag}\_\text{[Zone3b,Gravel]} + \\
& \text{Critical\_depth\_flag}\_\text{[Zone2a,Gravel]} + \\
& \text{Critical\_depth\_flag}\_\text{[Zone2b,Gravel]} + \\
& \text{Critical\_depth\_flag}\_\text{[Zone1b,Gravel]})) = 0 \text{ AND} & \text{Critical\_depth\_flag}\_\text{[Zone1a,Gravel]} = 1) \\
& \text{THEN} &
\end{align*}
\]
To_be_extracted_nominal_surface_per_type[Gravel]
ELSE
(0)

To_be_extracted_nominal_surface_per_type[Fine_Sand]
ELSE
(0)

Surface_to_be_extracted_per_zone_and_type[Zone1b,Medium_Coarse_Sand] = IF ((Critical_depth_flag[Zone3a,Medium_Coarse_Sand]+ Critical_depth_flag[Zone3b,Medium_Coarse_Sand]+ Critical_depth_flag[Zone2a,Medium_Coarse_Sand]+ Critical_depth_flag[Zone2b,Medium_Coarse_Sand])=0 AND Critical_depth_flag[Zone1b,Medium_Coarse_Sand]=1) THEN
To_be_extracted_nominal_surface_per_type[Medium_Coarse_Sand]
ELSE
(0)

Surface_to_be_extracted_per_zone_and_type[Zone1b,Gravel] = IF ((Critical_depth_flag[Zone3a,Gravel]+ Critical_depth_flag[Zone3b,Gravel]+ Critical_depth_flag[Zone2a,Gravel]+ Critical_depth_flag[Zone2b,Gravel])=0 AND Critical_depth_flag[Zone1b,Gravel]=1) THEN
To_be_extracted_nominal_surface_per_type[Gravel]
ELSE
(0)

Surface_to_be_extracted_per_zone_and_type[Zone2a,Fine_Sand] = IF ((Critical_depth_flag[Zone3a,Fine_Sand]+ Critical_depth_flag[Zone3b,Fine_Sand])=0 AND Critical_depth_flag[Zone2a,Fine_Sand]=1) THEN
To_be_extracted_nominal_surface_per_type[Fine_Sand]
ELSE
(0)
Critical_depth_flag[Zone2a,Fine_Sand]=1)
THEN
   To_be_extracted_nominal_surface_per_type[Fine_Sand]
ELSE
   (0)

Surface_to_be_extracted_per_zone_and_type[Zone2a,Medium_Coarse_Sand] = IF
((Critical_depth_flag[Zone3a,Medium_Coarse_Sand]+Critical_depth_flag[Zone3b,Medium_Coarse_Sand])=0 AND
Critical_depth_flag[Zone2a,Medium_Coarse_Sand]=1)
THEN
   To_be_extracted_nominal_surface_per_type[Medium_Coarse_Sand]
ELSE
   (0)

Surface_to_be_extracted_per_zone_and_type[Zone2a,Gravel] = IF
((Critical_depth_flag[Zone3a,Gravel]+Critical_depth_flag[Zone3b,Gravel])=0 AND
Critical_depth_flag[Zone2a,Gravel]=1)
THEN
   To_be_extracted_nominal_surface_per_type[Gravel]
ELSE
   (0)

Surface_to_be_extracted_per_zone_and_type[Zone2b,Fine_Sand] = IF
((Critical_depth_flag[Zone3a,Fine_Sand]+Critical_depth_flag[Zone3b,Fine_Sand]+Critical_depth_flag[Zone2a,Fine_Sand])=0 AND
Critical_depth_flag[Zone2b,Fine_Sand]=1)
THEN
   To_be_extracted_nominal_surface_per_type[Fine_Sand]
ELSE
   (0)

Surface_to_be_extracted_per_zone_and_type[Zone2b,Medium_Coarse_Sand] = IF
((Critical_depth_flag[Zone3a,Medium_Coarse_Sand]+Critical_depth_flag[Zone3b,Medium_Coarse_Sand]+Critical_depth_flag[Zone2a,Medium_Coarse_Sand])=0 AND
Critical_depth_flag[Zone2b,Medium_Coarse_Sand]=1)
THEN

To be extracted nominal surface per type [Medium Coarse Sand]
ELSE
(0)

Surface to be extracted per zone and type [Zone2b, Gravel] = IF
((Critical_depth_flag[Zone3a, Gravel] +
Critical_depth_flag[Zone3b, Gravel] +
Critical_depth_flag[Zone2a, Gravel]) = 0 AND
Critical_depth_flag[Zone2b, Gravel] = 1)
THEN
To be extracted nominal surface per type [Gravel]
ELSE
(0)

Surface to be extracted per zone and type [Zone2c, Fine Sand] = IF
((Critical_depth_flag[Zone3a, Fine Sand] +
Critical_depth_flag[Zone3b, Fine Sand] +
Critical_depth_flag[Zone2a, Fine Sand] +
Critical_depth_flag[Zone2b, Fine Sand] +
Critical_depth_flag[Zone1b, Fine Sand] +
Critical_depth_flag[Zone1a, Fine Sand]) = 0 AND
Critical_depth_flag[Zone2c, Fine Sand] = 1)
THEN
To be extracted nominal surface per type [Fine Sand]
ELSE
(0)

Surface to be extracted per zone and type [Zone2c, Medium Coarse Sand] = IF
((Critical_depth_flag[Zone3a, Medium Coarse Sand] +
Critical_depth_flag[Zone3b, Medium Coarse Sand] +
Critical_depth_flag[Zone2a, Medium Coarse Sand] +
Critical_depth_flag[Zone2b, Medium Coarse Sand] +
Critical_depth_flag[Zone1b, Medium Coarse Sand] +
Critical_depth_flag[Zone1a, Medium Coarse Sand]) = 0 AND
Critical_depth_flag[Zone2c, Medium Coarse Sand] = 1)
THEN
To be extracted nominal surface per type [Medium Coarse Sand]
ELSE
(0)
Surface_to_be_extracted_per_zone_and_type[Zone2c,Gravel] = IF
((Critical_depth_flag[Zone3a,Gravel]+
Critical_depth_flag[Zone3b,Gravel]+
Critical_depth_flag[Zone2a,Gravel]+
Critical_depth_flag[Zone2b,Gravel]+
Critical_depth_flag[Zone1b,Gravel]+
Critical_depth_flag[Zone1a,Gravel])=0 AND
Critical_depth_flag[Zone2c,Gravel]=1)
THEN
To_be_extracted_nominal_surface_per_type[Gravel]
ELSE
(0)

Surface_to_be_extracted_per_zone_and_type[Zone3a,Fine_Sand] = IF
(Critical_Depth_flag[Zone3a,Fine_Sand]=1)
THEN
To_be_extracted_nominal_surface_per_type[Fine_Sand]
ELSE (0)

Surface_to_be_extracted_per_zone_and_type[Zone3a,Medium_Coarse_Sand] = IF
(Critical_Depth_flag[Zone3a,Medium_Coarse_Sand]=1)
THEN
To_be_extracted_nominal_surface_per_type[Medium_Coarse_Sand]
ELSE (0)

Surface_to_be_extracted_per_zone_and_type[Zone3a,Gravel] = IF
(Critical_Depth_flag[Zone3a,Gravel]=1)
THEN
To_be_extracted_nominal_surface_per_type[Gravel]
ELSE (0)

Surface_to_be_extracted_per_zone_and_type[Zone3b,Fine_Sand] = IF
(Critical_depth_flag[Zone3a,Fine_Sand]=0 AND
Critical_depth_flag[Zone3b,Fine_Sand]=1)
THEN
To_be_extracted_nominal_surface_per_type[Fine_Sand]
ELSE
(0)
Surface_to_be_extracted_per_zone_and_type[Zone3b,Medium_Coarse_Sand] = IF (Critical_depth_flag[Zone3a,Medium_Coarse_Sand]=0 AND Critical_depth_flag[Zone3b,Medium_Coarse_Sand]=1) THEN To_be_extracted_nominal_surface_per_type[Medium_Coarse_Sand] ELSE (0)

Surface_to_be_extracted_per_zone_and_type[Zone3b,Gravel] = IF (Critical_depth_flag[Zone3a,Gravel]=0 AND Critical_depth_flag[Zone3b,Gravel]=1) THEN To_be_extracted_nominal_surface_per_type[Gravel] ELSE (0)


To be extracted nominal surface per type[Medium_Coarse_Sand] ELSE (0)

Surface to be extracted per zone and type[Zone4,Gravel] = IF ((Critical_depth_flag[Zone3a,Gravel] + Critical_depth_flag[Zone3b,Gravel] + Critical_depth_flag[Zone2a,Gravel] + Critical_depth_flag[Zone2b,Gravel] + Critical_depth_flag[Zone1b,Gravel] + Critical_depth_flag[Zone1a,Gravel] + Critical_depth_flag[Zone2c,Gravel])=0 AND Critical_depth_flag[Zone4,Gravel]=1) THEN To be extracted nominal surface per type[Gravel] ELSE (0)

4 FLEET AND TRIPS

4.1 average loading capacity of fleet A
DATA:
- Dataset: Maximum loading capacity of each fleet A vessel with an average as one set value)

<table>
<thead>
<tr>
<th>Vessels of fleet A</th>
<th>Loading capacity in m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banjaard</td>
<td>1320</td>
</tr>
<tr>
<td>Reimerswaal</td>
<td>1600</td>
</tr>
<tr>
<td>Saeftinge</td>
<td>877</td>
</tr>
<tr>
<td>Average for fleet A vessels</td>
<td>1266</td>
</tr>
</tbody>
</table>

4.2 number of fleet A vessels
DATA:
- Dataset: 3 (see dataset in section 4.1 of annex for vessel names)
4.3 maximum number of trips per day and per vessel

**DATA:**
- Dataset: 2

4.4 maximum number of extraction days per month

**DATA:** available as one set value = 30

4.5 number of fleet B vessels

**DATA:**
- Dataset: 9 (see dataset in section 4.6 of annex for vessel names)

4.6 average loading capacity of fleet B

**DATA:**
- Dataset: Maximum loading capacity of each Fleet B vessel with an average as one set value

<table>
<thead>
<tr>
<th>Vessels of fleet B</th>
<th>Loading capacity in m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arco Beck</td>
<td>2739</td>
</tr>
<tr>
<td>Arco Bourne</td>
<td>2600</td>
</tr>
<tr>
<td>Charlemagne</td>
<td>5000</td>
</tr>
<tr>
<td>Delta</td>
<td>1235</td>
</tr>
<tr>
<td>Orisant</td>
<td>2600</td>
</tr>
<tr>
<td>Swalinge</td>
<td>1800</td>
</tr>
<tr>
<td>Scelveringhe</td>
<td>3933</td>
</tr>
<tr>
<td>Schotsman</td>
<td>1523</td>
</tr>
<tr>
<td>Ulienspiegel</td>
<td>13700</td>
</tr>
<tr>
<td>Average for Fleet B</td>
<td>3903</td>
</tr>
</tbody>
</table>

4.9 extraction by fleet A

**DEFINITION:** The total sediment extracted by Fleet A over one month and not exceeding the maximum loading capacity of this fleet for ‘fine sand’, ‘medium-coarse sand’ and ‘gravel’.
EQUATION:

\[
\text{Extraction\_by\_fleet\_A[Zone1a,Fine\_Sand]} = \begin{cases} 
\text{if} (\text{Maximum\_monthly\_capacity\_of\_fleet\_A} - \text{Extraction\_per\_zone\_and\_type[Zone3a,Fine\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone3b,Fine\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone2a,Fine\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone2b,Fine\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone1b,Fine\_Sand]}) > 0 \\
\text{MIN(Extraction\_per\_zone\_and\_type[Zone1a,Fine\_Sand], Maximum\_monthly\_capacity\_of\_fleet\_A} - \text{Extraction\_per\_zone\_and\_type[Zone3a,Fine\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone3b,Fine\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone2a,Fine\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone2b,Fine\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone1b,Fine\_Sand]}) \\
\text{ELSE (0)}
\end{cases}
\]

\[
\text{Extraction\_by\_fleet\_A[Zone1a,Medium\_Coarse\_Sand]} = \begin{cases} 
\text{if} (\text{Maximum\_monthly\_capacity\_of\_fleet\_A} - \text{Extraction\_per\_zone\_and\_type[Zone3a,Medium\_Coarse\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone3b,Medium\_Coarse\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone2a,Medium\_Coarse\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone2b,Medium\_Coarse\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone1b,Medium\_Coarse\_Sand]}) > 0 \\
\text{MIN(Extraction\_per\_zone\_and\_type[Zone1a,Medium\_Coarse\_Sand], Maximum\_monthly\_capacity\_of\_fleet\_A} - \text{Extraction\_per\_zone\_and\_type[Zone3a,Medium\_Coarse\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone3b,Medium\_Coarse\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone2a,Medium\_Coarse\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone2b,Medium\_Coarse\_Sand]} - \text{Extraction\_per\_zone\_and\_type[Zone1b,Medium\_Coarse\_Sand]}) \\
\text{ELSE (0)}
\end{cases}
\]

\[
\text{Extraction\_by\_fleet\_A[Zone1a,Gravel]} = \begin{cases} 
\text{if} (\text{Maximum\_monthly\_capacity\_of\_fleet\_A} - \text{Extraction\_per\_zone\_and\_type[Zone3a,Gravel]} - \text{Extraction\_per\_zone\_and\_type[Zone3b,Gravel]} - \text{Extraction\_per\_zone\_and\_type[Zone2a,Gravel]} - \text{Extraction\_per\_zone\_and\_type[Zone2b,Gravel]}) > 0 \\
\text{ELSE (0)}
\end{cases}
\]
-Extraction_per_zone_and_type[Zone1b,Gravel]) > 0
THEN
(MIN(Extraction_per_zone_and_type[Zone1a,Gravel],Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Gravel]
-Extraction_per_zone_and_type[Zone3b,Gravel]
-Extraction_per_zone_and_type[Zone2a,Gravel]
-Extraction_per_zone_and_type[Zone2b,Gravel]
-Extraction_per_zone_and_type[Zone1b,Gravel]))
ELSE (0)

Extraction_by_fleet_A[Zone1b,Fine_Sand]
= if(Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Fine_Sand]
-Extraction_per_zone_and_type[Zone3b,Fine_Sand]
-Extraction_per_zone_and_type[Zone2a,Fine_Sand]
-Extraction_per_zone_and_type[Zone2b,Fine_Sand]) > 0
THEN
(MIN(Extraction_per_zone_and_type[Zone1b,Fine_Sand],Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Fine_Sand]
-Extraction_per_zone_and_type[Zone3b,Fine_Sand]
-Extraction_per_zone_and_type[Zone2a,Fine_Sand]
-Extraction_per_zone_and_type[Zone2b,Fine_Sand]))
ELSE (0)

Extraction_by_fleet_A[Zone1b,Medium_Coarse_Sand]
= if(Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone3b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2b,Medium_Coarse_Sand]) > 0
THEN
(MIN(Extraction_per_zone_and_type[Zone1b,Medium_Coarse_Sand],Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone3b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2b,Medium_Coarse_Sand]))
ELSE (0)
Extraction_by_fleet_A[Zone1b, Gravel] = if(Minimum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a, Gravel]
-Extraction_per_zone_and_type[Zone3b, Gravel]
-Extraction_per_zone_and_type[Zone2a, Gravel]
-Extraction_per_zone_and_type[Zone2b, Gravel]) > 0
THEN
(MIN(Extraction_per_zone_and_type[Zone1b, Gravel], Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a, Gravel]
-Extraction_per_zone_and_type[Zone3b, Gravel]
-Extraction_per_zone_and_type[Zone2a, Gravel]
-Extraction_per_zone_and_type[Zone2b, Gravel]))
ELSE (0)

Extraction_by_fleet_A[Zone2a, Fine_Sand] = if(Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a, Fine_Sand]
-Extraction_per_zone_and_type[Zone3b, Fine_Sand]) > 0
THEN
(MIN(Extraction_per_zone_and_type[Zone2a, Fine_Sand], Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a, Fine_Sand]
-Extraction_per_zone_and_type[Zone3b, Fine_Sand]))
ELSE (0)

Extraction_by_fleet_A[Zone2a, Medium_Coarse_Sand] = if(Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a, Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone3b, Medium_Coarse_Sand]) > 0
THEN
(MIN(Extraction_per_zone_and_type[Zone2a, Medium_Coarse_Sand], Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a, Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone3b, Medium_Coarse_Sand]))
ELSE (0)

Extraction_by_fleet_A[Zone2a, Gravel] = if(Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a, Gravel]
-Extraction_per_zone_and_type[Zone3b, Gravel]) > 0
THEN
(MIN(Extraction_per_zone_and_type[Zone2a,Gravel], Maximum_monthly_capacity_of_fleet_A \\
-Extraction_per_zone_and_type[Zone3a,Gravel] \\
-Extraction_per_zone_and_type[Zone3b,Gravel]))
ELSE (0)

Extraction_by_fleet_A[Zone2b,Fine_Sand] = if(Maximum_monthly_capacity_of_fleet_A \\
-Extraction_per_zone_and_type[Zone3a,Fine_Sand] \\
-Extraction_per_zone_and_type[Zone3b,Fine_Sand] \\
-Extraction_per_zone_and_type[Zone2a,Fine_Sand]) > 0 \\
THEN (MIN(Extraction_per_zone_and_type[Zone2b,Fine_Sand], Maximum_monthly_capacity_of_fleet_A \\
-Extraction_per_zone_and_type[Zone3a,Fine_Sand] \\
-Extraction_per_zone_and_type[Zone3b,Fine_Sand] \\
-Extraction_per_zone_and_type[Zone2a,Fine_Sand]))
ELSE (0)

Extraction_by_fleet_A[Zone2b,Medium_Coarse_Sand] = if(Maximum_monthly_capacity_of_fleet_A \\
-Extraction_per_zone_and_type[Zone3a,Medium_Coarse_Sand] \\
-Extraction_per_zone_and_type[Zone3b,Medium_Coarse_Sand] \\
-Extraction_per_zone_and_type[Zone2a,Medium_Coarse_Sand]) > 0 \\
THEN (MIN(Extraction_per_zone_and_type[Zone2b,Medium_Coarse_Sand], Maximum_monthly_capacity_of_fleet_A \\
-Extraction_per_zone_and_type[Zone3a,Medium_Coarse_Sand] \\
-Extraction_per_zone_and_type[Zone3b,Medium_Coarse_Sand] \\
-Extraction_per_zone_and_type[Zone2a,Medium_Coarse_Sand]))
ELSE (0)

Extraction_by_fleet_A[Zone2b,Gravel] = if(Maximum_monthly_capacity_of_fleet_A \\
-Extraction_per_zone_and_type[Zone3a,Gravel] \\
-Extraction_per_zone_and_type[Zone3b,Gravel] \\
-Extraction_per_zone_and_type[Zone2a,Gravel]) > 0 \\
THEN (MIN(Extraction_per_zone_and_type[Zone2b,Gravel], Maximum_monthly_capacity_of_fleet_A \\
-Extraction_per_zone_and_type[Zone3a,Gravel] \\
-Extraction_per_zone_and_type[Zone3b,Gravel] \\
-Extraction_per_zone_and_type[Zone2a,Gravel]))
ELSE (0)
Extraction by fleet A[Zone2c,Fine_Sand] =
if(Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Fine_Sand]
-Extraction_per_zone_and_type[Zone3b,Fine_Sand]
-Extraction_per_zone_and_type[Zone2a,Fine_Sand]
-Extraction_per_zone_and_type[Zone2b,Fine_Sand]
-Extraction_per_zone_and_type[Zone1b,Fine_Sand]
-Extraction_per_zone_and_type[Zone1a,Fine_Sand]) > 0
THEN
(MIN(Extraction_per_zone_and_type[Zone2c,Fine_Sand],Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Fine_Sand]
-Extraction_per_zone_and_type[Zone3b,Fine_Sand]
-Extraction_per_zone_and_type[Zone2a,Fine_Sand]
-Extraction_per_zone_and_type[Zone2b,Fine_Sand]
-Extraction_per_zone_and_type[Zone1b,Fine_Sand]
-Extraction_per_zone_and_type[Zone1a,Fine_Sand]))
ELSE (0)

Extraction by fleet A[Zone2c,Medium_Coarse_Sand] =
if(Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone3b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone1b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone1a,Medium_Coarse_Sand]) > 0
THEN
(MIN(Extraction_per_zone_and_type[Zone2c,Medium_Coarse_Sand],Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone3b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone1b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone1a,Medium_Coarse_Sand]))
ELSE (0)
ELSE (0)

Extraction_by_fleet_A[Zone2c,Gravel] = if(Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Gravel]
-Extraction_per_zone_and_type[Zone3b,Gravel]
-Extraction_per_zone_and_type[Zone2a,Gravel]
-Extraction_per_zone_and_type[Zone2b,Gravel]
-Extraction_per_zone_and_type[Zone1b,Gravel]
-Extraction_per_zone_and_type[Zone1a,Gravel]) > 0
THEN
(MIN(Extraction_per_zone_and_type[Zone2c,Gravel],Maximum_monthly_capacity_of
_fleet_A
-Extraction_per_zone_and_type[Zone3a,Gravel]
-Extraction_per_zone_and_type[Zone3b,Gravel]
-Extraction_per_zone_and_type[Zone2a,Gravel]
-Extraction_per_zone_and_type[Zone2b,Gravel]
-Extraction_per_zone_and_type[Zone1b,Gravel]
-Extraction_per_zone_and_type[Zone1a,Gravel]))
ELSE (0)

Extraction_by_fleet_A[Zone3a,Fine_Sand] = MIN(Extraction_per_zone_and_type[Zone3a,Fine_Sand],Maximum_monthly_capacity_of_fleet_A)

Extraction_by_fleet_A[Zone3a,Medium_Coarse_Sand] = MIN(Extraction_per_zone_and_type[Zone3a,Medium_Coarse_Sand],Maximum_monthly_capacity_of_fleet_A)

Extraction_by_fleet_A[Zone3a,Gravel] = MIN(Extraction_per_zone_and_type[Zone3a,Gravel],Maximum_monthly_capacity_of_fleet_A)

Extraction_by_fleet_A[Zone3b,Fine_Sand] = if(Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Fine_Sand]) > 0
THEN
(MIN(Extraction_per_zone_and_type[Zone3b,Fine_Sand],Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Fine_Sand]))
ELSE (0)
Extraction_by_fleet_A[Zone3b,Medium_Coarse_Sand] = if(Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Medium_Coarse_Sand])> 0
THEN
(MIN(Extraction_per_zone_and_type[Zone3b,Medium_Coarse_Sand],Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Medium_Coarse_Sand]))
ELSE (0)

Extraction_by_fleet_A[Zone3b,Gravel] = if(Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Gravel])> 0
THEN
(MIN(Extraction_per_zone_and_type[Zone3b,Gravel],Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Gravel]))
ELSE (0)

Extraction_by_fleet_A[Zone4,Fine_Sand] = IF
((Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Fine_Sand]
-Extraction_per_zone_and_type[Zone3b,Fine_Sand]
-Extraction_per_zone_and_type[Zone2a,Fine_Sand]
-Extraction_per_zone_and_type[Zone2b,Fine_Sand]
-Extraction_per_zone_and_type[Zone1b,Fine_Sand]
-Extraction_per_zone_and_type[Zone1a,Fine_Sand]
-Extraction_per_zone_and_type[Zone2c,Fine_Sand])> 0)
THEN
(MIN(Extraction_per_zone_and_type[Zone4,Fine_Sand],Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Fine_Sand]
-Extraction_per_zone_and_type[Zone3b,Fine_Sand]
-Extraction_per_zone_and_type[Zone2a,Fine_Sand]
-Extraction_per_zone_and_type[Zone2b,Fine_Sand]
-Extraction_per_zone_and_type[Zone1b,Fine_Sand]
-Extraction_per_zone_and_type[Zone1a,Fine_Sand]
-Extraction_per_zone_and_type[Zone2c,Fine_Sand]))
ELSE (0)

Extraction_by_fleet_A[Zone4,Medium_Coarse_Sand] = IF
((Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone3b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone1b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone1a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2c,Medium_Coarse_Sand]))
ELSE (0)
-Extraction_per_zone_and_type[Zone3a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone3b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone1b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone1a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2c,Medium_Coarse_Sand]) > 0)
THEN
(MIN(Extraction_per_zone_and_type[Zone4,Medium_Coarse_Sand],Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone3b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone1b,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone1a,Medium_Coarse_Sand]
-Extraction_per_zone_and_type[Zone2c,Medium_Coarse_Sand]))
ELSE (0)

Extraction_by_fleet_A[Zone4,Gravel] = IF (((Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Gravel]
-Extraction_per_zone_and_type[Zone3b,Gravel]
-Extraction_per_zone_and_type[Zone2a,Gravel]
-Extraction_per_zone_and_type[Zone2b,Gravel]
-Extraction_per_zone_and_type[Zone1b,Gravel]
-Extraction_per_zone_and_type[Zone1a,Gravel]
-Extraction_per_zone_and_type[Zone2c,Gravel]) > 0)
THEN
(MIN(Extraction_per_zone_and_type[Zone4,Gravel],Maximum_monthly_capacity_of_fleet_A
-Extraction_per_zone_and_type[Zone3a,Gravel]
-Extraction_per_zone_and_type[Zone3b,Gravel]
-Extraction_per_zone_and_type[Zone2a,Gravel]
-Extraction_per_zone_and_type[Zone2b,Gravel]
-Extraction_per_zone_and_type[Zone1b,Gravel]
-Extraction_per_zone_and_type[Zone1a,Gravel]
-Extraction_per_zone_and_type[Zone2c,Gravel]))
ELSE (0)
5 DISTANCES TRAVELLED

5.2 distance between zone and port

DATA:
- Source: Management Unit of the North Sea Mathematical Models, Royal Belgian Institute of Natural Sciences (BMDC, S. Jans 20050919)
- Dataset: Distances between center of concession zones and the 4 different ports with an average as 8 set values for the 8 zones

<table>
<thead>
<tr>
<th>Distance to center of zone</th>
<th>Average distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>41,900</td>
</tr>
<tr>
<td>1b</td>
<td>40,400</td>
</tr>
<tr>
<td>2a</td>
<td>36,500</td>
</tr>
<tr>
<td>2b</td>
<td>38,000</td>
</tr>
<tr>
<td>2c</td>
<td>43,500</td>
</tr>
<tr>
<td>3a</td>
<td>32,800</td>
</tr>
<tr>
<td>3b</td>
<td>34,000</td>
</tr>
<tr>
<td>4</td>
<td>57,800</td>
</tr>
</tbody>
</table>
Annex 2

BALANS
BALANCING IMPACTS OF HUMAN ACTIVITIES
IN THE NORTH SEA

EV/21

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Prof. Dr. M. Vincx, Marine Biology Section, University Gent
Prof. Dr. Colin Janssen, Laboratory for Biological Research in Aquatic Pollution, University Gent
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February 2007
ANNEX 2:
SAND AND GRAVEL EXTRACTION ENVIRONMENT
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1 MACROBENTHIC DENSITY AT EXTRACTION SITE: STOCK AND FLOWS

1.1 density extraction site

DATA:
- Source: MACRODAT database (Section Marine Biology), Van Hoey et al. (2004)
- Dataset: available at Section Marine Biology, University of Ghent

TABLE 1: Characterization of the species assemblages of the Belgian Continental Shelf (adapted from Van Hoey et al., 2004)

<table>
<thead>
<tr>
<th>Species assemblage</th>
<th>SA1</th>
<th>SA2</th>
<th>SA3</th>
<th>SA4</th>
<th>SA5</th>
<th>SA6</th>
<th>SA7</th>
<th>SA8</th>
<th>SA9</th>
<th>SA10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment type</td>
<td>FS</td>
<td>FS</td>
<td>MS</td>
<td>MS</td>
<td>MS</td>
<td>MS</td>
<td>FS</td>
<td>FS</td>
<td>FS</td>
<td>FS</td>
</tr>
<tr>
<td>Median grain size (µm)</td>
<td>219</td>
<td>208</td>
<td>268</td>
<td>274</td>
<td>333</td>
<td>409</td>
<td>219</td>
<td>243</td>
<td>230</td>
<td>248</td>
</tr>
<tr>
<td>Mud content (%)</td>
<td>5.8</td>
<td>4.3</td>
<td>1.9</td>
<td>0.4</td>
<td>0.2</td>
<td>0.3</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>-13</td>
<td>-8</td>
<td>-14</td>
<td>-12</td>
<td>-16</td>
<td>-15</td>
<td>-2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Species richness (#/m²)</td>
<td>30</td>
<td>18</td>
<td>13</td>
<td>7</td>
<td>8</td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Density</td>
<td>6432</td>
<td>2746</td>
<td>2017</td>
<td>402</td>
<td>304</td>
<td>190</td>
<td>135</td>
<td>482</td>
<td>101</td>
<td>983</td>
</tr>
<tr>
<td>Name</td>
<td>Abra alba-Mysella bidentata community</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Type I SA</td>
<td>Type II SA</td>
<td>Type II SA</td>
<td>Type I SA</td>
<td>Type II SA</td>
<td>Type I SA</td>
<td>Type II SA</td>
<td>Type I SA</td>
<td>Type II SA</td>
<td>Type I SA</td>
</tr>
</tbody>
</table>
1.3 mortality rate

DATA:
- Source: Blackford (1997); Duplisea (1998)
- Dataset: Although several data for mortality rate of macrobenthos are circulating in literature, we chose the value of Blackford (1997) for deposit feeders and suspension feeders because these functional groups dominate in continental shelf ecosystems according to Silvert (1991). The value of Blackford (1997) is also determined for environmental conditions similar to the ones valid for the BPNS.

TABLE 2: Data on mortality rate found in literature

<table>
<thead>
<tr>
<th>Source</th>
<th>Mortality rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackford (1997)</td>
<td>- deposit feeders/suspension feeders 0.001/d 0.003/d</td>
</tr>
<tr>
<td></td>
<td>- predators</td>
</tr>
<tr>
<td>Duplisea (1998)</td>
<td>0.0014/d</td>
</tr>
<tr>
<td>Chosen value (Blackford, 1997)</td>
<td>0.001/d or 0.05/month</td>
</tr>
</tbody>
</table>

1.5 density for competition

DATA:
- Source: MACRODAT database (Section Marine Biology)
- Dataset: available at Section Marine Biology, University of Ghent

1.8 birth rate

DATA:
- Source: Sohma et al. (2001); Duplisea (1998); Ortiz & Wolff (2002)
- Dataset: Although several data for birth rate of macrobenthos are circulating in literature, we chose the value of Ortiz & Wolff (2002) because this value is also determined for environmental conditions similar to the ones valid for the BPNS (i.e. sandy habitats).
TABLE 3: Data on birth rate found in literature

<table>
<thead>
<tr>
<th>Source</th>
<th>Birth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sohma et al. (2001)</td>
<td>0.053/d</td>
</tr>
<tr>
<td>Duplisea (1998)</td>
<td>0.185/d</td>
</tr>
<tr>
<td>Ortiz &amp; Wolff (2002)</td>
<td>0.012/d</td>
</tr>
<tr>
<td>Chosen value (Ortiz &amp; Wolff, 2002)</td>
<td>0.012/d or 0.36/month</td>
</tr>
</tbody>
</table>

2 EFFECT OF AMOUNT OF EXTRACTION

2.1 effect of amount on density

DATA: Calculated in meta-analysis

EXPLANATION OF METHODOLOGY OF META-ANALYSIS

Because a large amount of literature on the impact of aggregate extraction and shrimp fisheries is available it is difficult to deduct general trends in these impacts (because the different studies were carried out in different habitats, with different regimes, sampling times, intensities of extraction,…). Besides that, the effects of aggregate extraction or bottom fisheries on macrobenthos or sediment composition are not easily extracted from literature, because most articles give conflicting conclusions (ranging from a negligible effect to a huge effect). This problem can be solved by doing a meta-analysis.

Meta-analysis is the summary of multiple, independent studies to detect general relationships (Normand, 1999; Collie et al., 2000). It is a summary term for all quantitative methods that are used to combine evidence across studies (Myers & Mertz, 1998). Every treatment described in an article is treated as an independent replicate. Using this methodology on the available literature on the effects of extraction and fisheries on macrobenthos and sediment composition will allow the prediction of the “mean effects” (general trends).

Therefore, a compilation database of all available impact studies has been made and from these compiled data it will be possible to deduct consistent patterns in the responses of benthic organisms and sediment composition to these disturbances.

The magnitude of the response of a variable A (macrobenthic density/fraction of a certain grain size fraction) can then be calculated as follows:

\[
\text{% difference} = ((A_{\text{after}} - A_{\text{before}})/A_{\text{before}})*100
\]

or

\[
\text{% difference} = ((A_{\text{impact}} - A_{\text{control}})/A_{\text{control}})*100
\]
with $A_{\text{after}}/A_{\text{impact}}$ the value of the variable after the disturbance/at the impacted site and $A_{\text{before}}/A_{\text{control}}$ the value of the variable before the disturbance/at the control site

The resulting values of % difference are then log-transformed to get a normal distribution of the values. The meta-analysis investigates the following effects:

- The impact of aggregate extraction (effect of amount of sand extracted and effect of surface area extracted) on the macrobenthos
- The subsequent recolonisation rate after cessation of extraction (with respect to regime of extraction).
- The effect of aggregate extraction on the sediment composition (for different regimes of extraction)
- The impact of shrimp fisheries (effect of effort of fishing and effect of surface area fished) on the macrobenthic density
- The subsequent recolonisation rate after cessation of fishing (with respect to regime of extraction)
- The effect of shrimp fisheries on the sediment composition

The trends that merge from this analysis will be used to determine the equation which fits the trend best.

The document only gave the equations for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

**GRAPH 1**: Mean (logarithmic) effect of the extraction of a certain amount of sediment in fine sand habitats on the macrobenthic density at the extraction site

![Graph showing logarithmic effect of extraction on macrobenthic density](image)

```
effect_of_amount_on_density[Zone*,Fine_Sand] = IF (Extraction_per_zone_and_type[Zone*,Fine_Sand]<10) THEN 0 ELSE ((10^(-0.0731Ln(x) + 0.1807)) - 1)
effect_of_amount_on_density[Zone*,Coarse_Sand] = IF (Extraction_per_zone_and_type[Zone*,Coarse_Sand]<10) THEN 0 ELSE ((10^(-0.0731Ln(x) + 0.1807)) - 1)
effect_of_amount_on_density[Zone*,Very_Fine_Sand] = IF (Extraction_per_zone_and_type[Zone*,Very_Fine_Sand]<10) THEN 0 ELSE ((10^(-0.0731Ln(x) + 0.1807)) - 1)
effect_of_amount_on_density[Zone*,Very_Coarse_Sand] = IF (Extraction_per_zone_and_type[Zone*,Very_Coarse_Sand]<10) THEN 0 ELSE ((10^(-0.0731Ln(x) + 0.1807)) - 1)
effect_of_amount_on_density[Zone*,Gravel] = IF (Extraction_per_zone_and_type[Zone*,Gravel]<10) THEN 0 ELSE ((10^(-0.0731Ln(x) + 0.1807)) - 1)
```
ANNEX 2: Sand and Gravel Extraction

Environment

0.0731*LOGN(Extraction_per_zone_and_type[Zone*,Fine_Sand]/1000000)+0.1807 +2.004)-101)/100

Note: same equation for all zones for fine sand.

GRAPH 2: Mean (logarithmic) effect of the extraction of a certain amount of sediment in medium-coarse sand habitats on the macrobenthic density at the extraction site

\[ y = -2E-06x + 0.8348 \]
\[ R^2 = 1 \]

Note: same equation for all zones for medium-coarse sand.

GRAPH 3: Mean (logarithmic) effect of the extraction of a certain amount of sediment in all habitats on the macrobenthic density at the extraction site. Since there were not enough data available to detect a trend for gravel habitats, the general equation found for all habitats was used.

\[ y = -0.084 \ln(x) + 0.2533 \]
\[ R^2 = 0.1573 \]

Note: same equation for all zones for gravel.
0.084*LOGN(Extraction_per_zone_and_type[Zone*,Gravel]/10000000)+0.2533)+2.004)-101)/100

Note: same equation for all zones for gravel.

3 EFFECT OF SURFACE AREA OF EXTRACTION

3.1 r1

DATA: calculated from meta-analysis
For more information on the methodology of the meta-analysis see subsection 2.1.

TABLE 4: The amount of days between two consequent extraction events were classified into 4 regimes (continuous regime, regime 1, regime 2 and regime 3) following the evaluation of trends of mean effect of density against amount of days between two events.

<table>
<thead>
<tr>
<th>Grain type</th>
<th>Continuous regime</th>
<th>Regime 1</th>
<th>Regime 2</th>
<th>Regime 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel 0-15</td>
<td>0-15</td>
<td>15-200</td>
<td>201-750</td>
<td>&gt;750</td>
</tr>
<tr>
<td>Medium-coarse sand</td>
<td>0-15</td>
<td>15-200</td>
<td>201-600</td>
<td>&gt;600</td>
</tr>
<tr>
<td>Fine sand 0-15</td>
<td>0-15</td>
<td>15-100</td>
<td>101-600</td>
<td>&gt;600</td>
</tr>
</tbody>
</table>

The document only gave the equations for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

\[
R1[Zone*,Fine_Sand] = \text{IF} \ (\text{regime}[Zone*,Fine_Sand]>15) \ \text{AND} \ (\text{regime}[Zone*,Fine_Sand]<101) \ \text{THEN} \ 1 \ \text{ELSE} \ 0
\]

Note: same equation for all zones for fine sand.

\[
R1[Zone*,Medium_Coarse_Sand] = \text{IF} \ (\text{regime}[Zone*,Medium_Coarse_Sand]>15) \ \text{AND} \ (\text{regime}[Zone*,Medium_Coarse_Sand]<201) \ \text{THEN} \ 1 \ \text{ELSE} \ 0
\]

Note: same equation for all zones for medium-coarse sand.

\[
R1[Zone*,Gravel] = \text{IF} \ (\text{regime}[Zone*,Gravel]>15) \ \text{AND} \ (\text{regime}[Zone*,Gravel]<201) \ \text{THEN} \ 1 \ \text{ELSE} \ 0
\]

Note: same equation for all zones for gravel.
3.2  \textbf{r2}

\textbf{DATA}: calculated from meta-analysis
For more information on the methodology of the meta-analysis see subsection 2.1.
Data: see TABLE 4 above (subsection 3.1)

The document only gave the equations for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

\begin{align*}
R2[\text{Zone}^*,\text{Fine\_Sand}] &= \text{IF} \ (\text{regime}[\text{Zone}^*,\text{Fine\_Sand}]>100) \ \text{AND} \ (\text{regime}[\text{Zone}^*,\text{Fine\_Sand}]<601) \ \text{THEN} \ 1 \ \text{ELSE} \ 0 \\
\text{Note: same equation for all zones for fine sand.}
\end{align*}

\begin{align*}
R2[\text{Zone}^*,\text{Medium\_Coarse\_Sand}] &= \text{IF} \ (\text{regime}[\text{Zone}^*,\text{Medium\_Coarse\_Sand}]>200) \\
&\ \text{AND} \ (\text{regime}[\text{Zone}^*,\text{Medium\_Coarse\_Sand}]<601) \ \text{THEN} \ 1 \ \text{ELSE} \ 0 \\
\text{Note: same equation for all zones for medium-coarse sand.}
\end{align*}

\begin{align*}
R2[\text{Zone}^*,\text{Gravel}] &= \text{IF} \ (\text{regime}[\text{Zone}^*,\text{Gravel}]>200) \ \text{AND} \ (\text{regime}[\text{Zone}^*,\text{Gravel}]<751) \ \text{THEN} \ 1 \ \text{ELSE} \ 0 \\
\text{Note: same equation for all zones for gravel.}
\end{align*}

3.3  \textbf{r3}

\textbf{DATA}: calculated from meta-analysis
For more information on the methodology of the meta-analysis see subsection 2.1.
Data: see TABLE 4 above (subsection 3.1)

The document only gave the equations for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

\begin{align*}
R3[\text{Zone}^*,\text{Fine\_Sand}] &= \text{IF} \ (\text{regime}[\text{Zone}^*,\text{Fine\_Sand}]>600) \ \text{THEN} \ 1 \ \text{ELSE} \ 0 \\
\text{Note: same equation for all zones for fine sand.}
\end{align*}

\begin{align*}
R3[\text{Zone}^*,\text{Medium\_Coarse\_Sand}] &= \text{IF} \ (\text{regime}[\text{Zone}^*,\text{Medium\_Coarse\_Sand}]>600) \ \text{THEN} \ 1 \ \text{ELSE} \ 0 \\
\text{Note: same equation for all zones for medium-coarse sand.}
\end{align*}
R3[Zone*,Gravel] = IF (regime[Zone*,Gravel]>750) THEN 1 ELSE 0

Note: same equation for all zones for gravel.

3.4 *r* continuous

**DATA:** calculated from meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

Data: see TABLE 4 above (subsection 3.1)

3.5 effect surface 1

**DATA:** calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

GRAPH 4: Mean (logarithmic) effect of the extraction of a certain surface area in fine sand habitats on the macrobenthic density at the extraction site (when regime 1 is valid).

The document only gave the equations for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

\[
\text{Effect\_surface\_1 } [\text{Zone*}, \text{Fine\_sand}] = \text{IF}(\text{R1[Zone*,Fine\_Sand]}=1)\text{THEN}(((10^(((-6.9997*((\text{Effectively\_extracted\_surface\_per\_zone\_and\_type[Zone*,Fine\_Sand]}/1000000)^2)+(6.7046*(\text{Effectively\_extracted\_surface\_per\_zone\_and\_type[Zone*,Fine\_Sand]}/1000000))-0.694)+2.004))-101)/100)\text{ELSE}0
\]

Note: same equation for all zones for fine sand.
GRAPH 5: Mean (logarithmic) effect of the extraction of a certain surface area in medium-coarse sand habitats on the macrobenthic density at the extraction site (when regime 1 is valid).

\[
y = 0.475 \ln(x) + 0.5384 \\
R^2 = 0.9351
\]

\[
effect\_surface\_1[\text{Zone*}, \text{Medium\_Coarse\_Sand}] = \text{IF}(R1[\text{Zone*}, \text{Medium\_Coarse\_Sand}] = 1 \text{ AND } \text{Effectively\_extracted\_surface\_per\_zone\_and\_type}[\text{Zone*}, \text{Medium\_Coarse\_Sand}] > 100) \text{ THEN} \\
(((10^{(0.475 \cdot \ln(\text{Effectively\_extracted\_surface\_per\_zone\_and\_type}[\text{Zone*}, \text{Medium\_Coarse\_Sand]/1000000}]]+0.5384)+2.004)-101)/100) \text{ ELSE 0}
\]

Note: same equation for all zones for medium-coarse sand.

GRAPH 6: Mean (logarithmic) effect of the extraction of a certain surface area in gravel habitats on the macrobenthic density at the extraction site (when regime 1 is valid).

\[
y = 0.0036x^3 - 0.1026x^2 + 0.741x - 0.5728 \\
R^2 = 0.7504
\]

\[
effect\_surface\_1[\text{Zone*}, \text{Gravel}] = \text{IF}(R1[\text{Zone1a,Gravel}] = 1) \text{ THEN}(((10^{((0.0036*}
\]
((Effectively_extracted_surface_per_zone_and_type[Zone*,Gravel]/1000000)^3)-(0.1026*((Effectively_extracted_surface_per_zone_and_type[Zone*,Gravel]/1000000)^2)+(0.741*(Effectively_extracted_surface_per_zone_and_type[Zone*,Gravel]/1000000)-0.5728)+2.004)-101)/100) ELSE 0

Note: same equation for all zones for gravel.

3.6 effect surface 2
DATA: calculated in meta-analysis
For more information on the methodology of the meta-analysis see subsection 2.1.

GRAPH 7: Mean (logarithmic) effect of the extraction of a certain surface area in fine sand habitats on the macrobenthic density at the extraction site (when regime 2 is valid).

The document only gave the equations for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

effect_surface_2[Zone*,Fine_Sand] = IF(R2[Zone*,Fine_Sand]=1)THEN(((10^((-152.86*((Effectively_extracted_surface_per_zone_and_type[Zone*,Fine_Sand]/1000000)^6))-(705.03*((Effectively_extracted_surface_per_zone_and_type[Zone*,Fine_Sand]/1000000)^5))+(1200.4*((Effectively_extracted_surface_per_zone_and_type[Zone*,Fine_Sand]/1000000)^4))-(912.8*((Effectively_extracted_surface_per_zone_and_type[Zone*,Fine_Sand]/1000000)^3))+(293.38*((Effectively_extracted_surface_per_zone_and_type[Zone*,Fine_Sand]/1000000)^2))-(29.757*((Effectively_extracted_surface_per_zone_and_type[Zone*,Fine_Sand]/1000000))+0.3803)+2.004))-101)/100)) ELSE 0
Note: Equations for all other zones and fine sand are the same.

**GRAPH 8:** Mean (logarithmic) effect of the extraction of a certain surface area in medium-coarse sand habitats on the macrobenthic density at the extraction site (when regime 2 is valid).

\[ y = -0.0638x^2 + 0.5363x - 0.865 \]
\[ R^2 = 0.6659 \]

\[ \text{effect} \_\text{surface} \_2[\text{Zone}^*,\text{Medium\_Coarse\_Sand}] = \text{IF}(R^2[\text{Zone}^*,\text{Medium\_Coarse\_Sand}] = 1) \text{THEN}(((10^(((10^((-0.0638*(\text{Effectively\_extracted\_surface\_per\_zone\_and\_type}[\text{Zone}^*,\text{Medium\_Coarse\_Sand]/1000000)^2))+(0.5363*(\text{Effectively\_extracted\_surface\_per\_zone\_and\_type}[\text{Zone}^*,\text{Medium\_Coarse\_Sand]/10000000)))-0.865)+2.004))-101)/100)\text{ELSE} 0 \]

Note: Equations for all other zones and medium-coarse sand are the same.

**GRAPH 9:** Mean (logarithmic) effect of the extraction of a certain surface area in gravel habitats on the macrobenthic density at the extraction site (when regime 2 is valid).

\[ y = 0.149x^3 - 1.0681x^2 + 2.0863x - 0.9646 \]
\[ R^2 = 0.6841 \]

\[ \text{effect} \_\text{surface} \_2[\text{Zone}^*,\text{Gravel}] = \text{IF}(R^2[\text{Zone}^*,\text{Gravel}] = 1) \text{THEN}(((10^(((10^((0.149*})-0.865)+2.004))-101)/100)\text{ELSE} 0 \]
((Effectively_extracted_surface_per_zone_and_type[Zone*,Gravel]/1000000)^3)-(1.0681*((Effectively_extracted_surface_per_zone_and_type[Zone*,Gravel]/1000000)^2)+(2.0863*((Effectively_extracted_surface_per_zone_and_type[Zone*,Gravel]/1000000))-0.9646))+2.004)-101)/100) ELSE 0

Note: Equations for all other zones and gravel are the same.

### 3.7 effect surface 3

**DATA:** calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

**GRAPH 10:** Mean (logarithmic) effect of the extraction of a certain surface area in fine sand habitats on the macrobenthic density at the extraction site (when regime 3 is valid).

The document only gave the equations for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

\[
\text{effect\_surface\_3[Zone*,Fine\_Sand]} = \text{IF(R3[Zone*,Fine\_Sand]=1 AND Effectively\_extracted\_surface\_per\_zone\_and\_type[Zone*,Fine\_Sand]>100) THEN}((10^((-0.1323*\log((\text{Effectively\_extracted\_surface\_per\_zone\_and\_type[Zone*,Fine\_Sand]/1000000}))-0.3102)+2.004))-101)/100) ELSE 0
\]

Note: Equations for all other zones and fine sand are the same.
GRAPH 11: Mean (logarithmic) effect of the extraction of a certain surface area in medium-coarse sand habitats on the macrobenthic density at the extraction site (when regime 3 is valid).

\[ y = 0.4928x - 0.4705 \]
\[ R^2 = 1 \]

\[ \text{effect}_{-}\text{surface}_{-}3[\text{Zone}*\text{,Medium\_Coarse\_Sand}] = \text{IF}(\text{R3[Zone}*\text{,Medium\_Coarse\_Sand]}=1)\text{THEN}(((10^((0.4928*(\text{Effectively\_extracted\_surface\_per\_zone\_and\_type[Zone}*\text{,Medium\_Coarse\_Sand])/1000000)-0.4705)+2.004))-101)/100)\text{ELSE 0} \]

Note: Equations for all other zones and medium-coarse sand are the same.

GRAPH 12: Mean (logarithmic) effect of the extraction of a certain surface area in gravel habitats on the macrobenthic density at the extraction site (when regime 3 is valid).

\[ y = -0.2533\ln(x) - 0.7898 \]
\[ R^2 = 0.5946 \]

\[ \text{effect}_{-}\text{surface}_{-}3[\text{Zone}*\text{,Gravel}] = \text{IF}(\text{R3[Zone}*\text{,Gravel]}=1 AND \text{Effectively\_extracted\_surface\_per\_zone\_and\_type[Zone}*\text{,Gravel]}>100)\text{ELSE 0} \]
THEN(((10^((-0.2533*LOGN((Effectively_extracted_surface_per_zone_and_type[Zone*,Gravel]/1000000))-0.7898)+2.004))-101)/100)ELSE 0

Note: Equations for all other zones and gravel are the same.

4 MACROBENTHIC DENSITY AT DEPOSITION SITE: STOCK AND FLOWS

4.1 density deposition site

DATA:
- Source: MACRODAT database (Section Marine Biology), Van Hoey et al. (2004)
- Dataset: available at Section Marine Biology, University of Ghent

See subsection 1.1 above.

4.3 effect of amount on smothering

DATA: calculated from meta-analysis
For more information on the methodology of the meta-analysis see subsection 2.1.

GRAPH 13: Mean (logarithmic) effect of the extraction of a certain amount of sediment in fine sand habitats on the macrobenthic density at the deposition site (effect on smothering of macrobenthos).

\[
y = -3E-05x + 0.4006 \\
R^2 = 1
\]

effect_of_amount_on_smothering[Zone*,Fine_Sand] = ((10^(((-3*(10^(-5))*Extraction_per_zone_and_type[Zone*,Fine_Sand]/1000000)+0.4006)+2.004))-101)/100

Note: The equations for all other zones for fine sand is the same.
GRAPH 14: Mean (logarithmic) effect of the extraction of a certain amount of sediment in medium-coarse sand habitats on the macrobenthic density at the deposition site (effect on smothering of macrobenthos).

\[
\text{effect}_{\text{of\_amount\_on\_smothering}}[\text{Zone\_*,Medium\_Coarse\_Sand}] = (10^\left((-(3\times10^{-9})\times\left(\frac{\text{Extraction\_per\_zone\_and\_type}[\text{Zone\_*,Medium\_Coarse\_Sand]}{1000000}\right)^2\right)+(0.0002\times\left(\frac{\text{Extraction\_per\_zone\_and\_type}[\text{Zone\_*,Medium\_Coarse\_Sand]}{1000000}\right)\right)-3.1649)+2.004)\times10^{-1}\times100
\]

Note: The equations for all zones for medium-coarse sand are the same.

GRAPH 15: Mean (logarithmic) effect of the extraction of a certain amount of sediment in gravel habitats on the macrobenthic density at the deposition site (effect on smothering of macrobenthos).
effect_of_amount_on_smothering[Zone*,Gravel] = \((10^(((2*(10^{-13}))*((Extraction_{per\_zone\_and\_type}[Zone*,Gravel]/1000000)^3))-1*(10^{-8}))*((Extraction_{per\_zone\_and\_type}[Zone*,Gravel]/1000000)^2))+0.0003*Extraction_{per\_zone\_and\_type}[Zone*,Gravel]/1000000-1.8648+2.004))-101)/100

Note: The equations for all zones for gravel are the same.

4.5 effect of amount on depositing

**DATA:** calculated from meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

**GRAPH 16:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in fine sand habitats on the macrobenthic density at the deposition site (effect on depositing macrobenthic individuals).

```
FS
y = -7E-07x + 0.4042
R^2 = 1
```

effect_of_amount_on_depositing[Zone*,Fine_Sand] = \((10^((-7*(10^{-7}))*Extraction_{per\_zone\_and\_type}[Zone*,Fine_Sand]/1000000)+0.4042+2.004))-101)/100

Note: The equations for all zones for fine sand are the same.

**GRAPH 17:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in medium-coarse sand habitats on the macrobenthic density at the deposition site (effect on depositing macrobenthic individuals).
effect_of_amount__on_depositing[Zone*,Medium_Coarse_Sand] = ((10^(((8*(10^-7))*Extraction_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)+0.1448)+2.004))-101)/100

Note: The equations for all other zones for medium-coarse sand are the same.

**GRAPH 18:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in gravel habitats on the macrobenthic density at the deposition site (effect on depositing macrobenthic individuals).

effect_of_amount__on_depositing[Zone*,Gravel] = ((10^(((-5*(10^-8))*((Extraction_per_zone_and_type[Zone*,Gravel]/1000000)^2))+(0.001*Extraction_per_zone_and_type[Zone*,Gravel]/1000000)-4.0545)+2.004))-101)/100

Note: The equations for all other zones and gravel are the same.

**4.7 effect of organic matter on density**

**DATA:** calculated from meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.
GRAPH 19: Effect of the difference in organic matter on the macrobenthic density at the deposition site.

\[ y = -91.625x^3 - 84.84x^2 - 17.338x - 0.4019 \]

\[ R^2 = 1 \]

4.8 difference in organic matter

**DATA**: calculated from meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

GRAPH 20: Mean (logarithmic) effect of the organic enrichment (due to extraction and deposition of sediment) on the difference in organic matter in the sediment before and after the extraction.
4.9 organic matter enrichment

DATA:
- Source: Newell et al. (1999)
- Dataset:

TABLE 5: Data on organic matter release after aggregate extraction found in literature.

<table>
<thead>
<tr>
<th>Source</th>
<th>Mean amount of organic matter released (during normal loading operations of a hopper dredger with a capacity of 4500 t/trip)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newell et al. (1999)</td>
<td>1.98089 t/trip</td>
</tr>
<tr>
<td>Fraction of total amount of sediment removed</td>
<td>0.0004402 (0.044 %)</td>
</tr>
</tbody>
</table>

4.11 dying off 2

DEFINITION: The amount of macrobenthic individuals that die off naturally

EQUATION: density_deposition_site[*,*] * mortality_rate

ARRAY: zone vs. grain type

UNITS: ind/m²

VALUE: range between 0 and unlimited; only +

TYPE: flow
FUNCTION: calculation

LINKS:
- Input: Density deposition site; Mortality rate

DATA: calculated but not verifiable

4.12 competition 2

DEFINITION: The amount of macrobenthic individuals that die off or leave due to competition effects

EQUATION: IF(density__deposition_site[Zone,Grain]>density_for_competition[Zone, Grain])THEN(density__deposition_site[Zone,Grain]-density_for_competition[Zone,Grain])/DTELSE 0

ARRAY: zone vs. grain type

UNITS: ind/m²

VALUE: range between 0 and unlimited, only +

TYPE: flow

FUNCTION: calculation

LINKS:
- Input: Density deposition site; Density for competition

DATA: calculated but not verifiable

4.13 recruiting 2

DEFINITION: The amount of macrobenthic individuals that are being born

EQUATION: density__deposition_site[Zone,Grain]*birth_rate

ARRAY: zone vs. grain type

UNITS: ind/m²

VALUE: range between 0 and unlimited; only +

TYPE: flow

FUNCTION: calculation

LINKS:
- Input: Density deposition site; Birth rate

DATA: calculated but not verifiable

4.14 density for competition

DEFINITION: The maximum macrobenthic density which can be sustained in a zone of the BCS

EQUATION: constant

ARRAY: none

UNITS: ind/m²
VALUE: 1000 (maximum macrobenthic density found on sandbank tops of BCS)
TYPE: flow
FUNCTION: scenario
LINKS:
  - Output: Competition 2
DATA:
  - Source: MACRODAT database (Section Marine Biology)
  - Dataset: available at Section Marine Biology, University of Ghent

4.15 birth rate
DEFINITION: The rate with which macrobenthic individuals are being born
EQUATION: constant
ARRAY: none
UNITS: numerical
VALUE: 0.36
TYPE: parameter
FUNCTION: scenario
LINKS:
  - Output: Recruiting 2
DATA:
  - Source: Sohma et al. (2001); Duplisea (1998); Ortiz & Wolff (2002)
  - Dataset: see subsection 1.8 above

4.16 mortality rate
DEFINITION: The rate with which macrobenthic individuals die off
EQUATION: constant
ARRAY: none
UNITS: numerical
VALUE: 0.0505
TYPE: parameter
FUNCTION: scenario
LINKS:
  - Output: Dying off 2
DATA:
  - Source: Blackford (1997); Duplisea (1998)
  - Dataset: see subsection 1.3 above
5  SEDIMENT COMPOSITION AT THE EXTRACTION SITE

5.1 sediment extraction site fs

DATA: Calculated from meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

TABLE 6: The initial values of the different grain size fractions of each grain type (as determined in the meta-analysis).

<table>
<thead>
<tr>
<th>Grain type</th>
<th>Grain size fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gravel</td>
</tr>
<tr>
<td>Gravel</td>
<td>61.84</td>
</tr>
<tr>
<td>Medium-coarse sand</td>
<td>11.69</td>
</tr>
<tr>
<td>Fine sand</td>
<td>8.40</td>
</tr>
</tbody>
</table>

The document only gave the equations for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

\[ \text{sediment\_extraction\_site\_FS}\left[\text{Zone}\*,\text{Fine\_Sand}\right]\left(t\right) = \text{sediment\_extraction\_site\_FS}\left[\text{Zone}\*,\text{Fine\_Sand}\right]\left(t\ -\ dt\right) + \left(\text{natural\_input\_FS}\left[\text{Zone1b},\text{Fine\_Sand}\right] + \text{infilling\_FS}\left[\text{Zone}\*,\text{Fine\_Sand}\right] - \text{decrease\_by\_extraction\_FS}\left[\text{Zone}\*,\text{Fine\_Sand}\right] - \text{natural\_decrease\_by\_transport\_FS}\left[\text{Zone}\*,\text{Fine\_Sand}\right]\right) * dt \]

Note: The equations for all other zones of fine sand are the same.

\[ \text{sediment\_extraction\_site\_FS}\left[\text{Zone}\*,\text{Medium\_Coarse\_Sand}\right]\left(t\right) = \text{sediment\_extraction\_site\_FS}\left[\text{Zone}\*,\text{Medium\_Coarse\_Sand}\right]\left(t\ -\ dt\right) + \left(\text{natural\_input\_FS}\left[\text{Zone}\*,\text{Medium\_Coarse\_Sand}\right] + \text{infilling\_FS}\left[\text{Zone}\*,\text{Medium\_Coarse\_Sand}\right] - \text{decrease\_by\_extraction\_FS}\left[\text{Zone}\*,\text{Medium\_Coarse\_Sand}\right] - \text{natural\_decrease\_by\_transport\_FS}\left[\text{Zone}\*,\text{Medium\_Coarse\_Sand}\right]\right) * dt \]

Note: The equations for all other zones of medium-coarse sand are the same.

\[ \text{sediment\_extraction\_site\_FS}\left[\text{Zone}\*,\text{Gravel}\right]\left(t\right) = \text{sediment\_extraction\_site\_FS}\left[\text{Zone 1a},\text{Gravel}\right]\left(t\ -\ dt\right) + \left(\text{natural\_input\_FS}\left[\text{Zone}\*,\text{Gravel}\right] + \text{infilling\_FS}\left[\text{Zone}\*,\text{Gravel}\right] - \text{decrease\_by\_extraction\_FS}\left[\text{Zone}\*,\text{Gravel}\right] - \text{natural\_decrease\_by\_transport\_FS}\left[\text{Zone}\*,\text{Gravel}\right]\right) * dt \]
Note: The equations for all other zones of gravel are the same.

5.3 infilling rate $fs$

**DATA:** Calculated from meta-analysis
For more information on the methodology of the meta-analysis see subsection 2.1.

**TABLE 7:** The infilling rates of the different grain size fractions of each grain type (as determined in the meta-analysis).

<table>
<thead>
<tr>
<th>Grain type</th>
<th>Infilling rate of the grain size fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gravel</td>
</tr>
<tr>
<td>Gravel</td>
<td>1.0102</td>
</tr>
<tr>
<td>Medium-coarse sand</td>
<td>1.049</td>
</tr>
<tr>
<td>Fine sand</td>
<td>1.0215</td>
</tr>
</tbody>
</table>

5.6 sand transport $fs$

**DATA:** Calculated from meta-analysis
For more information on the methodology of the meta-analysis see subsection 2.1.

**TABLE 8:** The natural sand transport rates of the different grain size fractions of each grain type (as determined in the meta-analysis).

<table>
<thead>
<tr>
<th>Grain type</th>
<th>Natural sand transport rate of the grain size fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gravel</td>
</tr>
<tr>
<td>Gravel</td>
<td>1.01</td>
</tr>
<tr>
<td>Medium-coarse sand</td>
<td>1.0056</td>
</tr>
<tr>
<td>Fine sand</td>
<td>1.00084</td>
</tr>
</tbody>
</table>

5.8 sediment extraction site $mcs$

**DEFINITION:** The percentage of the medium-coarse sand grain size fraction that is present in a zone (different for all grain types)

**EQUATION:**

\[
\text{sediment\_extraction\_site\_MCS[Zone1a,Fine\_Sand](t - dt) + (natural\_input\_MSC[Zone1a,Fine\_Sand] + infilling\_MSC[Zone1a,Fine\_Sand] - decrease\_by\_extraction\_MSC[Zone1a,Fine\_Sand] - natural\_decrease\_by\_transport\_MSC [Zone1a,Fine\_Sand])*dt}
\]

**ARRAY:** zone vs. grain type

**UNITS:** %
VALUE: initial value = 31.22; range between 0 and unlimited
TYPE: stock
FUNCTION: objective
LINKS:
- Input: Sediment extraction site MCS; Natural input 2; Infilling 2
- Output: Decrease by extraction 2; Decrease by natural transport 2
DATA: Calculated from meta-analysis

For initial values, see subsection 5.1 above. The description of the stocks of the other grain size types and zones are identical and only the equations are given:

\[
\text{sediment\_extraction\_site\_MCS[Zone*,Fine\_Sand](t)} = \text{sediment\_extraction\_site\_MCS[Zone*,Fine\_Sand](t-dt)} + \text{(natural\_input\_MSC[Zone*,Fine\_Sand]+infilling\_MSC[Zone*,Fine\_Sand]-decrease\_by\_extraction\_MSC[Zone*,Fine\_Sand]-natural\_decrease\_by\_transport\_MSC[Zone*,Fine\_Sand])}\times dt
\]

Note: The equations for all other zones of fine sand are the same.

\[
\text{sediment\_extraction\_site\_MCS[Zone*,Medium\_Coarse\_Sand](t)} = \text{sediment\_extraction\_site\_MCS[Zone1a,Medium\_Coarse\_Sand](t-dt)} + \text{(natural\_input\_MSC[Zone*,Medium\_Coarse\_Sand]+infilling\_MSC[Zone*,Medium\_Coarse\_Sand]-decrease\_by\_extraction\_MSC[Zone*,Medium\_Coarse\_Sand]-natural\_decrease\_by\_transport\_MSC[Zone*,Medium\_Coarse\_Sand])}\times dt
\]

Note: The equations for all other zones of medium-coarse sand are the same.

\[
\text{sediment\_extraction\_site\_MCS[Zone*,Gravel](t)} = \text{sediment\_extraction\_site\_MCS[Zone*,Gravel](t-dt)} + \text{(natural\_input\_MSC[Zone*,Gravel]+infilling\_MSC[Zone*,Gravel]-decrease\_by\_extraction\_MSC[Zone*,Gravel]-natural\_decrease\_by\_transport\_MSC[Zone*,Gravel])}\times dt
\]

Note: The equations for all other zones of gravel are the same.

5.9 sediment extraction site gravel
DEFINITION: The percentage of the gravel grain size fraction that is present in a zone (different for all grain types)
EQUATION: \[
\text{sediment\_extraction\_site\_gravel[Zone1a,Fine\_Sand](t-dt)} + \text{(natural\_input\_Gravel[Zone1a,Fine\_Sand]+infilling\_Gravel[Zone1a,Fine\_Sand]-decrease\_by\_extraction\_MSC[Zone1a,Fine\_Sand]-natural\_decrease\_by\_transport\_MSC[Zone1a,Fine\_Sand])}\times dt
\]
decrease_by_extraction_Gravel[Zone1a,Fine_Sand] = sediment_extraction_site_gravel[Zone1a,Fine_Sand](t) - sediment_extraction_site_gravel[Zone1a,Fine_Sand](t - dt) + (natural_input_Gravel[Zone1b,Fine_Sand] + infilling_Gravel[Zone1a,Fine_Sand] - decrease_by_extraction_Gravel[Zone1a,Fine_Sand] - natural_decrease_by_transport_Gravel[Zone1a,Fine_Sand]) * dt

Note: The equations for all other zones of fine sand are the same.

sediment_extraction_site_gravel[Zone*,Medium_Coarse_Sand](t) = sediment_extraction_site_gravel[Zone*,Medium_Coarse_Sand](t - dt) + (natural_input_Gravel[Zone*,Medium_Coarse_Sand] + infilling_Gravel[Zone*,Medium_Coarse_Sand] - decrease_by_extraction_Gravel[Zone*,Medium_Coarse_Sand] - natural_decrease_by_transport_Gravel[Zone*,Medium_Coarse_Sand]) * dt

Note: The equations for all other zones of medium-coarse sand are the same.

decrease_by_extraction_Gravel[Zone*,Gravel] = sediment_extraction_site_gravel[Zone1a,Gravel](t-dt)+(natural_input_Gravel[Zone*,Gravel]+infilling_Gravel[Zone*,Gravel]–decrease_by_extraction_Gravel[Zone*,Gravel]+natural_decrease_by_transport_Gravel[Zone*,Gravel])*dt

Note: The equations for all other zones of gravel are the same.
5.10 natural input MCS

**DEFINITION:** The percentage of the medium-coarse sand grain size fraction that is coming in the zone due to natural sediment transport processes

**EQUATION:** \( \text{infilling\_rate\_MCS} \times \text{sediment\_extraction\_site\_MCS} \)

**ARRAY:** zone vs. grain type

**UNITS:** %

**VALUE:** range from 0 to unlimited; only +

**TYPE:** flow

**FUNCTION:** calculation

**LINKS:**
- Input: Infilling rate MCS; sediment extraction site MCS
- Output: Sediment extraction site MCS

**DATA:** calculated but not verifiable

5.11 natural input gravel

**DEFINITION:** The percentage of the gravel grain size fraction that is coming in the zone due to natural sediment transport processes

**EQUATION:** \( \text{infilling\_rate\_Gravel} \times \text{sediment\_extraction\_site\_gravel} \)

**ARRAY:** zone vs. grain type

**UNITS:** %

**VALUE:** range from 0 to unlimited; only +

**TYPE:** flow

**FUNCTION:** calculation

**LINKS:**
- Input: Infilling rate Gravel; sediment extraction site gravel
- Output: Sediment extraction site gravel

**DATA:** calculated but not verifiable

5.12 infilling rate MCS

**DEFINITION:** The rate at which the medium-coarse sand grain size fraction is transported to an area

**EQUATION:** Constant

**ARRAY:** zone vs. grain type

**UNITS:** numerical

**VALUE:** 1.028 (for gr=Fine Sand), 1.0168 (for gr=Medium Coarse Sand), 1.0101 (for gr=gravel) for zone 1A

**TYPE:** parameter

**FUNCTION:** scenario
LINKS:
- Output: Natural input MCS

DATA: Calculated from meta-analysis

See TABLE 7 above for data.

5.13 infilling rate gravel
DEFINITION: The rate at which the fine sand grain size fraction is transported to an area
EQUATION: Constant
ARRAY: zone vs. grain type
UNITS: numerical
VALUE: 1.0215 (for gr=Fine Sand), 1.049 (for gr= Medium Coarse Sand), 1.0102 (for gr=gravel) for zone 1A
TYPE: parameter
FUNCTION: scenario
LINKS:
- Output: Natural input Gravel

DATA: Calculated from meta-analysis

See TABLE 7 above for data.

5.14 infilling MCS
DEFINITION: The percentage of the medium-coarse sand grain size fraction that fills in the extraction tracks
EQUATION: IF(sum_of_effects_surface_MCS[zone,gr]=0)THEN(0)ELSE((sum_of_effects_surface_MCS[zone,gr]+1)*sediment_extraction_site_MCS[zone,gr])-(sum_of_effects_surface_MCS[zone,gr]+1)*sediment_extraction_site_MCS[zone,gr])
ARRAY: zone vs. grain type
UNITS: %
VALUE: range from 0 to unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:
- Input: Sum of effects surface MCS; Sediment extraction site MCS
- Output: Sediment extraction site MCS

DATA: calculated but not verifiable
5.15 infilling gravel

**DEFINITION:** The percentage of the gravel grain size fraction that fills in the extraction tracks

**EQUATION:** IF(sum_of_effects_surface_gravel[zone,gr]=0)THEN(0)ELSE((sum_of_effects_surface_gravel[zone,gr]+1)*sediment_extraction_site_gravel[zone,gr])-(sum_of_effects_surface_gravel[zone,gr]+1)*sediment_extraction_site_gravel[zone,gr])

**ARRAY:** zone vs. grain type

**UNITS:** %

**VALUE:** range from 0 to unlimited; only +

**TYPE:** flow

**FUNCTION:** calculation

**LINKS:**
- Input: Sum of effects surface gravel; Sediment extraction site gravel
- Output: Sediment extraction site gravel

**DATA:** calculated but not verifiable

5.16 natural decrease by transport MCS

**DEFINITION:** The percentage of the medium-coarse sand grain size fraction that leaves the zone due to natural sediment transport processes

**EQUATION:** sand_transport_MCS[zone,gr]*sediment_extraction_site_MCS[zone,gr]

**ARRAY:** zone vs. grain type

**UNITS:** %

**VALUE:** range from 0 to unlimited; only +

**TYPE:** flow

**FUNCTION:** calculation

**LINKS:**
- Input: Sand transport MCS; Sediment extraction site MCS

**DATA:** calculated but not verifiable

5.17 natural decrease by transport gravel

**DEFINITION:** The percentage of the gravel grain size fraction that leaves the zone due to natural sediment transport processes

**EQUATION:** sand_transport_gravel[zone,gr]*sediment_extraction_site_gravel[zone,gr]

**ARRAY:** zone vs. grain type

**UNITS:** %

**VALUE:** range from 0 to unlimited; only +

**TYPE:** flow
FUNCTION: calculation

LINKS:
- Input: Sand transport Gravel; Sediment extraction site gravel

DATA: calculated but not verifiable

5.18 sand transport MCS

DEFINITION: The rate at which the medium-coarse sand grain size fraction is transported away from an area

EQUATION: constant

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: 1.0015 (for gr=Fine Sand), 1.0063 (for gr= Medium Coarse Sand), 1.0077 (for gr=gravel) for zone 1A

TYPE: parameter

FUNCTION: scenario

LINKS:
- Output: Natural decrease by transport MCS

DATA: Calculated from meta-analysis

See TABLE 8 above for data.

5.19 sand transport gravel

DEFINITION: The rate at which the gravel grain size fraction is transported away from an area

EQUATION: constant

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: 1.00084 (for gr=Fine Sand), 1.0056 (for gr= Medium Coarse Sand), 1.01 (for gr=gravel) for zone 1A

TYPE: parameter

FUNCTION: scenario

LINKS:
- Output: Natural decrease by transport Gravel

DATA: Calculated from meta-analysis

See TABLE 8 above for data.
5.20 decrease by extraction MCS

**DEFINITION:** The percentage of the medium-coarse sand grain size fraction that is removed from the zone due to the extraction activities.

**EQUATION:**
\[
\text{IF}(\text{sum\_of\_effects\_amount\_MCS}[\text{zone,gr}]<0)\text{THEN}\left(\text{sediment\_extraction\_site\_MCS}[\text{zone,gr}]-\left(\text{sum\_of\_effects\_amount\_MCS}[\text{zone,gr}]+1\right)\times\text{sediment\_extraction\_site\_MCS}[\text{zone,gr}]\right)\text{ELSE}0
\]

**ARRAY:** zone vs. grain type

**UNITS:** %

**VALUE:** range from 0 to unlimited; only +

**TYPE:** flow

**FUNCTION:** calculation

**LINKS:**
- Input: Sum of effects amount MCS; Sediment extraction site MCS

**DATA:** calculated but not verifiable

5.21 decrease by extraction gravel

**DEFINITION:** The percentage of the gravel grain size fraction that is removed from the zone due to the extraction activities.

**EQUATION:**
\[
\text{IF}(\text{sum\_of\_effects\_amount\_gravel}[\text{zone,gr}]<0)\text{THEN}\left(\text{sediment\_extraction\_site\_gravel}[\text{zone,gr}]-\left(\text{sum\_of\_effects\_amount\_gravel}[\text{zone,gr}]+1\right)\times\text{sediment\_extraction\_site\_gravel}[\text{zone,gr}]\right)\text{ELSE}0
\]

**ARRAY:** zone vs. grain type

**UNITS:** %

**VALUE:** range from 0 to unlimited; only +

**TYPE:** flow

**FUNCTION:** calculation

**LINKS:**
- Input: Sum of effects amount gravel; Sediment extraction site gravel

**DATA:** calculated but not verifiable

6 EFFECT OF SURFACE AREA EXTRACTED ON SEDIMENT COMPOSITION

These variables are described in the decision process diamond “Effect surface sediment”.

6.1 R1_2

**DEFINITION:** Regime 1, which is different for the different grain size types.

**EQUATION:**
\[
\text{IF}(\text{regime}[\text{Zone1a,Fine\_Sand}]>15)\text{AND}(\text{regime}[\text{Zone1a,Fine\_Sand}]<\text{...}
\]
For more information on the methodology of the meta-analysis see subsection 2.1.

The regimes are equal to the ones described in TABLE 4.

The description above only gives the equation for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

\[
R_{1,2}[\text{Zone}^*,\text{Fine Sand}] = \text{IF} \ (\text{regime}[\text{Zone}^*,\text{Fine Sand}]>15) \ \text{AND} \ (\text{regime}[\text{Zone}^*,\text{Fine Sand}]<101) \ \text{THEN} \ 1 \ \text{ELSE} \ 0
\]

Note: The equations for all other zones of fine sand are the same.

\[
R_{1,2}[\text{Zone}^*,\text{Medium Coarse Sand}] = \text{IF} \ (\text{regime}[\text{Zone}^*,\text{Medium Coarse Sand}]>15) \ \text{AND} \ (\text{regime}[\text{Zone}^*,\text{Medium Coarse Sand}]<201) \ \text{THEN} \ 1 \ \text{ELSE} \ 0
\]

Note: The equations for all other zones of medium-coarse sand are the same.

\[
R_{1,2}[\text{Zone}^*,\text{Gravel}] = \text{IF} \ (\text{regime}[\text{Zone}^*,\text{Gravel}]>15) \ \text{AND} \ (\text{regime}[\text{Zone}^*,\text{Gravel}]<201) \ \text{THEN} \ 1 \ \text{ELSE} \ 0
\]

Note: The equations for all other zones of gravel are the same.

### 6.2 R2_2

**DEFINITION:** Regime 2, which is different for the different grain size types

**EQUATION:** IF(regime[Zone1a,Fine_Sand]>100)AND(regime[Zone1a,Fine_Sand]<601) THEN 1 ELSE 0

**ARRAY:** zone vs. grain type
**UNITS**: numerical  
**VALUE**: range between 0 and 1; only +  
**TYPE**: variable  
**FUNCTION**: calculation  
**LINKS**:  
- Input: Regime  
- Output: Effect surface gravel 2; Effect surface MCS 2; Effect surface FS 2  
**DATA**: calculated from meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

The regimes are equal to the ones described in TABLE 4.

The description above only gives the equation for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

\[
R_{2,2}[\text{Zone}, \text{Fine}_{\text{Sand}}] = \begin{cases} 
1 & \text{if } \text{regime}[\text{Zone}, \text{Fine}_{\text{Sand}}] > 100 \text{ AND } \text{regime}[\text{Zone}, \text{Fine}_{\text{Sand}}] < 601 \\
0 & \text{otherwise} 
\end{cases}
\]

Note: The equations for all other zones of fine sand are the same.

\[
R_{2,2}[\text{Zone}, \text{Fine}_{\text{Sand}}] = R_{2,2}[\text{Zone}, \text{Medium}_{\text{Coarse}_{\text{Sand}}}] = \begin{cases} 
1 & \text{if } \text{regime}[\text{Zone}, \text{Medium}_{\text{Coarse}_{\text{Sand}}}] > 200 \text{ AND } \text{regime}[\text{Zone}, \text{Medium}_{\text{Coarse}_{\text{Sand}}}] < 601 \\
0 & \text{otherwise} 
\end{cases}
\]

Note: The equations for all other zones of medium-coarse sand are the same.

\[
R_{2,2}[\text{Zone}, \text{Gravel}] = \begin{cases} 
1 & \text{if } \text{regime}[\text{Zone}, \text{Gravel}] > 200 \text{ AND } \text{regime}[\text{Zone}, \text{Gravel}] < 751 \\
0 & \text{otherwise} 
\end{cases}
\]

Note: The equations for all other zones of gravel are the same.

### 6.3 R3_2

**DEFINITION**: Regime 3, which is different for the different grain size types  
**EQUATION**: IF (\text{regime}[\text{Zone1a}, \text{Fine}_{\text{Sand}}] > 600) THEN 1 ELSE 0  
**ARRAY**: zone vs. grain type  
**UNITS**: numerical  
**VALUE**: range between 0 and 1; only +
TYPE: variable
FUNCTION: calculation
LINKS:
  • Input: Regime
  • Output: Effect surface gravel 3; Effect surface MCS 3; Effect surface FS 3
DATA: calculated from meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

The regimes are equal to the ones described in TABLE 4.

The description above only gives the equation for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

R3_2[Zone*,Fine_Sand] = IF (regime[Zone*,Fine_Sand]>600) THEN 1 ELSE 0

Note: The equations for all other zones of fine sand are the same.

R3_2[Zone*,Medium_Coarse_Sand] = IF (regime[Zone*,Medium_Coarse_Sand]>600) THEN 1 ELSE 0

Note: The equations for all other zones of medium-coarse sand are the same.

R3_2[Zone*,Gravel] = IF (regime[Zone*,Gravel]>750) THEN 1 ELSE 0

Note: The equations for all other zones of gravel are the same.

6.4 r continuous

DEFINITION: Continuous regime (when the mean number of days between two trips is less than 15), which is similar for all grain size types

EQUATION: IF (Mean_number_of_days_between_2_trips[Zone1a,Fine_Sand]<15) OR (regime[Zone1a,Fine_Sand]=0) THEN 1 ELSE 0

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range between 0 and 1; only +

TYPE: variable

FUNCTION: calculation

LINKS:
- **Input:** Regime; Mean number of days between 2 trips
- **Output:** Sum of effects surface gravel; Sum of effects surface MCS; Sum of effects surface FS

**DATA:** calculated from meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

The regimes are equal to the ones described in TABLE 4.

The description above only gives the equation for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

\[
R_{\text{continuous}_2}[\text{Zone}*,\text{Fine}_\text{Sand}] = \begin{cases} 
1 & \text{IF (Mean\_number\_of\_days\_between\_2\_trips[Zone*,\text{Fine}_\text{Sand}] < 15) OR (regime[Zone*,\text{Fine}_\text{Sand}] = 0)} \ \text{THEN}\ 1 \ \text{ELSE}\ 0 \\
0 & \text{Note: The equations for all other zones of fine sand are the same.} 
\end{cases}
\]

\[
R_{\text{continuous}_2}[\text{Zone}*,\text{Medium}\_\text{Coarse}_\text{Sand}] = \begin{cases} 
1 & \text{IF (Mean\_number\_of\_days\_between\_2\_trips[Zone*,\text{Medium}\_\text{Coarse}_\text{Sand}] < 15) OR (regime[Zone*,\text{Medium}\_\text{Coarse}_\text{Sand}] = 0)} \ \text{THEN}\ 1 \ \text{ELSE}\ 0 \\
0 & \text{Note: The equations for all other zones of medium-coarse sand are the same.} 
\end{cases}
\]

\[
R_{\text{continuous}_2}[\text{Zone}*,\text{Gravel}] = \begin{cases} 
1 & \text{IF (Mean\_number\_of\_days\_between\_2\_trips[Zone1a,\text{Gravel}] < 15) OR (regime[Zone*,\text{Gravel}] = 0)} \ \text{THEN}\ 1 \ \text{ELSE}\ 0 \\
0 & \text{Note: The equations for all other zones of gravel are the same.} 
\end{cases}
\]

### 6.5 **effect surface gravel 1**

**DEFINITION:** Effect of the extraction of a certain surface area on the gravel grain size fraction when regime 1_2 is valid

**EQUATION:**
\[
\text{IF}(R1\_2[\text{Zone1a},\text{Fine}_\text{Sand}]=1)\ \text{THEN}(((10^((-70.929*(\text{Effectively\_extracted\_surface\_per\_zone\_and\_type[Zone1a,\text{Fine}_\text{Sand}]/1000000)))+3.7327)+2.004))-101)/100)\ \text{ELSE}\ 0
\]

**ARRAY:** zone vs. grain type

**UNITS:** numerical

**VALUE:** range between 0 and unlimited; +/-

**TYPE:** variable
**FUNCTION:** calculation

**LINKS:**
- Input: R1_2; Effectively extracted surface per zone and type
- Output: Sum of effects surface gravel

**DATA:** calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

**GRAPH 21:** Mean (logarithmic) effect of the extraction of a certain surface area of sediment in fine sand habitats on the gravel grain size fraction of the sediment (when regime 1_2 is valid).

![Graph 21](image)

The description above only gives the equation for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

\[
\text{effect\_surface\_gravel\_1[Zone*,Fine\_Sand]} = \begin{cases} 
\text{IF}(R1\_2[Zone*,Fine\_Sand]=1)\text{THEN} & \left((10^{((-70.929\times\text{Effectively\_extracted\_surface\_per\_zone\_and\_type[Zone*,Fine\_Sand]/10000})+3.7327)}+2.004)-101)/100\text{ELSE }0
\end{cases}
\]

Note: The equations for all other zones of fine sand are the same.

**GRAPH 22:** Mean (logarithmic) effect of the extraction of a certain surface area of sediment in medium-coarse sand habitats on the gravel grain size fraction of the sediment (when regime 1_2 is valid).
effect_surface_gravel_1[Zone*,Medium_Coarse_Sand] = IF(R1_2[Zone*,Medium_Coarse_Sand]=1)THEN(((10^(((-0.2667*((Effectively_extracted_surface_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)^2))+(0.7226*(Effectively_extracted_surface_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000))+0.2947)+2.004))-101)/100)ELSE 0

Note: The equations for all other zones of medium-coarse sand are the same.

GRAPH 23: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in gravel habitats on the gravel grain size fraction of the sediment (when regime 1_2 is valid).

effect_surface_gravel_1[Zone*,Gravel] = IF(R1_2[Zone*,Gravel]=1)THEN(((10^((0.0007*((Effectively_extracted_surface_per_zone_and_type[Zone*,Gravel]/1000000)^4))-(0.0 191*((Effectively_extracted_surface_per_zone_and_type[Zone*,Gravel]/1000000)^4)))-0.2357x + 0.0721)+2.004))-101)/100)ELSE 0

Note: The equations for all other zones of gravel are the same.
Note: The equations for all other zones of gravel are the same.

6.6 effect surface MCS 1

**DEFINITION:** Effect of the extraction of a certain surface area on the medium-coarse sand grain size fraction when regime 1_2 is valid

**EQUATION:**

\[
\text{IF}(R1_2[\text{Zone1a,Fine_Sand}]=1)\text{THEN}((10^{((-26.678*(\text{Effectively_extracted_surface_per_zone_and_type[Zone1a,Fine_Sand]/1000000})+1.4842)+2.004))-101)/100) \text{ ELSE 0}
\]

**ARRAY:** zone vs. grain type

**UNITS:** numerical

**VALUE:** range between 0 and unlimited; +/-

**TYPE:** variable

**FUNCTION:** calculation

**LINKS:**

- Input: R1_2; Effectively extracted surface per zone and type
- Output: Sum of effects surface MCS

**DATA:** calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

**GRAPH 24:** Mean (logarithmic) effect of the extraction of a certain surface area of sediment in fine sand habitats on the medium-coarse sand grain size fraction of the sediment (when regime 1_2 is valid).
effect_surface_MCS_1[Zone*,Fine_Sand] = IF(R1_2[Zone*,Fine_Sand]=1)THEN(((10^(((-26.678*(Effectively_extracted_surface_per_zone_and _type[Zone*,Fine_Sand]/100000)))+1.4842)+2.004))-101)/100)ELSE 0

Note: The equations for all other zones of fine sand are the same.

GRAPH 25: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in medium-coarse sand habitats on the medium-coarse sand grain size fraction of the sediment (when regime 1_2 is valid).

effect_surface_MCS_1[Zone*,Medium_Coarse_Sand]=IF(R1_2[Zone*,Medium_Coarse_Sand]=1)THEN(((10^(((-4.2328*(Effectively_extracted_surface_per_zone_and _type[Zone*,Medium_Coarse_Sand]/100000))^2))+(7.2387*(Effectively_extracted_surface_per_zone_and _type[Zone*,Medium_Coarse_Sand]/1000000)))+1.5037))ELSE 0
Note: The equations for all other zones of medium-coarse sand are the same.

GRAPH 26: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in gravel habitats on the medium-coarse sand grain size fraction of the sediment (when regime 1_2 is valid).

Note: The equations for all other zones of gravel are the same.

6.7 effect surface FS 1

**DEFINITION:** Effect of the extraction of a certain surface area on the fine sand grain size fraction when regime 1_2 is valid

**EQUATION:** IF(R1_2[Zone1a,Fine_Sand]=1)THEN(((10^(((4.8656*((Effectively_extracted_surface_per_zone_and_type[Zone1a,Fine_Sand]/1000000)^2))+(5.2302*(Effectively_extracted_surface_per_zone_and_type[Zone1a,Fine_Sand]/1000000))-0.2861)+2.004))-101)/100)ELSE 0

**ARRAY:** zone vs. grain type

**UNITS:** numerical
VALUE: range between 0 and unlimited; +/-
TYPE: variable
FUNCTION: calculation
LINKS:
- Input: R1_2; Effectively extracted surface per zone and type
- Output: Sum of effects surface FS
DATA: calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

GRAPH 27: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in fine sand habitats on the fine sand grain size fraction of the sediment (when regime 1_2 is valid).

\[
y = -4.8656x^2 + 5.2302x - 0.2861 \\
R^2 = 0.5421
\]

Note: The equations for all other zones of fine sand are the same.

GRAPH 28: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in medium-coarse sand habitats on the fine sand grain size fraction of the sediment (when regime 1_2 is valid).
effect_surface_FS_1[Zone*,Medium_Coarse_Sand] = IF(R1_2[Zone*,Medium_Coarse_Sand]=1)THEN(((10^(((-1.0002*(Effectively_extracted_surface_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)^2))+(2.028*(Effectively_extracted_surface_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000))-1.3269)+2.004))-101)/100)ELSE 0

Note: The equations for all other zones of medium-coarse are the same.

GRAPH 29: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in gravel habitats on the fine sand grain size fraction of the sediment (when regime 1_2 is valid).

effect_surface_FS_1[Zone*,Gravel] = IF(R1_2[Zone*,Gravel]=1)THEN(((10^(((0.0676*(Effectively_extracted_surface_per_zone_and_type[Zone*,Gravel]/1000000))-0.1336)+2.004))-101)/100) ELSE 0
Note: The equations for all other zones of gravel are the same.

6.8 effect surface gravel 2

**DEFINITION:** Effect of the extraction of a certain surface area on the gravel grain size fraction when regime 2_2 is valid

**EQUATION:**

\[
\text{IF}(R2_2[\text{Zone1a,Fine_Sand}]=1)\text{THEN}(((10^((-1.6326*(\text{Effectively_extracted_surface_per_zone_and_type}[\text{Zone1a,Fine_Sand}]/100000)+2.1952)+2.004))-101)/100)) \text{ELSE} 0
\]

**ARRAY:** zone vs. grain type

**UNITS:** numerical

**VALUE:** range between 0 and unlimited; +/-

**TYPE:** variable

**FUNCTION:** calculation

**LINKS:**
- Input: R2_2; Effectively Extracted surface per zone and type
- Output: Sum of effects surface gravel

**DATA:** calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

**GRAPH 30:** Mean (logarithmic) effect of the extraction of a certain surface area of sediment in fine sand habitats on the gravel grain size fraction of the sediment (when regime 2_2 is valid).

\[
y = -1.6326x + 2.1952 \\
R^2 = 1
\]
effect_surface__gravel_2[Zone*,Fine_Sand] = IF(R2_2[Zone*,Fine_Sand]=1)THEN 
(((10^(((−1.6326*(Effectively_extracted_surface_per_zone_and_type[Zone*,Fine_Sand]/100 0000)+2.1952)+2.004))-101)/100)) ELSE 0

Note: The equations for all other zones of fine sand are the same.

GRAPH 31: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in medium-coarse sand habitats on the gravel grain size fraction of the sediment (when regime 2_2 is valid).

effect_surface__gravel_2[Zone1a,Medium_Coarse_Sand] = IF(R2_2[Zone*,Medium_Coarse_Sand]=1)THEN 
(((10^(((0.01*((Effectively_extracted_surface_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)^4))-(0.0816*((Effectively_extracted_surface_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)^3))-(0.0669*((Extracted_surface_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)^2)))+(0.9856*(Effectively_extracted_surface_per_zone_and_type[Zone*,Medium_Coarse_Sand]/10000000))-0.43 53)+2.004))-101)/100)ELSE 0

Note: The equations for all other zones of medium-coarse sand are the same.

GRAPH 32: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in gravel habitats on the gravel grain size fraction of the sediment (when regime 2_2 is valid).
**6.9 effect surface MCS 2**

**DEFINITION:** Effect of the extraction of a certain surface area on the medium-coarse sand grain size fraction when regime 2_2 is valid

**EQUATION:**

$$\text{effect surface MCS } 2 = \text{IF}(R2_2[\text{Zone1a,Fine_Sand}] = 1) \text{THEN}((10^{((-0.0249 \times (\text{Effectively_extracted_surface_per_zone_and_type}[\text{Zone1a,Fine_Sand}] / 1000000)^3))} + 0.2043 \times (\text{Effectively_extracted_surface_per_zone_and_type}[\text{Zone1a,Fine_Sand}] / 1000000)^2) - 0.4887 \times (\text{Effectively_extracted_surface_per_zone_and_type}[\text{Zone1a,Fine_Sand}] / 1000000) + 0.2255)) + 2.004) - 101)/100) \text{ ELSE 0}$$

**ARRAY:** zone vs. grain type

**UNITS:** numerical

**VALUE:** range between 0 and unlimited; +/-

**TYPE:** variable

**FUNCTION:** calculation

**LINKS:**
- Input: R2_2; Effectively_extracted_surface_per_zone_and_type
- Output: Sum of effects surface MCS

**DATA:** calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.
GRAPH 33: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in fine sand habitats on the medium-coarse sand grain size fraction of the sediment (when regime 2_2 is valid).

\[
y = -0.2441 \ln(x) - 0.7414 \\
R^2 = 0.8325
\]

Note: The equations for all other zones fine sand are the same.

GRAPH 34: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in medium-coarse sand habitats on the medium-coarse sand grain size fraction of the sediment (when regime 2_2 is valid).

\[
y = 0.04 \ln(x) - 0.1413 \\
R^2 = 0.2259
\]
effect_surface__MCS_2[Zone*,Medium_Coarse_Sand] = IF(R2_2[Zone*,Medium_Coarse_Sand]=1)THEN(((10^(((0.04*LOGN(Effectively_extracted_surface_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000))-0.1413)+2.004))-101)/100) ELSE 0

Note: The equations for all other zones of medium-coarse sand are the same.

GRAPH 35: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in gravel habitats on the medium-coarse sand grain size fraction of the sediment (when regime 2_2 is valid).

effect_surface__MCS_2[Zone*,Gravel] = IF(R2_2[Zone*,Gravel]=1)THEN(((10^((0.0528*LOGN(Effectively_extracted_surface_per_zone_and_type[Zone*,Gravel]/1000000))-0.1395)+2.004))-101)/100) ELSE 0

Note: The equations for all other zones of gravel are the same.

6.10 effect surface FS 2

DEFINITION: Effect of the extraction of a certain surface area on the fine sand grain size fraction when regime 2_2 is valid

EQUATION: IF(R2_2[Zone1a,Fine_Sand]=1)THEN(((10^(((8.0265*((Effectively_extracted_surface_per_zone_and_type[Zone1a,Fine_Sand]/1000000)^3))-(14.337*((Effectively_extracted_surface_per_zone_and_type[Zone1a,Fine_Sand]/1000000)^2))+(4.5428*(Effectively_extracted_surface_per_zone_and_type[Zone1a,Fine_Sand]/1000000))))-0.1395)+2.004))-101)/100) ELSE 0
acted_surface_per_zone_and_type[Zone1a,Fine_Sand]/1000000)-0.1432)+2.004))-101)/100)) ELSE 0

**ARRAY:** zone vs. grain type  
**UNITS:** numerical  
**VALUE:** range between 0 and unlimited; +/-  
**TYPE:** variable  
**FUNCTION:** calculation

**LINKS:**  
- Input: R2_2; Effectively_extracted surface per zone and type  
- Output: Sum of effects surface FS

**DATA:** calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

**GRAPH 36:** Mean (logarithmic) effect of the extraction of a certain surface area of sediment in fine sand habitats on the fine sand grain size fraction of the sediment (when regime 2_2 is valid).

![Graph showing mean log effect vs. surface area extracted (km²)](image)

\[y = 8.0265x^3 - 14.337x^2 + 4.5428x - 0.1432\]  
\[R^2 = 0.9879\]

\[\text{effect_surface__FS_2}[\text{Zone},\text{Fine_Sand}] = \text{IF}(R2_2[\text{Zone},\text{Fine_Sand}]=1)\text{THEN}((10^{(((8.0265*((\text{Effectively_extracted_surface_per_zone_and_type}[\text{Zone},\text{Fine_Sand}]/1000000)^3))-(14.337*([\text{Effectively_extracted_surface_per_zone_and_type}[\text{Zone},\text{Fine_Sand}]/1000000)^2])+(4.5428*([\text{Effectively_extracted_surface_per_zone_and_type}[\text{Zone},\text{Fine_Sand}]/1000000))-0.1432)+2.004))}-101)/100)) \text{ ELSE 0}\]

Note: The equations for all other zones of fine sand are the same.
GRAPH 37: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in medium-coarse sand habitats on the fine sand grain size fraction of the sediment (when regime 2_2 is valid).

\[ y = 0.0132x^3 - 0.0278x^2 - 0.1813x + 0.9868 \]
\[ R^2 = 0.0767 \]

Note: The equations for all other zones of medium-coarse sand are the same.

GRAPH 38: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in gravel habitats on the fine sand grain size fraction of the sediment (when regime 2_2 is valid).
effect_surface__FS_2[Zone*,Gravel] = IF(R2_2[Zone*,Gravel]=1)THEN(((10^(((0.223*LOGN(Effectively_extracted_surface_per_zone_and_type[Zone*,Gravel]/1000000))-0.1607)+2.004))-101)/100) ELSE 0

Note: The equations for all other zones of gravel are the same.

6.11 effect surface gravel 3

DEFINITION: Effect of the extraction of a certain surface area on the gravel grain size fraction when regime 3_2 is valid

EQUATION: IF(R3_2[Zone1a,Fine_Sand]=1)THEN(((10^(((0.76*LOGN(Effectively_extracted_surface_per_zone_and_type[Zone1a,Fine_Sand]/1000000))-0.148)+2.004))-101)/100) ELSE 0

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range between 0 and unlimited; +/-

TYPE: variable

FUNCTION: calculation

LINKS:
- Input: R3_2; Effectively_extracted surface per zone and type
- Output: Sum of effects surface gravel

DATA: calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.
GRAPH 39: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in fine sand habitats on the gravel grain size fraction of the sediment (when regime 3_2 is valid).

\[
y = 0.76x - 0.148 \\
R^2 = 1
\]

Note: The equations for all other zones of fine sand are the same.

GRAPH 40: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in medium-coarse sand habitats on the gravel grain size fraction of the sediment (when regime 3_2 is valid).

\[
y = -0.2109x + 0.0196 \\
R^2 = 1
\]
**ANNEX 2: Sand and Gravel Extraction**

**Environment**

**6.12 effect surface MCS 3**

**DEFINITION:** Effect of the extraction of a certain surface area on the medium-coarse sand grain size fraction when regime 3_2 is valid

**EQUATION:** IF(R3_2[Zone1a,Fine_Sand]=1) THEN(((10^(((0.76*LOGN(Effectively_extracted_surface_per_zone_and_type[Zone1a,Fine_Sand]/1000000))-0.148)+2.004))-101)/100) ELSE 0

**ARRAY:** zone vs. grain type

**UNITS:** numerical

**VALUE:** range between 0 and unlimited; +/-
TYPE: variable
FUNCTION: calculation
LINKS:
- Input: R3_2; Effectively_extracted surface per zone and type
- Output: Sum of effects surface MCS
DATA: calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

GRAPH 42: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in fine sand habitats on the medium-coarse grain size fraction of the sediment (when regime 3_2 is valid).

\[
y = 0.76x - 0.148
\]

\[R^2 = 1\]

Note: The equations for all other zones of fine sand are the same.

GRAPH 43: Mean (logarithmic) effect of the extraction of a certain surface area of sediment in medium-coarse sand habitats on the medium-coarse grain size fraction of the sediment (when regime 3_2 is valid).
ANNEX 2: Sand and Gravel Extraction

**Environment**

**SPSD II – Part 2 – Global change, ecosystems and biodiversity – North Sea**

**M-CS regime 3_2**

\[ y = -0.1286x + 0.0112 \]

\[ R^2 = 1 \]

**Note:** The equations for all other zones of medium-coarse sand are the same.

**GRAPH 44:** Mean (logarithmic) effect of the extraction of a certain surface area of sediment in gravel habitats on the medium-coarse grain size fraction of the sediment (when regime 3_2 is valid).

\[ \text{effect}_{\text{surface}_\text{MCS}_3}[\text{Zone}^*,\text{Medium Coarse Sand}] = \text{IF}(R3_2[\text{Zone}^*,\text{Medium Coarse Sand}]=1)THEN(((10^{((-0.1286*E_{\text{surface per zone and type}[\text{Zone}^*,\text{Medium Coarse Sand}]/1000000})+0.0112)+2.004))-101)/100)ELSE 0 \]

**GRAVEL regime 3_2**

\[ y = 182.69x - 17.381 \]

\[ R^2 = 1 \]

**Note:** The equations for all other zones of gravel are the same.

**GRAPH 45:** Mean (logarithmic) effect of the extraction of a certain surface area of sediment in gravel habitats on the medium-coarse grain size fraction of the sediment (when regime 3_2 is valid).

\[ \text{effect}_{\text{surface}_\text{MCS}_3}[\text{Zone}^*,\text{Gravel}] = \text{IF}(R3_2[\text{Zone}^*,\text{Gravel}]=1)THEN(((10^{((182.69*E_{\text{surface per zone and type}[\text{Zone}^*,\text{Gravel}]/1000000})-17.381)+2.004))-101)/100)ELSE 0 \]
Note: The equations for all other zones of gravel are the same.

6.13 effect surface FS 3

**DEFINITION:** Effect of the extraction of a certain surface area on the fine sand grain size fraction when regime 3_2 is valid

**EQUATION:** IF(R3_2[Zone1a,Fine_Sand]=1)THEN(((10^(((0.76*LOGN(Effectively_extracted_surface_per_zone_and_type[Zone1a,Fine_Sand]/1000000))-0.148)+2.004))-101)/100) ELSE 0

**ARRAY:** zone vs. grain type

**UNITS:** numerical

**VALUE:** range between 0 and unlimited; +/-

**TYPE:** variable

**FUNCTION:** calculation

**LINKS:**
- Input: R3_2; Effectively_extracted surface per zone and type
- Output: Sum of effects surface FS

**DATA:** calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

**GRAPH 45:** Mean (logarithmic) effect of the extraction of a certain surface area of sediment in fine sand habitats on the fine sand grain size fraction of the sediment (when regime 3_2 is valid).

![Graph](image)

\[
\text{effect_surface_FS_3[Zone*,Fine_Sand]} = \begin{cases} 
\text{IF(R3_2[Zone*,Fine_Sand]=1)THEN(((10^(((0.76*LOGN(Effectively_extracted_surface_per_zone_and_type[Zone*,Fine_Sand]/1000000))-0.148)+2.004))-101)/100) ELSE 0}
\end{cases}
\]
Note: The equations for all other zones of fine sand are the same.

**GRAPH 46:** Mean (logarithmic) effect of the extraction of a certain surface area of sediment in medium-coarse sand habitats on the fine sand grain size fraction of the sediment (when regime 3_2 is valid).

\[ y = 0.4201x + 0.1145 \]
\[ R^2 = 1 \]

\[
\text{effect}_{-}\text{surface\_FS\_3[Zone*,Medium\_Coarse\_Sand]} = \text{IF}(R3\_2[\text{Zone*},\text{Medium\_Coarse\_Sand}]=1)\text{THEN}((10^((0.4201*(\text{Effectively\_extracted\_surface\_per\_zone\_and\_type[Zone*,Medium\_Coarse\_Sand]/1000000}+0.1145)+2.004))-101)/100)\text{ELSE} 0
\]

Note: The equations for all other zones of medium-coarse sand are the same.

**GRAPH 47:** Mean (logarithmic) effect of the extraction of a certain surface area of sediment in gravel habitats on the fine sand grain size fraction of the sediment (when regime 3_2 is valid).
effect_surface_FS_3[Zone*,Gravel] = IF(R3_2[Zone*,Gravel]=1)THEN(((10^(((402.28*(Effectively_extracted_surface_per_zone_and_type[Zone*,Gravel]/1000000))-37.938)+2.004))-101)/100)ELSE 0

Note: The equations for all other zones of gravel are the same.

6.14 sum of effects of surface gravel
DEFINITION: Sum of the effects of the extraction of a certain surface area for all regimes on the gravel grain size fraction
EQUATION: IF(R_continuous_2[Zone,Grain]=1)THEN 0 ELSE (SUM(effect_surface_gravel_1[Zone,Grain]+effect_surface_gravel_3[Zone,Grain]+effect_surface__gravel_2[Zone,Grain]))
ARRAY: zone vs. grain type
UNITS: numerical
VALUE: range between 0 and unlimited; +/-
TYPE: variable
FUNCTION: calculation
LINKS:
- Input: R continuous 2; Effect surface gravel 1; Effect surface gravel 2; Effect surface gravel 3
- Output: Infilling
DATA: calculated but not verifiable

6.15 sum of effects of surface MCS
DEFINITION: Sum of the effects of the extraction of a certain surface area for all regimes on the medium-coarse sand grain size fraction
EQUATION: IF(R_continuous_2[Zone,Grain]=1) THEN 0 ELSE (SUM(effect_surface_MCS_1[Zone,Grain]+effect_surface_MCS_3[Zone,Grain]+effect_surface__MCS_2[Zone,Grain]))

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range between 0 and unlimited; +/-

TYPE: variable

FUNCTION: calculation

LINKS:
- Input: R continuous 2; Effect surface MCS 1; Effect surface MCS 2; Effect surface MCS 3
- Output: Infilling 2

DATA: calculated but not verifiable

6.16 sum of effects of surface FS

DEFINITION: Sum of the effects of the extraction of a certain surface area for all regimes on the gravel grain size fraction

EQUATION: IF(R_continuous_2[Zone,Grain]=1) THEN 0 ELSE (SUM(effect_surface_FS_1[Zone,Grain]+effect_surface_FS_3[Zone,Grain]+effect_surface__FS_2[Zone,Grain]))

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range between 0 and unlimited; +/-

TYPE: variable

FUNCTION: calculation

LINKS:
- Input: R continuous 2; Effect surface FS 1; Effect surface FS 2; Effect surface FS 3
- Output: Infilling 3

DATA: calculated but not verifiable

7 EFFECT OF AMOUNT OF AGGREGATES EXTRACTED ON SEDIMENT COMPOSITION

These variables are described in the decision process diamond “Effect amount sediment”.

7.1 R1_3

**DEFINITION:** Regime 1, which is different for the different grain size types

**EQUATION:**
\[ \text{IF}(\text{regime}[\text{Zone1a}, \text{Fine_Sand}] > 15) \text{ AND } (\text{regime}[\text{Zone1a}, \text{Fine_Sand}] < 101) \text{ THEN } 1 \text{ ELSE } 0 \]

**ARRAY:** zone vs. grain type

**UNITS:** numerical

**VALUE:** range between 0 and 1; only +

**TYPE:** variable

**FUNCTION:** calculation

**LINKS:**
- Input: Regime
- Output: Effect amount gravel 1; Effect amount MCS 1; Effect amount FS 1

**DATA:** calculated from meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

The regimes are equal to the ones described in TABLE 4.

The description above only gives the equation for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

\[ R1_3[\text{Zone*}, \text{Fine_Sand}] = \text{IF} \ (\text{regime}[\text{Zone*}, \text{Fine_Sand}] > 15) \text{ AND } (\text{regime}[\text{Zone*}, \text{Fine_Sand}] < 101) \text{ THEN } 1 \text{ ELSE } 0 \]

Note: The equations for all other zones of fine sand are the same.

\[ R1_3[\text{Zone*}, \text{Medium_Coarse_Sand}] = \text{IF} \ (\text{regime}[\text{Zone*}, \text{Medium_Coarse_Sand}] > 15) \text{ AND } (\text{regime}[\text{Zone*}, \text{Medium_Coarse_Sand}] < 201) \text{ THEN } 1 \text{ ELSE } 0 \]

Note: The equations for all other zones of medium-coarse sand are the same.

\[ R1_3[\text{Zone*}, \text{Gravel}] = \text{IF} \ (\text{regime}[\text{Zone*}, \text{Gravel}] > 15) \text{ AND } (\text{regime}[\text{Zone*}, \text{Gravel}] < 201) \text{ THEN } 1 \text{ ELSE } 0 \]

Note: The equations for all other zones of gravel are the same.
7.2 R2_3
DEFINITION: Regime 2, which is different for the different grain size types
EQUATION:
\[ \text{IF}(\text{regime}[\text{Zone}^*,\text{Fine}_\text{Sand}]>100)\text{AND}(\text{regime}[\text{Zone}^*,\text{Fine}_\text{Sand}]<601) \text{ THEN } 1 \text{ ELSE } 0 \]
ARRAY: zone vs. grain type
UNITS: numerical
VALUE: range between 0 and 1; only +
TYPE: variable
FUNCTION: calculation
LINKS:
- Input: Regime
- Output: Effect amount gravel 2; Effect amount MCS 2; Effect amount FS 2
DATA: calculated from meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

The regimes are equal to the ones described in TABLE 4.

The description above only gives the equation for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

R2_3[Zone*,Fine_Sand] = IF (regime[Zone*,Fine_Sand]>100) AND (regime[Zone*,Fine_Sand]<601) THEN 1 ELSE 0

Note: The equations for all other zones of fine sand are the same.

R2_3[Zone*,Medium_Coarse_Sand] = IF (regime[Zone*,Medium_Coarse_Sand]>200) AND (regime[Zone*,Medium_Coarse_Sand]<601) THEN 1 ELSE 0

Note: The equations for all other zones of medium-coarse sand are the same.

R2_3[Zone*,Gravel] = IF (regime[Zone*,Gravel]>200) AND (regime[Zone*,Gravel]<751) THEN 1 ELSE 0

Note: The equations for all other zones of gravel are the same.
7.3 R3_3
 DEFINITION: Regime 3, which is different for the different grain size types
 EQUATION: IF (regime[Zone1a,Fine_Sand]>600) THEN 1 ELSE 0
 ARRAY: zone vs. grain type
 UNITS: numerical
 VALUE: range between 0 and 1; only +
 TYPE: variable
 FUNCTION: calculation
 LINKS:
 • Input: Regime
 • Output: Effect amount gravel 3; Effect amount MCS 3; Effect amount FS 3
 DATA: calculated from meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

The regimes are equal to the ones described in TABLE 4.

The description above only gives the equation for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

R3_3[Zone*,Fine_Sand] = IF (regime[Zone*,Fine_Sand]>600) THEN 1 ELSE 0

Note: The equations for all other zones of fine sand are the same.

R3_3[Zone*,Medium_Coarse_Sand] = IF (regime[Zone*,Medium_Coarse_Sand]>600) THEN 1 ELSE 0

Note: The equations for all other zones of medium-coarse sand are the same.

R3_3[Zone*,Gravel] = IF (regime[Zone*,Gravel]>750) THEN 1 ELSE 0

Note: The equations for all other zones of gravel are the same.

7.4 r continuous 3
 DEFINITION: Continuous regime (when the mean number of days between two trips is less than 15), which is similar for all grain size types
 EQUATION: IF (Mean_number_of_days_between_2_trips[Zone1a,Fine_Sand]<15) OR (regime[Zone1a,Fine_Sand]=0) THEN 1 ELSE 0
ARRAY: zone vs. grain type
UNIT: numerical
VALUE: range between 0 and 1; only +
TYPE: variable
FUNCTION: calculation
LINKS:
- Input: Regime; Mean number of days between 2 trips
- Output: Sum of effects amount gravel; Sum of effects amount MCS; Sum of effects amount FS
DATA: calculated from meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

The regimes are equal to the ones described in TABLE 4.

The description above only gives the equation for this variable for the fine sand grain type in Zone 1a. Here the equations for the other grain types and zones are described.

\[ R_{\text{continuous}_3}[\text{Zone}^*,\text{Fine\_Sand}] = \text{IF} \ (\text{Mean\_number\_of\_days\_between\_2\_trips}[\text{Zone}^*,\text{Fine\_Sand}]<15) \text{ OR } (\text{regime}[\text{Zone}^*,\text{Fine\_Sand}]=0) \text{ THEN } 1 \text{ ELSE } 0 \]

Note: The equations for all other zones of fine sand are the same.

\[ R_{\text{continuous}_3}[\text{Zone}^*,\text{Medium\_Coarse\_Sand}] = \text{IF} \ (\text{Mean\_number\_of\_days\_between\_2\_trips}[\text{Zone}^*,\text{Medium\_Coarse\_Sand}]<15) \text{ OR } (\text{regime}[\text{Zone}^*,\text{Medium\_Coarse\_Sand}]=0) \text{ THEN } 1 \text{ ELSE } 0 \]

Note: The equations for all other zones of medium-coarse sand are the same.

\[ R_{\text{continuous}_3}[\text{Zone}^*,\text{Gravel}] = \text{IF} \ (\text{Mean\_number\_of\_days\_between\_2\_trips}[\text{Zone}^*,\text{Gravel}]<15) \text{ OR } (\text{regime}[\text{Zone}^*,\text{Gravel}]=0) \text{ THEN } 1 \text{ ELSE } 0 \]

Note: The equations for all other zones of gravel are the same.

7.5 effect amount gravel 1

DEFINITION: Effect of the extraction of a certain amount of sediment on the gravel grain size fraction when regime 1_3 is valid
**EQUATION:** IF(R1_3[Zone1a,Fine_Sand]=1)THEN(((10^((-1*(10^(-5))*(Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000)+0.1867)+2.004))-101)/100)ELSE 0

**ARRAY:** zone vs. grain type

**UNITS:** numerical

**VALUE:** range between 0 and unlimited; +/-

**TYPE:** variable

**FUNCTION:** calculation

**LINKS:**
- Input: R1_3, Extraction per zone and type
- Output: Sum of effects amount gravel

**DATA:** calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

**GRAPH 48:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in fine sand habitats on the gravel grain size fraction of the sediment (when regime 1_3 is valid).

```
<table>
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<th>amount extracted (m³/month)</th>
<th>mean log effect</th>
</tr>
</thead>
<tbody>
<tr>
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<td>-10</td>
</tr>
<tr>
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<td>-8</td>
</tr>
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</tr>
<tr>
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<td>0</td>
</tr>
<tr>
<td>700000</td>
<td>2</td>
</tr>
<tr>
<td>800000</td>
<td>4</td>
</tr>
<tr>
<td>900000</td>
<td>6</td>
</tr>
</tbody>
</table>
```

**GRAPH 49:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in medium-coarse sand habitats on the gravel grain size fraction of the sediment (when regime 1_3 is valid).

**Note:** The equations for all other zones of fine sand are the same.
effect_amount_gravel_1[Zone*,Medium_Coarse_Sand] = IF(R1_3[Zone*,Medium_Coarse_Sand]=1)THEN(((10^((-6*(10^(-6))*(Extraction_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)+0.7964)+2.004))-101)/100)ELSE 0

Note: The equations for all other zones of medium-coarse sand are the same.

GRAPH 50: Mean (logarithmic) effect of the extraction of a certain amount of sediment in gravel habitats on the gravel grain size fraction of the sediment (when regime 1_3 is valid).

effect_amount_gravel_1[Zone*,Gravel] = IF(R1_3[Zone*,Gravel]=1)THEN(((10^((-2*(10^(-7))*(Extraction_per_zone_and_type[Zone*,Gravel]/1000000)-0.0324)+2.004))-101)/100) ELSE 0
Note: The equations for all other zones of gravel are the same.

7.6  effect amount MCS 1
DEFINITION: Effect of the extraction of a certain amount of sediment on the medium-coarse sand grain size fraction when regime 1_3 is valid
EQUATION: IF(R1_3[Zone1a,Fine_Sand]=1)THEN(\((10^((-2*(10^(-9))*((\text{Extraction\_per\_zone\_and\_type}[\text{Zone1a,Fine_Sand}]/1000000)^2))-(0.0001*(\text{Extraction\_per\_zone\_and\_type}[\text{Zone1a,Fine_Sand}]/1000000)))-0.0097)+2.004))-101)/100)ELSE 0
ARRAY: zone vs. grain type
UNITS: numerical
VALUE: range between 0 and unlimited; +/-
TYPE: variable
FUNCTION: calculation
LINKS:
- Input: R1_3; Extraction per zone and type
- Output: Sum of effects amount MCS
DATA: calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

GRAPH 51: Mean (logarithmic) effect of the extraction of a certain amount of sediment in fine sand habitats on the medium-coarse sand grain size fraction of the sediment (when regime 1_3 is valid).

![Graph showing the logarithmic effect of extraction on mean effect with equation $y = 2E-09x^2 - 0.0001x - 0.0097$ and $R^2 = 1$.]
**ANNEX 2: Sand and Gravel Extraction**

### Environment

The equations for all other zones of fine sand are the same.

**GRAPH 52:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in medium-coarse sand habitats on the medium-coarse sand grain size fraction of the sediment (when regime 1_3 is valid).

\[ y = -3E-06x - 0.3327 \]

\[ R^2 = 1 \]

**GRAPH 53:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in gravel habitats on the medium-coarse sand grain size fraction of the sediment (when regime 1_3 is valid).

\[ \text{effect}_{\text{amount}_\text{MCS}}_1[\text{Zone}^*,\text{Medium\_Coarse\_Sand}] = \text{IF}(\text{R1\_3}[\text{Zone}^*,\text{Medium\_Coarse\_Sand}]=1)\text{THEN}(((10^((-3*(10^(-6))*(\text{Extraction\_per\_zone\_and\_type}[\text{Zone}^*,\text{Medium\_Coarse\_Sand}]/1000000)-0.3327)+2.004))-101)/100)\text{ELSE} 0 \]

Note: The equations for all other zones of medium-coarse sand are the same.
effect_amount_MCS_1[Zone*,Gravel] = IF(R1_3[Zone*,Gravel]=1)THEN(((10^(-9*(10^(-7))* (Extraction_per_zone_and_type[Zone*,Gravel]/1000000)+0.0639)+2.004)-101)/100) ELSE 0

Note: The equations for all other zones of gravel are the same.

7.7 effect amount FS 1
DEFINITION: Effect of the extraction of a certain amount of sediment on the fine sand grain size fraction when regime 1_3 is valid
EQUATION: IF(R1_3[Zone1a,Fine_Sand]=1)THEN(((10^((-3*(10^(-21))*((Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000)^4))+(2*(10^(-15))*((Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000)^3))-(5*(10^(-10))*((Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000)^2))+(3*(10^(-5))*(Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000))+0.3643)+2.004))-101)/100)ELSE 0

ARRAY: zone vs. grain type

UNITs: numerical
VALUE: range between 0 and unlimited; +/-
TYPE: variable
FUNCTION: calculation
LINKS:
- Input: R1_3; Extraction per zone and type
- Output: Sum of effects amount FS

DATA: calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.
GRAPH 54: Mean (logarithmic) effect of the extraction of a certain amount of sediment in fine sand habitats on the fine sand grain size fraction of the sediment (when regime 1_3 is valid).

\[
y = -3 \times 10^{-21}x^4 + 2 \times 10^{-15}x^3 - 5 \times 10^{-10}x^2 + 3 \times 10^{-5}x + 0.3643
\]

\[
R^2 = 0.2187
\]

Note: The equations for all other zones of fine sand are the same.

GRAPH 55: Mean (logarithmic) effect of the extraction of a certain amount of sediment in fine sand habitats on the medium-coarse sand grain size fraction of the sediment (when regime 1_3 is valid).
ANNEX 2: Sand and Gravel Extraction

Environment

effect_amount_FS_1[Zone*,Medium_Coarse_Sand] = IF(R1_3[Zone*,Medium_Coarse_Sand]=1)THEN(((10^((-2*(10^(-6))*(Extraction_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)+0.8179)+2.004))-101)/100)ELSE 0

Note: The equations for all other zones of medium-coarse sand are the same.

GRAPH 56: Mean (logarithmic) effect of the extraction of a certain amount of sediment in fine sand habitats on the gravel grain size fraction of the sediment (when regime 1_3 is valid).

effect_amount_FS_1[Zone*,Gravel] = IF(R1_3[Zone*,Gravel]=1)THEN(((10^(((-9*(10^(-7))*(Extraction_per_zone_and_type[Zone*,Gravel]/1000000))-0.0242)+2.004))-101)/100) ELSE 0
Note: The equations for all other zones of gravel are the same.

7.8 effect amount gravel 2

**DEFINITION:** Effect of the extraction of a certain amount of sediment on the gravel grain size fraction when regime 2_3 is valid

**EQUATION:** IF(R2_3[Zone1a,Fine_Sand]=1)THEN(((10^((-1*(10^(-5))*(Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000) +0.1867)+2.004))-101)/100)ELSE 0

**ARRAY:** zone vs. grain type

**UNITS:** numerical

**VALUE:** range between 0 and unlimited; +/-

**TYPE:** variable

**FUNCTION:** calculation

**LINKS:**
- Input: R2_3; Extraction per zone and type
- Output: Sum of effects amount gravel

**DATA:** calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

**GRAPH 57:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in fine sand habitats on the gravel grain size fraction of the sediment (when regime 2_3 is valid).

![Graph showing the relationship between amount extracted (m³/month) and mean log effect.]

**EQUATION:**

\[
effect\_\_amount\_\_gravel\_2[\text{Zone}^*,\text{Fine Sand}] = IF(R2\_3[\text{Zone}^*,\text{Fine Sand}]=1)THEN(((10^((-1*(10^(-5))*(Extraction\_\_per\_\_zone\_\_and\_\_type[\text{Zone}^*,\text{Fine Sand}]\text{/1000000}) +0.1867)+2.004))-101)/100)ELSE 0
\]

Note: The equations for all other zones of fine sand are the same.
**GRAPH 58:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in medium-coarse sand habitats on the gravel grain size fraction of the sediment (when regime 2_3 is valid).

\[
y = -2E-25x^5 + 2E-19x^4 - 8E-14x^3 + 1E-08x^2 - 0,0008x + 17,396
\]

\[R^2 = 0,941\]

Note: The equations for all other zones of medium-coarse sand are the same.

**GRAPH 59:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in gravel habitats on the gravel grain size fraction of the sediment (when regime 2_3 is valid).
effect_amount__gravel_2[Zone*,Gravel] = IF(R2_3[Zone*,Gravel]=1)THEN(((10^ (((-9*(10^(-21))*((Extraction_per_zone_and_type[Zone*,Gravel]/1000000)^4))+(5*(10^(-15))*((Extraction_per_zone_and_type[Zone*,Gravel]/1000000)^3)))-(9*(10^(-10)) *((Extraction_per_zone_and_type[Zone*,Gravel]/1000000)^2))+(7*(10^(-5))*((Extraction_per_zone_and_type[Zone*,Gravel]/1000000)))-1.7417))+2.004))-101)/100) ELSE 0

Note: The equations for all other zones of gravel are the same.

7.9 effect amount MCS 2

**DEFINITION:** Effect of the extraction of a certain amount of sediment on the medium-coarse sand grain size fraction when regime 2_3 is valid

**EQUATION:** IF(R2_3[Zone1a,Fine_Sand]=1)THEN(((10^(((2*(10^(-9))*((Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000)^2))-(0.0001*((Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000))-0.0097)+2.004))-101)/100)) ELSE 0

**ARRAY:** zone vs. grain type

**UNITS:** numerical

**VALUE:** range between 0 and unlimited; +/-

**TYPE:** variable

**FUNCTION:** calculation

**LINKS:**
- Input: R2_3; Extraction per zone and type
- Output: Sum of effects amount MCS

**DATA:** calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.
GRAPH 60: Mean (logarithmic) effect of the extraction of a certain amount of sediment in fine sand habitats on the medium-coarse sand grain size fraction of the sediment (when regime 2_3 is valid).

\[
y = 2 \times 10^{-9}x^2 - 0.0001x - 0.0097
\]
\[
R^2 = 1
\]

```
effect_amount__MCS_2[Zone*,Fine_Sand] = IF(R2_3[Zone*,Fine_Sand]=1)\(\frac{10^\left((2*(10^-9))^2-(0.0001-(0.0097)+2.004))-101\right)}{100})\) ELSE 0
```

Note: The equations for all other zones of fine sand are the same.

GRAPH 61: Mean (logarithmic) effect of the extraction of a certain amount of sediment in medium-coarse sand habitats on the medium-coarse sand grain size fraction of the sediment (when regime 2_3 is valid).
ANNEX 2: Sand and Gravel Extraction

**Environment**

**ANNEX 2: Sand and Gravel Extraction**

**effect_amount__MCS_2[Zone*,Medium_Coarse_Sand] = IF(R2_3[Zone*,Medium_Coarse_Sand]=1)THEN(((10^((4*(10^(-26))*((Extraction_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)^5))-(4*(10^(-20))*((Extraction_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)^4))+(1*(10^(-14))*((Extraction_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)^3))-(2*(10^(-9))*((Extraction_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)^2))+(0.0001*(Extraction_per_zone_and_type[Zone*,Medium_Coarse_Sand]/10000000))-2.0977)+2.004))-101)/100) ELSE 0

Note: The equations for all other zones of medium-coarse sand are the same.

**GRAPH 62:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in gravel habitats on the medium-coarse sand grain size fraction of the sediment (when regime 2_3 is valid).

![Graph 62](image)

**effect_amount__MCS_2[Zone*,Gravel] = IF(R2_3[Zone*,Gravel]=1)THEN(((10^((2*(10^(-24))*((Extraction_per_zone_and_type[Zone*,Gravel]/1000000)^5))-(1*(10^(-18))*((Extraction_per_zone_and_type[Zone*,Gravel]/1000000)^4))+(3*(10^(-13))*((Extraction_per_zone_and_type[Zone*,Gravel]/1000000)^3))-(3*(10^(-8))*((Extraction_per_zone_and_type[Zone*,Gravel]/1000000)^2))+(0.0013*(Extraction_per_zone_and_type[Zone*,Gravel]/1000000))-19.13)+2.004))-101)/100) ELSE 0

Note: The equations for all other zones of gravel are the same.
7.10 effect amount FS 2

**DEFINITION:** Effect of the extraction of a certain amount of sediment on the fine sand grain size fraction when regime 2_3 is valid

**EQUATION:** IF(R2_3[Zone1a,Fine_Sand]=1)THEN(((10^((-3*(10^(-21))*(Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000)^4))+(2*(10^(-15))*(Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000)^3))-(5*(10^(-10))*(Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000)^2)+(3*(10^(-5))*(Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000))+0.3643)+2.004)-101)/100)) ELSE 0

**ARRAY:** zone vs. grain type

**UNITS:** numerical

**VALUE:** range between 0 and unlimited; +/-

**TYPE:** variable

**FUNCTION:** calculation

**LINKS:**
- Input: R2_3; Extraction per zone and type
- Output: Sum of effects amount FS

**DATA:** calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

**GRAPH 63:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in fine sand habitats on the fine sand grain size fraction of the sediment (when regime 2_3 is valid).

\[
y = -3E-21x^4 + 2E-15x^3 - 5E-10x^2 + 3E-05x + 0.3643
\]

\[R^2 = 0.2187\]

**effect_amount__FS_2[Zone*,Fine_Sand] = IF(R2_3[Zone*,Fine_Sand]=1)THEN(((10^((-3*(10^(-21))*(Extraction_per_zone_and_type[Zone*,Fine_Sand]/1000000)^4))+(2*(10^(-15))*(Extraction_per_zone_and_type[Zone*,Fine_Sand]/1000000)^3))-(5*(10^(-10))*(Extraction_per_zone_and_type[Zone*,Fine_Sand]/1000000)^2)+(3*(10^(-5))*(Extraction_per_zone_and_type[Zone*,Fine_Sand]/1000000))+0.3643)+2.004)-101)/100)) ELSE 0**
\[-5*(10^{-10})*(\text{Extraction per zone and type}[\text{Zone}^*, \text{Fine Sand}]/1000000)^2) + (3*(10^{-5})*(\text{Extraction per zone and type}[\text{Zone}^*, \text{Fine Sand}]/1000000) + 0.3643) + 2.004) - 101)/100) \] ELSE 0

Note: The equations for all other zones of fine sand are the same.

**GRAPH 64:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in medium-coarse sand habitats on the fine sand grain size fraction of the sediment (when regime 2_3 is valid).

\[
y = -1E-25x^5 + 1E-19x^4 - 3E-14x^3 + 4E-09x^2 - 0.0002x + 4.0836
\]

\[R^2 = 0.9306\]

**GRAPH 65:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in gravel habitats on the fine sand grain size fraction of the sediment (when regime 2_3 is valid).

\[
\text{effect amount }_{\text{FS}_2}[\text{Zone}^*, \text{Medium Coarse Sand}] = \begin{cases} \text{IF}(R2_3[\text{Zone}^*, \text{Medium Coarse Sand}] = 1) \text{THEN} ((10^((-1*(10^{-25}))*((\text{Extraction per zone and type}[\text{Zone}^*, \text{Medium Coarse Sand}]/1000000)^5)) + (1*(10^{-19}))*((\text{Extraction per zone and type}[\text{Zone}^*, \text{Medium Coarse Sand}]/1000000)^4) - (3*(10^{-14}))*((\text{Extraction per zone and type}[\text{Zone}^*, \text{Medium Coarse Sand}]/1000000)^3)) + (4*(10^{-9}))*((\text{Extraction per zone and type}[\text{Zone}^*, \text{Medium Coarse Sand}]/1000000)^2)) - 0.0002*(\text{Extraction per zone and type}[\text{Zone}^*, \text{Medium Coarse Sand}]/1000000) + 4.0836 + 2.004) - 101)/100) & \text{ELSE 0} \\
\end{cases}
\]

Note: The equations for all other zones of medium-coarse sand are the same.
effect_amount__FS_2[Zone*,Gravel] = IF(R2_3[Zone*,Gravel]=1)THEN((((((6*(10^(-20))*((Extraction_per_zone_and_type[Zone*,Gravel]/1000000)^4))-(3*(10^(-14))*((Extraction_per_zone_and_type[Zone*,Gravel]/1000000)^3))+(6*(10^(-9))*((Extraction_per_zone_and_type[Zone*,Gravel]/1000000)^2))-(0.0005*((Extraction_per_zone_and_type[Zone*,Gravel]/1000000))+9.9168)))+2.004))-101)/100) ELSE 0

Note: The equations for all other zones of gravel are the same.

7.11 effect amount gravel 3

DEFINITION: Effect of the extraction of a certain amount of sediment on the gravel grain size fraction when regime 3_3 is valid

EQUATION: IF(R3_3[Zone1a,Fine_Sand]=1)THEN((((10^((-1*(10^(-5))*(Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000)+0.1867)+2.004))-101)/100)ELSE 0

ARRAY: zone vs. grain type

UNIT: numerical

VALUE: range between 0 and unlimited; +/-

TYPE: variable

FUNCTION: calculation

LINKS:
- Input: R3_3; Extraction per zone and type
- Output: Sum of effects amount gravel

DATA: calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.
GRAPH 66: Mean (logarithmic) effect of the extraction of a certain amount of sediment in fine sand habitats on the gravel grain size fraction of the sediment (when regime 3_3 is valid).

\[
effect_{\text{amount_gravel}_3[\text{Zone*},\text{Fine_Sand}]} = \text{IF}(R3_3[\text{Zone*},\text{Fine_Sand}]=1)\text{THE}N(((10^{-(-1*(10^{-(-5)}))*(\text{Extraction_per_zone_and_type[Zone*},\text{Fine_Sand]}/100000)+(0.1867)+2.004))-101)/100)\text{ELSE} 0
\]

Note: The equations for all other zones of fine sand are the same.

GRAPH 67: Mean (logarithmic) effect of the extraction of a certain amount of sediment in medium-coarse sand habitats on the gravel grain size fraction of the sediment (when regime 3_3 is valid).

\[
effect_{\text{amount_gravel}_3[\text{Zone*},\text{Medium_Coarse_Sand}]} = \text{IF}(R3_3[\text{Zone*},\text{Medium_Coarse_Sand}]=1)\text{THEN}(((10^{-(-3*(10^{-(-16)})}))((\text{Extraction_per_zone_and_type[Zon}}}})
\]
ANNEX 2: Sand and Gravel Extraction

Note: The equations for all other zones of medium-coarse sand are the same.

GRAPH 68: Mean (logarithmic) effect of the extraction of a certain amount of sediment in gravel habitats on the gravel grain size fraction of the sediment (when regime 3_3 is valid).

```
\[
\text{effect\_amount\_gravel\_3[Zone*,Gravel] = IF(R3\_3[Zone*,Gravel]=1)THEN(((10^(((2*(10^(-9))*((Extraction\_per\_zone\_and\_type[Zone1a,Fine\_Sand]/1000000)^2))-(0.0001*((Extraction\_per\_zone\_and\_type[Zone1a,Fine\_Sand]/1000000))-0.0097)+2.004))-101)/100)) ELSE 0
\]
```

Note: The equations for all other zones of gravel are the same.

7.12 effect amount MCS 3

**DEFINITION:** Effect of the extraction of a certain amount of sediment on the medium-coarse sand grain size fraction when regime 3_3 is valid

**EQUATION:** IF(R3_3[Zone1a,Fine_Sand]=1)THEN(((10^(((2*(10^(-9))*((Extraction\_per\_zone\_and\_type[Zone1a,Fine\_Sand]/1000000)^2))-(0.0001*((Extraction\_per\_zone\_and\_type[Zone1a,Fine\_Sand]/1000000))-0.0097)+2.004))-101)/100)) ELSE 0

**ARRAY:** zone vs. grain type

**UNITS:** numerical

**VALUE:** range between 0 and unlimited; +/-

**TYPE:** variable
**FUNCTION:** calculation

**LINKS:**
- Input: R3_3; Extraction per zone and type
- Output: Sum of effects amount MCS

**DATA:** calculated in meta-analysis

For more information on the methodology of the meta-analysis see subsection 2.1.

**GRAPH 69:** Mean (logarithmic) effect of a certain amount of sediment in fine sand habitats on the medium-coarse grain size fraction of the sediment (when regime 3_3 is valid).

![Graph 69](image)

$$\text{effect}_\text{amount}_\text{MCS}_3[\text{Zone}^*, \text{Fine}_\text{Sand}] = \text{IF}(R3_3[\text{Zone}^*, \text{Fine}_\text{Sand}]=1)\text{THEN}(\left((10^\text{y})\left((2\times10^{-9})\times(\text{Extraction}_\text{per}_\text{zone}_\text{and}_\text{type}[\text{Zone}^*, \text{Fine}_\text{Sand}]/1000000)^2\right)-0.0001\times(\text{Extraction}_\text{per}_\text{zone}_\text{and}_\text{type}[\text{Zone}^*, \text{Fine}_\text{Sand}]/1000000)-0.0097+2.004)\times100)/100) \text{ ELSE } 0$$

Note: The equations for all other zones of fine sand are the same.

**GRAPH 70:** Mean (logarithmic) effect of a certain amount of sediment in medium-coarse sand habitats on the medium-coarse grain size fraction of the sediment (when regime 3_3 is valid).
ANNEX 2: Sand and Gravel Extraction

**Environment**

M-CS regime 3_3

\[ y = 4 \times 10^{-11} x^2 - 2 \times 10^{-5} x + 1.0891 \]

\[ R^2 = 0.9998 \]

**GRAPH 71:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in gravel habitats on the medium-coarse grain size fraction of the sediment (when regime 3_3 is valid).

**Note:** The equations for all other zones of medium-coarse sand are the same.

\[ \text{effect_amount_MCS}_3[\text{Zone}^*,\text{Medium_Coarse_Sand}] = \begin{cases} 
\text{IF}(\text{R3}_3[\text{Zone}^*,\text{Medium_Coarse_Sand}] = 1) & \text{THEN}((10^((4\times(10^{-11})\times(\text{Extraction_per_zone_and_type}[\text{Zone}^*,\text{Medium_Coarse_Sand}]\div1000000)^2))-(2\times(10^{-5})\times(\text{Extraction_per_zone_and_type}[\text{Zone}^*,\text{Medium_Coarse_Sand}]\div1000000)+1.0891)+2.004)-101)/100) \end{cases} \text{ELSE 0} \]

**GRAPH 72:**

**GRAPH 71:**

**GRAPH 72:**

**Note:** The equations for all other zones of medium-coarse sand are the same.

\[ \text{effect_amount_MCS}_3[\text{Zone}^*,\text{Gravel}] = \begin{cases} 
\text{IF}(\text{R3}_3[\text{Zone}^*,\text{Gravel}] = 1) & \text{THEN}((10^((2 \times(10^{-6})\times(\text{Extraction_per_zone_and_type}[\text{Zone}^*,\text{Gravel}]\div1000000)-0.5183)+2.004)-101)/100) \end{cases} \text{ELSE 0} \]
Note: The equations for all other zones of gravel are the same.

7.13  effect amount FS 3  

**DEFINITION:** Effect of the extraction of a certain amount of sediment on the fine sand grain size fraction when regime 3_3 is valid  

**EQUATION:**  
\[
\text{IF}(R3_{-3}[\text{Zone1a,Fine_Sand}]=1) \text{THEN} \left((10^\left((-3*(10^{-21})*\left(\frac{\text{Extraction_per_zone_and_type[Zone1a,Fine_Sand]}}{1000000}\right)^4\right) + (2*(10^{-15})*\left(\frac{\text{Extraction_per_zone_and_type[Zone1a,Fine_Sand]}}{1000000}\right)^3\right) - (5*(10^{-10})*\left(\frac{\text{Extraction_per_zone_and_type[Zone1a,Fine_Sand]}}{1000000}\right)^2\right) + (3*(10^{-5})*\left(\frac{\text{Extraction_per_zone_and_type[Zone1a,Fine_Sand]}}{1000000}\right) + 0.3643) + 2.004) - 101)/100) \text{ ELSE } 0
\]

**ARRAY:** zone vs. grain type  

**UNITS:** numerical  

**VALUE:** range between 0 and unlimited; +/−  

**TYPE:** variable  

**FUNCTION:** calculation  

**LINKS:**  
- Input: R3_{-3}; Extraction per zone and type  
- Output: Sum of effects amount FS  

**DATA:** calculated in meta-analysis  

For more information on the methodology of the meta-analysis see subsection 2.1.

**GRAPH 72:** Mean (logarithmic) effect of the extraction of a certain amount of sediment in fine sand habitats on the fine sand grain size fraction of the sediment (when regime 3_3 is valid).

![Graph showing the mean log effect of sediment extraction on fine sand grain size fraction](image)

**FINE SAND: all regimes**  

\[
y = -3\times10^{-21}x^4 + 2\times10^{-15}x^3 - 5\times10^{-10}x^2 + 3\times10^{-5}x + 0.3643  
\]

\[
R^2 = 0.2187
\]
effect_amount_FS_3[Zone*,Fine_Sand] = IF(R3_3[Zone*,Fine_Sand]=1)THEN(((10^((-3*(10^(-21))*((Extraction_per_zone_and_type[Zone*,Fine_Sand]/1000000)^4))+(2*(10^(-15))*((Extraction_per_zone_and_type[Zone*,Fine_Sand]/1000000)^3)) - (5*(10^(-10))*((Extraction_per_zone_and_type[Zone*,Fine_Sand]/1000000)^2))+(3*(10^(-5))*((Extraction_per_zone_and_type[Zone*,Fine_Sand]/1000000))+0.3643)+2.004))-101)/100)) ELSE 0

Note: The equations for all other zones of fine sand are the same.

GRAPH 73: Mean (logarithmic) effect of the extraction of a certain amount of sediment in medium-coarse sand habitats on the fine sand grain size fraction of the sediment (when regime 3_3 is valid).

effect_amount_FS_3[Zone*,Medium_Coarse_Sand] =IF(R3_3[Zone*,Medium_Coarse_Sand]=1)THEN(((10^((2*(10^(-16))*((Extraction_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)^3))-(1*(10^(-10))*((Extraction_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000)^2))+(2*(10^(-5))*((Extraction_per_zone_and_type[Zone*,Medium_Coarse_Sand]/1000000))+0.6119)+2.004))-101)/100)ELSE0

Note: The equations for all other zones of medium-coarse sand are the same.

GRAPH 74: Mean (logarithmic) effect of the extraction of a certain amount of sediment in gravel habitats on the fine sand grain size fraction of the sediment (when regime 3_3 is valid).
**ANNEX 2: Sand and Gravel Extraction**

**Environment**

**7.14 sum of effects of amount gravel**

**DEFINITION:** Sum of the effects of the extraction of a certain amount of sediment for all regimes on the gravel grain size fraction

**EQUATION:** 

\[ \text{effect}_{\text{amount gravel}}_3[\text{Zone*},\text{Gravel}] = \text{IF}(R3_3[\text{Zone*},\text{Gravel}]=1)\text{THEN}(((10^((5*(10^-6))*(\text{Extraction per zone and type}[\text{Zone*},\text{Gravel}]/1000000)-0.8081)+2.004)-101)/100)\text{ELSE} 0 \]

**Note:** The equations for all other zones of gravel are the same.

**7.15 sum of effects of amount MCS**

**DEFINITION:** Sum of the effects of the extraction of a certain amount of sediment for all regimes on the medium-coarse sand grain size fraction
EQUATION: IF(R_continuous_3[Zone,Grain]=1) THEN 0 ELSE (SUM(effect_amount_MCS_1[Zone,Grain]+effect_amount_MCS_3[Zone,Grain]+effect_amount__MCS_2[Zone,Grain]))
ARRAY: zone vs. grain type
UNITS: numerical
VALUE: range between 0 and unlimited; +/-
TYPE: variable
FUNCTION: calculation
LINKS:
- Input: R continuous 3; Effect amount MCS 1; Effect amount MCS 2; Effect amount MCS 3
- Output: Decrease by extraction 2
DATA: calculated but not verifiable

7.16 sum of effects of amount FS
DEFINITION: Sum of the effects of the extraction of a certain amount of sediment for all regimes on the gravel grain size fraction
EQUATION: IF(R_continuous_3[Zone,Grain]=1) THEN 0 ELSE (SUM(effect_amount_FS_1[Zone,Grain]+effect_amount_FS_3[Zone,Grain]+effect_amount__FS_2[Zone,Grain]))
ARRAY: zone vs. grain type
UNITS: numerical
VALUE: range between 0 and unlimited; +/-
TYPE: variable
FUNCTION: calculation
LINKS:
- Input: R continuous 3; Effect amount FS 1; Effect amount FS 2; Effect amount FS 3
- Output: Decrease by extraction 3
DATA: calculated but not verifiable
Part 2:
Global change, Ecosystems and Biodiversity

Annex 3

BALANS
BALANCING IMPACTS OF HUMAN ACTIVITIES
IN THE NORTH SEA

EV/21

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Prof. Dr. Colin Janssen, Laboratory for Biological Research in Aquatic Pollution, University Gent
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Ir. D. Leroy, Ecolas nv

February 2007
ANNEX 3:
SAND AND GRAVEL EXTRACTION
SOCIO-ECONOMY
1 ECONOMIC RESULT

1.6 aggregate price
DATA:
- Source: Communication L. Vandekerckhove (August 2006)
- Dataset: range between 3 and 5 EUR/m³ (independent of grain type; dependent of landing facility)

1.10 fee rate
DATA:
- Source: Royal Decree of 01/09/2004 concerning the conditions, the geographical delimitation and the allocation procedure of the concessions for the exploration and the exploitation of mineral and other non-living resources in the territorial sea and on the continental shelf (RD 01/09/2004)
- Dataset:

<table>
<thead>
<tr>
<th>Zone</th>
<th>Fine sand (€)</th>
<th>Medium-coarse sand (€)</th>
<th>Gravel (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1a</td>
<td>0.54</td>
<td>0.54</td>
<td>1.14</td>
</tr>
<tr>
<td>Zone 1b</td>
<td>0.54</td>
<td>0.54</td>
<td>1.14</td>
</tr>
<tr>
<td>Zone 2a</td>
<td>0.54</td>
<td>0.54</td>
<td>1.14</td>
</tr>
<tr>
<td>Zone 2b</td>
<td>0.54</td>
<td>0.54</td>
<td>1.14</td>
</tr>
<tr>
<td>Zone 2c</td>
<td>0.54</td>
<td>0.54</td>
<td>1.14</td>
</tr>
<tr>
<td>Zone 3a</td>
<td>0.35</td>
<td>0.35</td>
<td>1.14</td>
</tr>
<tr>
<td>Zone 3b</td>
<td>0.35</td>
<td>0.35</td>
<td>1.14</td>
</tr>
<tr>
<td>Zone 4</td>
<td>0.54</td>
<td>0.54</td>
<td>1.14</td>
</tr>
</tbody>
</table>

1.11 adaptation coefficient
DATA: calculated but not verifiable
2 VARIABLE COST

2.7 average loading capacity per fleet type

DATA:
- Data: Fleet A (1266 m³); Fleet B (3903 m³)

<table>
<thead>
<tr>
<th></th>
<th>Average loading capacity (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleet A</td>
<td>1266</td>
</tr>
<tr>
<td>Fleet B</td>
<td>3903</td>
</tr>
</tbody>
</table>
2.9 fuel consumption extraction per vessel type

**DATA:**
- Source: Zeegra Vzw (2005)
- Data: Fleet A (350 l/h); Fleet B (400 l/h)

<table>
<thead>
<tr>
<th></th>
<th>Fuel consumption extraction (l/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleet A</td>
<td>350</td>
</tr>
<tr>
<td>Fleet B</td>
<td>400</td>
</tr>
</tbody>
</table>

2.10 time extraction per trip per vessel type

**DATA:**
- Source: Reimerswaal (May 2004); Zeegra vzw (2005)
- Dataset: Fleet A (1hr); Fleet B (1.5 hr)

2.12 fuel consumption sailing per vessel type

**DATA:**
- Source: Zeegra Vzw (2005)
- Dataset: Fleet A (0.05 l/m); Fleet B (0.075 l/m)

<table>
<thead>
<tr>
<th></th>
<th>Fuel consumption sailing (l/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleet A</td>
<td>0.050</td>
</tr>
<tr>
<td>Fleet B</td>
<td>0.075</td>
</tr>
</tbody>
</table>

2.13 fuel price

**DATA:**
- Dataset: 0.54 €/l (last update from 20/12/2005); 0.51 €/l (average 2005)

3 SEI-FIXED COST

3.6 maintenance ratio fleet B

**DATA:**
- Source: Expert judgement Ecolas
- Dataset: 0.02 (=2%)
3.7 **monthly maintenance cost per vessel type**

**DATA:**
- Source: Estimation by Ecolas based on interview Reimerswael (2004)
- Dataset: Fleet A (37,500 EUR/vessel); Fleet B (50,000 EUR/Vessel)

3.9 **cost per employee**

**DATA:**
- Source: Bel-First (database of financial data from Belgian corporations), Average cost per employee for the year 2002 for the following companies: ALGEMENE ZAND- EN GRINTHANDELMAATSCHAPPIJ ALZAGRI, BELMAGRI, CAMBEL AGREGATS, CHARLES KESTELEYN ZAND EN GRINTHANDEL, DEME BUILDING MATERIALS, GHENT DREDGING, HANSON AGGREGATES BELGIUM and INTERNATIONAL SAND AND GRAVEL
- Dataset: 4583 EUR/employee

3.10 **number of employees per vessel type**

**DATA:**
- Dataset: Fleet A (4 Employee/vessel); Fleet B (6 Employee/Vessel)

4 **FIXED COST**

4.6 **investment ratio fleet B**

**DATA:**
- Source: Expert judgement Ecolas
- Dataset: 0.02 (=2%)

4.9 **investment cost per vessel per vessel type**

**DATA:**
- Dataset: Fleet A (10,000,000 EUR); Fleet B (13,000,000 EUR)

4.10 **insurance rate**

**DATA:**
- Source: Expert judgement Ecolas
- Dataset: 0.075 (=7.5%)
4.11 economic lifetime

**DATA:**
- Source: Expert judgement Ecolas
- Dataset: 30 years

4.12 monthly interest rate

**DATA:** calculated but not verifiable

A one time investment cost can be expressed in **yearly costs** using the annuity formula:

\[
I_0 = \frac{r(1+r)^n}{(1+r)^n-1}
\]

Where:
- \(I_0\) = One time investment
- \(r\) = yearly real interest rate (= nominal interest rate corrected for inflation)
- \(n\) = economic lifetime of the investment in years

Example: investment cost for a vessel of 10 million euro with an economic lifetime of 30 years and applying an interest rate of 10% \(\Rightarrow\) yearly investment cost = 1.06 million euro.

A one time investment cost can be expressed in **monthly costs** using the same annuity formula, taking into account the following adaptations:
- \(n\) = economic lifetime of the investment in months (number of years * 12)
- \(r\) = real interest rate expressed per month

This monthly interest rate can be calculated starting from the yearly real interest rate:

\[
\frac{((1+(\text{yearly real interest rate}/12))^{12}-1)/12}{12}
\]

Example: investment cost for a vessel of 10 million euro with an economic lifetime of 30 years and applying a yearly interest rate of 10% \(\Rightarrow\) monthly interest rate: 0.8726% \(\Rightarrow\) monthly investment cost: 91259 euro
4.13 yearly real interest rate

**DATA:**

- Dataset: 0.1 (≈ 10%)
Part 2:
Global change, Ecosystems and Biodiversity

Annex 4

BALANS
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Ir. D. Leroy, Ecolas nv

February 2007
ANNEX 4:
SHRIMP FISCHERIES
DRIVING FORCE
1 SWEPT AREA

1.1 effort

**DATA:**
- **Source:** Ministry of the Flemish Community. Administration of the Agriculture and Horticulture. Department of Agriculture and Fishery Management – Sea Services Division (Period 2003-2005)
- **Dataset:** in hr (depending per month)

<table>
<thead>
<tr>
<th></th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>Average per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>366</td>
<td>230</td>
<td>103</td>
<td>233</td>
</tr>
<tr>
<td>Feb</td>
<td>86</td>
<td>143</td>
<td>71</td>
<td>100</td>
</tr>
<tr>
<td>Mrt</td>
<td>172</td>
<td>369</td>
<td>263</td>
<td>268</td>
</tr>
<tr>
<td>Apr</td>
<td>320</td>
<td>317</td>
<td>465</td>
<td>367</td>
</tr>
<tr>
<td>Mei</td>
<td>260</td>
<td>527</td>
<td>551</td>
<td>446</td>
</tr>
<tr>
<td>Jun</td>
<td>547</td>
<td>547</td>
<td>957</td>
<td>683</td>
</tr>
<tr>
<td>Jul</td>
<td>789</td>
<td>930</td>
<td>749</td>
<td>822</td>
</tr>
<tr>
<td>Aug</td>
<td>994</td>
<td>922</td>
<td>1006</td>
<td>974</td>
</tr>
<tr>
<td>Sep</td>
<td>997</td>
<td>834</td>
<td>713</td>
<td>848</td>
</tr>
<tr>
<td>Okt</td>
<td>972</td>
<td>1077</td>
<td>932</td>
<td>993</td>
</tr>
<tr>
<td>Nov</td>
<td>854</td>
<td>982</td>
<td>1009</td>
<td>948</td>
</tr>
<tr>
<td>Dec</td>
<td>733</td>
<td>938</td>
<td>750</td>
<td>807</td>
</tr>
</tbody>
</table>

1.4 speed

**DATA:**
- **Source:** Polet, 2003
- **Dataset:** 5093 m/h

1.5 width

**DATA:**
- **Source:** Polet, 2003
- **Dataset:** 7.65 m
1.6 shrimp density submodel

DATA:
- Dataset:

Numbers of shrimp per m²

<table>
<thead>
<tr>
<th>Length</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>1.5</td>
<td>0.000</td>
<td>0.610</td>
<td>0.067</td>
<td>0.000</td>
</tr>
<tr>
<td>2</td>
<td>0.045</td>
<td>1.627</td>
<td>0.494</td>
<td>0.043</td>
</tr>
<tr>
<td>2.5</td>
<td>0.037</td>
<td>2.435</td>
<td>1.144</td>
<td>0.210</td>
</tr>
<tr>
<td>3</td>
<td>0.138</td>
<td>2.914</td>
<td>1.048</td>
<td>0.482</td>
</tr>
<tr>
<td>3.5</td>
<td>0.441</td>
<td>2.823</td>
<td>0.978</td>
<td>0.516</td>
</tr>
<tr>
<td>4</td>
<td>0.534</td>
<td>1.558</td>
<td>0.763</td>
<td>0.389</td>
</tr>
<tr>
<td>4.5</td>
<td>0.410</td>
<td>0.738</td>
<td>0.487</td>
<td>0.229</td>
</tr>
<tr>
<td>5</td>
<td>0.356</td>
<td>0.434</td>
<td>0.300</td>
<td>0.117</td>
</tr>
<tr>
<td>5.5</td>
<td>0.226</td>
<td>0.363</td>
<td>0.206</td>
<td>0.070</td>
</tr>
<tr>
<td>6</td>
<td>0.167</td>
<td>0.116</td>
<td>0.170</td>
<td>0.051</td>
</tr>
<tr>
<td>6.5</td>
<td>0.071</td>
<td>0.026</td>
<td>0.073</td>
<td>0.022</td>
</tr>
<tr>
<td>7</td>
<td>0.011</td>
<td>0.006</td>
<td>0.017</td>
<td>0.005</td>
</tr>
<tr>
<td>7.5</td>
<td>0.001</td>
<td>0.001</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td>8</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>8.5</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>9</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

1.10 gs: gear selectivity

DATA:
- Source: Polet, 2003
- Dataset:

Definition:

Selectivity: The selection of fish by fishing gear in the widest possible sense, given in Wileman et al. (1996), is: the process which causes the catch of a gear to have a different composition from that of the fish population in the geographical area in which the gear is being used. There are many causes of these differences with chance playing a big part in the capture process. Gears will select by species and for each species there will also be size selection.

Also: Ability to target and capture fish by size and species during harvesting operations, allowing by-catch of juvenile fish and non-target species to escape
unharmed. In stock assessment, conventionally expressed as a relationship between retention and size (or age) with no reference to survival after escapement.

*Gear selection:* This process is described by the selectivity at the entrance of the gear, i.e. the net mouth.

*Application in the model:* For each species and each length class, the percentage of all animals in the trawl path that do not enter the gear.

**Unit:** % by species and length class

**Data:**

![Graph showing the relationship between percentage escaping and length class.](image)

\[ P_{Esc} = 0.0298 + 0.0014 \text{ LC} \]

\( P_{Esc} \): percentage escaping (%); \( \text{LC} \): Length class (mm)

More detailed data, inclusive confidence limits, are given in Polet (2003) but for practicability, a simple linear regression formula will be used.

**1.12 mrate swept escape**

**DATA:** between 0% and 100% but for the time being fixed at 1%
2 GEAR

2.1 ns standard: net selectivity

**DATA:**
- Source: Polet, 2003
- Dataset:

*Definition:* This process is described by the selectivity of the net (without cod-end).

*Application in the model:* For each species and each length class, the percentage of all animals entering the gear that escape through the net meshes (exclusive the cod-end).

*Unit:* % by species and length class

*Data:* For brown shrimps, detailed data are available (Polet, 2003).

PEsc: for simplicity, a linear model was fitted to the data in the ILVO-Fisheries database.

\[ PEsc = 0.9599 - 0.01362 \text{ LC} \]

with LC expressed in mm

2.3 mrate gear escape

**DATA:** between 0% and 100% but for the time being fixed at 1%

3 COD END

3.1 cs: cod end selectivity

**DATA:**
- Source: ILVO- Fisheries
- Dataset:

*Definition:* This process is described by the selectivity of the cod-end.

*Application in the model:* For each species and each length class, the percentage of all animals entering the cod-end that escapes through the cod-end meshes.
**Unit:** % by species and length class

**Data:** For brown shrimps, detailed data are available (Polet, 2003).

- Cod-end selection is usually represented by a selection curve \( r(l) \). \( r(l) \) is the probability that a fish of length \( l \) is retained in the cod-end, given it entered the cod-end. Often the logistic curve is used to describe cod-end selectivity (Wileman et al., 1996):

\[
r(l) = \frac{\exp(a + b*l)}{1 + \exp(a + b*l)}
\]

where \( a \) and \( b \) are the parameters to be estimated.

- Three other parameters are relevant:

  \( L50 \): the length at 50% retention = \(-a/b\)
  
  \( SR \): the selection range representing the slope of the curve = \(2.197/b\)
  
  \( SF \): the selection factor = \(L50/mesh \text{ size}\)

Based on these parameters, the \( a \) and \( b \) can be calculated for another mesh size.

- For a standard shrimp beam trawl, as used in the Belgian shrimp fishery, with a cod-end mesh opening of 20 mm, the parameters are:

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
<th>L50</th>
<th>SR</th>
<th>SF</th>
<th>Mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>-7.4622</td>
<td>0.1894</td>
<td>39.4 mm</td>
<td>11.6 mm</td>
<td>1.97</td>
<td>20 mm</td>
</tr>
</tbody>
</table>

Using the above mentioned formulae, the parameters can be calculated for e.g. a 30 mm cod-end mesh opening.

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
<th>L50</th>
<th>SR</th>
<th>SF</th>
<th>Mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>-11.1933</td>
<td>0.1894</td>
<td>59.1 mm</td>
<td>11.6 mm</td>
<td>1.97</td>
<td>30 mm</td>
</tr>
</tbody>
</table>

This selection curve can be used to calculate the numbers of shrimps caught and escaped for each length class.
3.3 mrate cod end escape

**DATA:** between 0% and 100% but for the time being fixed at 1%

4 FINAL CATCH

4.1 fs: fishermen’s selection

**DATA:**
- Source: ILVO- Fisheries
- Data:

**Definition:** The process where fishermen divide the catch into catch to be landed and discard.

**Application in the model:** For each species and each length class, the percentage of all animals retained and discarded by the crew.

**Unit:** % by species and length class

**Data:** Shrimps are processed on board through a rotating shrimp sieve. Each sieve has its typical selectivity properties which can be represented by a selection curve, along the same methodology as for the cod-end selectivity.

- An average selection curve was calculated for 5 shrimp trawlers:

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
<th>L50</th>
<th>SR</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20.96</td>
<td>0.43</td>
<td>48.7</td>
<td>5.1</td>
</tr>
</tbody>
</table>

4.3 mrate discard

**DATA:**
- Data: 25%
5 LANDINGs

5.1 weight per class
DATA:
• Dataset:

\[ W = 3.212 \times 10^{-6} \times TL^{3.178} \]
• \( W \) = fresh weight of a Brown Shrimp (g)
• TL = total length of a Brown Shrimp (cm)

5.4 processing
DATA: 0% - Not applicable for shrimp

5.9 total commerical biomass per month
DATA:
• Source: Ministry of the Flemish Community. Administration of the Agriculture and Horticulture. Department of Agriculture and Fishery Management – Sea Services Division (Period 2003-2005)
• Data: landings in kg for 7 vessels

<table>
<thead>
<tr>
<th></th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>Average per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>5,333.79</td>
<td>2,191.13</td>
<td>920.05</td>
<td>2,814.99</td>
</tr>
<tr>
<td>Feb</td>
<td>1,349.81</td>
<td>1,322.92</td>
<td>282.99</td>
<td>985.24</td>
</tr>
<tr>
<td>Mrt</td>
<td>1,353.83</td>
<td>2,403.12</td>
<td>1,160.79</td>
<td>1,639.24</td>
</tr>
<tr>
<td>Apr</td>
<td>2,931.75</td>
<td>4,322.90</td>
<td>4,528.68</td>
<td>3,927.78</td>
</tr>
<tr>
<td>Mei</td>
<td>3,129.12</td>
<td>12,771.43</td>
<td>9,668.72</td>
<td>8,523.09</td>
</tr>
<tr>
<td>Jun</td>
<td>6,735.51</td>
<td>12,710.36</td>
<td>16,265.93</td>
<td>11,903.93</td>
</tr>
<tr>
<td>Jul</td>
<td>13,816.98</td>
<td>19,667.75</td>
<td>13,525.00</td>
<td>15,669.91</td>
</tr>
<tr>
<td>Aug</td>
<td>31,202.63</td>
<td>22,194.56</td>
<td>24,692.75</td>
<td>26,029.98</td>
</tr>
<tr>
<td>Sep</td>
<td>34,543.16</td>
<td>23,042.92</td>
<td>20,685.75</td>
<td>26,090.61</td>
</tr>
<tr>
<td>Okt</td>
<td>29,800.04</td>
<td>24,725.60</td>
<td>31,558.69</td>
<td>28,694.78</td>
</tr>
<tr>
<td>Nov</td>
<td>12,971.44</td>
<td>13,155.73</td>
<td>23,562.02</td>
<td>16,563.07</td>
</tr>
<tr>
<td>Dec</td>
<td>9,205.11</td>
<td>8,212.33</td>
<td>11,707.28</td>
<td>9,708.24</td>
</tr>
<tr>
<td>Total per year</td>
<td>12,905.73</td>
<td>12,574.89</td>
<td>13,677.90</td>
<td></td>
</tr>
</tbody>
</table>
5.11 fish landings per unit of effort

**DATA:**
- Source: Ministry of the Flemish Community. Administration of the Agriculture and Horticulture. Department of Agriculture and Fishery Management – Sea Services Division (Period 2003-2005)
- Data: average 20.89 kg/hr

<table>
<thead>
<tr>
<th></th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>Average per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>14.57</td>
<td>9.53</td>
<td>8.93</td>
<td>11.67</td>
</tr>
<tr>
<td>Feb</td>
<td>15.70</td>
<td>9.25</td>
<td>3.99</td>
<td>10.22</td>
</tr>
<tr>
<td>Mrt</td>
<td>7.87</td>
<td>6.51</td>
<td>4.41</td>
<td>6.48</td>
</tr>
<tr>
<td>Apr</td>
<td>9.16</td>
<td>13.64</td>
<td>9.74</td>
<td>10.77</td>
</tr>
<tr>
<td>Mei</td>
<td>12.04</td>
<td>24.23</td>
<td>17.55</td>
<td>19.84</td>
</tr>
<tr>
<td>Jun</td>
<td>12.31</td>
<td>23.24</td>
<td>17.00</td>
<td>17.73</td>
</tr>
<tr>
<td>Jul</td>
<td>17.51</td>
<td>21.15</td>
<td>18.06</td>
<td>19.05</td>
</tr>
<tr>
<td>Aug</td>
<td>31.39</td>
<td>24.07</td>
<td>24.55</td>
<td>26.74</td>
</tr>
<tr>
<td>Sep</td>
<td>34.65</td>
<td>27.63</td>
<td>29.01</td>
<td>30.77</td>
</tr>
<tr>
<td>Okt</td>
<td>30.66</td>
<td>22.96</td>
<td>33.86</td>
<td>29.17</td>
</tr>
<tr>
<td>Nov</td>
<td>15.19</td>
<td>13.40</td>
<td>23.35</td>
<td>17.50</td>
</tr>
<tr>
<td>Dec</td>
<td>12.56</td>
<td>8.76</td>
<td>15.61</td>
<td>11.98</td>
</tr>
<tr>
<td>Average per year</td>
<td>21.84</td>
<td>19.31</td>
<td>21.69</td>
<td>20.89</td>
</tr>
</tbody>
</table>

5.12 shrimp size per class

**DATA:**
- Source: ILVO- Fisheries
- Data: 15, 25, 35, 45, 55, 65, 75, 85 (mm)
Part 2:
Global change, Ecosystems and Biodiversity

Annex 5

BALANS
BALANCING IMPACTS OF HUMAN ACTIVITIES
IN THE NORTH SEA

EV/21

Coordinator and promoter:
Prof. Dr. F. Maes, Maritime Institute, University Gent

Promotors:
Dr. Hans Polet, Institute for Agricultural and Fisheries Research
Prof. Dr. M. Vincx, Marine Biology Section, University Gent
Prof. Dr. Colin Janssen, Laboratory for Biological Research in Aquatic Pollution, University Gent
Ir. Serge Scory, Management Unit of the North Sea Mathematical Models
Ir. D. Leroy, Ecolas nv

February 2007
ANNEX 5:
SHRIMP FISCHERIES
ENVIRONMENT
1 MACROBENTHIC DENSITY AT THE FISHED SITE: STOCKS AND FLOWS

1.1 macrobenthos density

DATA:
- Source: MACRODAT database (Section Marine Biology); Van Hoey et al. (2004)
- Dataset: available at Section Marine Biology, University of Ghent

TABLE 1: Characterization of the species assemblages of the Belgian Continental Shelf (adapted from Van Hoey et al., 2004)

<table>
<thead>
<tr>
<th>Species assemblage</th>
<th>SA1</th>
<th>SA2</th>
<th>SA3</th>
<th>SA4</th>
<th>SA5</th>
<th>SA6</th>
<th>SA7</th>
<th>SA8</th>
<th>SA9</th>
<th>SA10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment type</td>
<td>FS</td>
<td>FS</td>
<td>MS</td>
<td>MS</td>
<td>MS</td>
<td>MS</td>
<td>FS</td>
<td>FS</td>
<td>FS</td>
<td>FS</td>
</tr>
<tr>
<td>Median grain size (µm)</td>
<td>219</td>
<td>208</td>
<td>268</td>
<td>274</td>
<td>333</td>
<td>409</td>
<td>219</td>
<td>243</td>
<td>230</td>
<td>248</td>
</tr>
<tr>
<td>Mud content (%)</td>
<td>5.8</td>
<td>4.3</td>
<td>1.9</td>
<td>0.4</td>
<td>0.2</td>
<td>0.3</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>-13</td>
<td>-8</td>
<td>-14</td>
<td>-12</td>
<td>-16</td>
<td>-15</td>
<td>-2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Species richness (#/m²)</td>
<td>30</td>
<td>18</td>
<td>13</td>
<td>7</td>
<td>8</td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Density</td>
<td>6432</td>
<td>2746</td>
<td>2017</td>
<td>402</td>
<td>304</td>
<td>190</td>
<td>135</td>
<td>482</td>
<td>101</td>
<td>983</td>
</tr>
<tr>
<td>Name</td>
<td>Abra alba-Mysella bidentata community</td>
<td>Type I SA</td>
<td>Type II SA</td>
<td>Type II SA</td>
<td>Type I SA</td>
<td>Nephys cirrosa community</td>
<td>Type I SA</td>
<td>Type II SA</td>
<td>Type I SA</td>
<td>Polyesteria-Glycera lapidum community</td>
</tr>
</tbody>
</table>
1.3 mortality rate
DATA:
- Source: Blackford (1997); Duplisea (1998)
- Dataset: Although several data for mortality rate of macrobenthos are circulating in literature, we chose the value of Blackford (1997) for deposit feeders and suspension feeders because these functional groups dominate in continental shelf ecosystems according to Silvert (1991). The value of Blackford (1997) is also determined for environmental conditions similar to the ones valid for the BPNS.

TABLE 2: Data on mortality rate found in literature

<table>
<thead>
<tr>
<th>Source</th>
<th>Mortality rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackford (1997)</td>
<td>- deposit feeders/suspension feeders 0.001/d 0.003/d</td>
</tr>
<tr>
<td>Duplisea (1998)</td>
<td>0.0014/d</td>
</tr>
<tr>
<td>Chosen value (Blackford, 1997)</td>
<td>0.001/d or 0.05/month</td>
</tr>
</tbody>
</table>

1.5 birth rate
DATA:
- Source: Sohma et al. (2001); Duplisea (1998); Ortiz & Wolff (2002)
- Dataset: Although several data for birth rate of macrobenthos are circulating in literature, we chose the value of Ortiz & Wolff (2002) because this value is also determined for environmental conditions similar to the ones valid for the BPNS (i.e. sandy habitats).

TABLE 3: Data on birth rate found in literature

<table>
<thead>
<tr>
<th>Source</th>
<th>Birth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sohma et al. (2001)</td>
<td>0.053/d</td>
</tr>
<tr>
<td>Duplisea (1998)</td>
<td>0.185/d</td>
</tr>
<tr>
<td>Ortiz &amp; Wolff (2002)</td>
<td>0.012/d</td>
</tr>
<tr>
<td>Chosen value (Ortiz &amp; Wolff, 2002)</td>
<td>0.012/d or 0.36/month</td>
</tr>
</tbody>
</table>

1.6 density for competition
DATA:
- Source: MACRODAT database (Section Marine Biology)
- Dataset: available at Section Marine Biology, University of Ghent
2 EFFECT OF FISHING

2.7 effect surface area c\text{r}  
DATA: calculated in meta-analysis  
For more information on the methodology of the meta-analysis see AnnexS&GEnvSofie.

GRAPH 3: Mean (logarithmic) effect of fishing a certain surface area, when the continuous regime is valid, on the macrobenthic density of the fished site.

\[ y = 0.0006x^2 - 0.0309x - 0.0639 \]

\[ R^2 = 0.3607 \]

2.8 effect surface area r  
DATA: calculated in meta-analysis  
For more information on the methodology of the meta-analysis see AnnexS&GEnvSofie.
GRAPH 1: Mean (logarithmic) effect of fishing a certain surface area, when regime 1 is valid, on the macrobenthic density of the fished site

\[ y = -0.0134x - 0.0134 \]
\[ R^2 = 0.6045 \]

GRAPH 2: Mean (logarithmic) effect of fishing a certain surface area, when regime 2 is valid, on the macrobenthic density of the fished site.

\[ y = -8E-05x - 0.13 \]
\[ R^2 = 0.0546 \]
3  SEDIMENT COMPOSITION AT THE FISHED SITE

The mean sediment composition at a fished site was deduced from the meta-analysis and was classified into three fractions: a fine sand fraction, a medium-coarse sand fraction and a gravel fraction. The equations for the fine sand fraction of the sediment at the fished site are given first. The equations for the medium-coarse sand fraction and gravel fraction of the sediment are given at the end of the annex (from 3.8 onwards).

3.1 sediment extraction site fs
DATA: Calculated from meta-analysis

TABLE 3: The initial value (%) of the sediment fractions present at the fished site (as deduced from meta-analysis).

<table>
<thead>
<tr>
<th>Sediment fraction</th>
<th>Initial value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>12.67</td>
</tr>
<tr>
<td>Medium-coarse sand</td>
<td>41.58</td>
</tr>
<tr>
<td>Fine sand</td>
<td>45.75</td>
</tr>
</tbody>
</table>

3.3 infilling rate fs
DATA: Calculated from meta-analysis
For more information on the methodology of the meta-analysis see AnnexS&GEnvSofie.

TABLE 4: The infilling rate of the sediment fractions present at the fished site (as deduced from meta-analysis).

<table>
<thead>
<tr>
<th>Sediment fraction</th>
<th>Infilling rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>1.0269</td>
</tr>
<tr>
<td>Medium-coarse sand</td>
<td>1.0183</td>
</tr>
<tr>
<td>Fine sand</td>
<td>1.0113</td>
</tr>
</tbody>
</table>

3.4 sand transport fs
DATA: Calculated from meta-analysis
For more information on the methodology of the meta-analysis see AnnexS&GEnvSofie.
TABLE 5: The sand transport rate of the sediment fractions present at the fished site (as deduced from meta-analysis).

<table>
<thead>
<tr>
<th>Sediment fraction</th>
<th>Sand transport rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>1.00548</td>
</tr>
<tr>
<td>Medium-coarse sand</td>
<td>1.0052</td>
</tr>
<tr>
<td>Fine sand</td>
<td>1.0083</td>
</tr>
</tbody>
</table>

3.6 effect of fishing fs
DATA: calculated in meta-analysis

For more information on the methodology of the meta-analysis see AnnexS&GEnvSofie.

GRAPH 4: Mean (logarithmic) effect of fishing a certain surface area, when the continuous regime is valid, on the fine sand fraction of the fished site sediment.

3.8 sediment extraction site MCS
DEFINITION: The percentage of the medium-coarse sand grain size fraction that is present in a fished area
EQUATION: sediment_extraction_site_MCS(t-dt)+(natural_input_3+increase_due_to_fishing_3-natural_decrease_by_transport_3-decrease_due_to_fishing_3)*dt
ARRAY: none
UNITS: %
VALUE: initial value = 41.58; range between 0 and unlimited; only +
TYPE: stock
FUNCTION: objective
LINKS:
- Input: Natural input MCS
- Output: Natural Decrease by transport MCS; Being influenced by fishing MCS; natural input MCS

DATA: Calculated from meta-analysis (see Annex)

See Table 3 above (subsection 3.1)

3.9 natural input MCS
DEFINITION: The percentage of the medium-coarse sand grain size fraction that is coming in the zone due to natural sediment transport processes

EQUATION: \( \text{infilling rate}_\text{MCS} \times \text{sediment extraction site}_\text{MCS} \)

ARRAY: none

UNITS: %

VALUE: range from 0 to unlimited; only +

TYPE: flow

FUNCTION: calculation

LINKS:
- Input: Infilling rate MCS; sediment extraction site MCS
- Output: Sediment extraction site MCS

DATA: calculated but not verifiable

3.10 infilling rate MCS
DEFINITION: The rate at which the medium-coarse sand grain size fraction is transported to an area

EQUATION: Constant

ARRAY: none

UNITS: numerical

VALUE: 1.0183

TYPE: parameter

FUNCTION: scenario

LINKS:
- Output: Natural input MCS

DATA: Calculated from meta-analysis (see Annex)

See TABLE 4 above (subsection 3.3)
3.11 sand transport MCS

**DEFINITION:** The rate at which the medium-coarse sand grain size fraction is transported away from an area.

**EQUATION:** constant

**ARRAY:** none

**UNITS:** numerical

**VALUE:** 1.0052

**TYPE:** parameter

**FUNCTION:** scenario

**LINKS:**
- Output: Natural decrease by transport MCS

**DATA:** Calculated from meta-analysis (see Annex)

For more information on the methodology of the meta-analysis see AnnexS&GEnvSofie.

See Table 5 above (subsection 3.4)

3.12 natural decrease by transport MCS

**DEFINITION:** The percentage of the medium-coarse sand grain size fraction that leaves the zone due to natural sediment transport processes.

**EQUATION:** \( \text{sand\_transport\_MCS} \times \text{sediment\_extraction\_site\_MCS} \)

**ARRAY:** none

**UNITS:** %

**VALUE:** range from 0 to unlimited; only +

**TYPE:** flow

**FUNCTION:** calculation

**LINKS:**
- Input: Sand transport MCS; Sediment extraction site MCS

**DATA:** calculated but not verifiable

3.13 effect of fishing MCS

**DEFINITION:** Effect of fishing a certain surface area on the percentage of the medium-coarse sand grain size type.

**EQUATION:** \( \left( \frac{10^\left(0.0406 \times \log(N(\text{Swept\_area})-0.0777)+2.004\right)-101}{100} \right) \)

**ARRAY:** none

**UNITS:** numerical

**VALUE:** range between 0 and unlimited; +/-
TYPE: variable
FUNCTION: calculation
LINKS:
- Input: Swept area from Driving Forces sub-model
- Output: Being influenced by fishing MCS
DATA: calculated in meta-analysis (see Annex)

For more information on the methodology of the meta-analysis see AnnexS&GEnvSofie.

GRAPH 5: Mean (logarithmic) effect of fishing a certain surface area, when the continuous regime is valid, on the medium-coarse sand fraction of the fished site sediment.

3.14 being influenced by fishing MCS
DEFINITION: The percentage of the medium-coarse sand grain size fraction that fills in or is removed from the fished area
EQUATION: (effect_of_fishing_MCS)*sediment_extraction_site_MCS
ARRAY: none
UNITS:%
VALUE: range from 0 to unlimited; +/-
TYPE: flow
FUNCTION: calculation
LINKS:
- Input: Effect of fishing MCS; Sediment extraction site MCS
DATA: calculated but not verifiable
3.15 sediment extraction site GR

**DEFINITION:** The percentage of the gravel grain size fraction that is present in a fished area

**EQUATION:** $\text{sediment\_extraction\_site\_GR}(t) + (\text{natural\_input\_GR + increase\_due\_to\_fishing\_GR}\ - \ \text{natural\_decrease\_by\_transport\_GR} - \ \text{decrease\_due\_to\_fishing\_GR}) \ dt$

**ARRAY:** none

**UNITS:** %

**VALUE:** initial value = 12.67; range between 0 and unlimited; only +

**TYPE:** stock

**FUNCTION:** objective

**LINKS:**
- Input: Natural input GR
- Output: Natural Decrease by transport GR; Being influenced by fishing GR; natural input GR

**DATA:** Calculated from meta-analysis (see Annex)

See Table 3 above (subsection 3.1)

3.16 natural input GR

**DEFINITION:** The percentage of the gravel grain size fraction that is coming in the zone due to natural sediment transport processes

**EQUATION:** $\text{infilling\_rate\_GR} \ \times \ \text{sediment\_extraction\_site\_GR}$

**ARRAY:** none

**UNITS:** %

**VALUE:** range from 0 to unlimited; only +

**TYPE:** flow

**FUNCTION:** calculation

**LINKS:**
- Input: Infilling rate GR; sediment extraction site GR
- Output: Sediment extraction site GR

**DATA:** calculated but not verifiable

3.17 infilling rate GR

**DEFINITION:** The rate at which the gravel grain size fraction is transported to an area

**EQUATION:** Constant

**ARRAY:** none
UNITS: numerical
VALUE: 1.0269
TYPE: parameter
FUNCTION: scenario
LINKS:
- Output: Natural input GR
DATA: Calculated from meta-analysis (see Annex)

See TABLE 4 above (subsection 3.3)

3.18 sand transport GR
DEFINITION: The rate at which the gravel grain size fraction is transported away from an area
EQUATION: constant
ARRAY: none
UNITS: numerical
VALUE: 1.00548
TYPE: parameter
FUNCTION: scenario
LINKS:
- Output: Natural decrease by transport GR
DATA: Calculated from meta-analysis (see Annex)

For more information on the methodology of the meta-analysis see AnnexS&GEnvSofie.

See Table 5 above (subsection 3.4)

3.19 natural decrease by transport GR
DEFINITION: The percentage of the gravel grain size fraction that leaves the zone due to natural sediment transport processes
EQUATION: sand_transport_GR*sediment_extraction_site_GR
ARRAY: none
UNITS: %
VALUE: range from 0 to unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:
• Input: Sand transport GR; Sediment extraction site GR

**DATA:** calculated but not verifiable

**3.20 effect of fishing GR**

**DEFINITION:** Effect of fishing a certain surface area on the percentage of the gravel grain size type.

**EQUATION:** 
\[
\frac{10^{((0.0127 \times \log(Swept\_area)) - 0.1204) + 2.004) - 101}}{100}
\]

**ARRAY:** none

**UNITS:** numerical

**VALUE:** range between 0 and unlimited; +/-

**TYPE:** variable

**FUNCTION:** calculation

**LINKS:**
- Input: Swept area from Driving Forces sub-model
- Output: Being influenced by fishing GR

**DATA:** calculated in meta-analysis (see Annex)

For more information on the methodology of the meta-analysis see AnnexS&GEnvSofie.

**GRAPH 6:** Mean (logarithmic) effect of fishing a certain surface area, when the continuous regime is valid, on the gravel fraction of the fished site sediment.

---

**3.21 being influenced by fishing GR**

**DEFINITION:** The percentage of the gravel grain size fraction that fills in or is removed from the fished area

**EQUATION:** 
\[
\text{effect\_of\_fishing\_GR} \times \text{sediment\_extraction\_site\_GR}
\]

**ARRAY:** none
UNITS: %
VALUE: range from 0 to unlimited; +/-
TYPE: flow
FUNCTION: calculation
LINKS:
  - Input: Effect of fishing GR; Sediment extraction site GR
DATA: calculated but not verifiable
SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY
(SPSD II)

Part 2:
Global change, Ecosystems and Biodiversity

Annex 6

BALANS
BALANCING IMPACTS OF HUMAN ACTIVITIES
IN THE NORTH SEA

EV/21

Coordinator and promotor:
Prof. Dr. F. Maes, Maritime Institute, University Gent

Promotors:
Dr. Hans Polet, Institute for Agricultural and Fisheries Research
Prof. Dr. M. Vincx, Marine Biology Section, University Gent
Prof. Dr. Colin Janssen, Laboratory for Biological Research in Aquatic Pollution, University Gent
Ir. Serge Scory, Management Unit of the North Sea Mathematical Models
Ir. D. Leroy, Ecolas nv

February 2007
ANNEX 6: 
SHRIMP FISCHERIES 
SOCIO-ECONOMY
1 ECONOMIC RESULT

1.5 fish price

DATA:
- Source: Ministry of the Flemish Community. Administration of the Agriculture and Horticulture. Department of Agriculture and Fishery Management – Sea Services Division (Period 1999-2005)
- Data: in Eur/kg

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Jan</td>
<td>4.58</td>
<td>4.31</td>
<td>3.21</td>
<td>8.06</td>
<td>4.30</td>
<td>5.72</td>
<td>5.39</td>
<td>4.68</td>
<td>4.86</td>
<td>6.60</td>
<td>5.17</td>
</tr>
<tr>
<td>Feb</td>
<td>6.52</td>
<td>5.01</td>
<td>8.25</td>
<td>5.15</td>
<td>5.93</td>
<td>5.26</td>
<td>4.23</td>
<td>6.20</td>
<td>4.92</td>
<td>5.72</td>
<td></td>
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<tr>
<td>Mrt</td>
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<td>5.00</td>
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<td>Apr</td>
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<td>6.79</td>
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<td>Mei</td>
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<td>6.65</td>
<td>7.90</td>
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<td>3.72</td>
<td>3.95</td>
<td>4.39</td>
<td>5.89</td>
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<tr>
<td>Jun</td>
<td>5.65</td>
<td>3.92</td>
<td>5.19</td>
<td>7.42</td>
<td>5.91</td>
<td>6.43</td>
<td>6.19</td>
<td>4.10</td>
<td>3.38</td>
<td>4.66</td>
<td>5.28</td>
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<tr>
<td>Jul</td>
<td>4.96</td>
<td>3.68</td>
<td>5.55</td>
<td>5.47</td>
<td>5.87</td>
<td>5.46</td>
<td>5.47</td>
<td>3.43</td>
<td>3.45</td>
<td>4.90</td>
<td>4.82</td>
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<tr>
<td>Aug</td>
<td>3.96</td>
<td>2.50</td>
<td>4.85</td>
<td>3.22</td>
<td>4.49</td>
<td>4.12</td>
<td>5.60</td>
<td>3.36</td>
<td>2.98</td>
<td>3.64</td>
<td>3.87</td>
</tr>
<tr>
<td>Sep</td>
<td>3.36</td>
<td>2.52</td>
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<td>3.58</td>
<td>3.44</td>
<td>2.66</td>
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<td>Okt</td>
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<td>1.84</td>
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<tr>
<td>Nov</td>
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<td>4.46</td>
<td>5.05</td>
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<td>3.21</td>
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<td>2.17</td>
<td>4.01</td>
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<tr>
<td>Dec</td>
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<td>4.58</td>
<td>7.21</td>
<td>6.14</td>
<td>5.61</td>
<td>5.41</td>
<td>4.63</td>
<td>4.18</td>
<td>5.66</td>
<td>4.31</td>
<td>5.16</td>
</tr>
<tr>
<td>Average per year</td>
<td>4.49</td>
<td>3.59</td>
<td>5.03</td>
<td>4.94</td>
<td>5.07</td>
<td>5.32</td>
<td>4.72</td>
<td>3.65</td>
<td>3.80</td>
<td>3.68</td>
<td>4.43</td>
</tr>
</tbody>
</table>
2 VARIABLE COST

2.3(& 2.4) trips per fish ground (inshore and offshore fish grounds)
DATA:
- Dataset: inshore 64 trips/month; offshore 19 trips/month (approximate values)

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Inshore fishery</td>
<td>70</td>
<td>67</td>
<td>47</td>
<td>68</td>
<td>55</td>
<td>53</td>
<td>62</td>
<td>69</td>
<td>75</td>
<td>79</td>
<td>64</td>
</tr>
<tr>
<td>Offshore fishery</td>
<td>23</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>24</td>
<td>21</td>
<td>20</td>
<td>24</td>
<td>26</td>
<td>18</td>
<td>19</td>
</tr>
</tbody>
</table>

(1) Inshore fishery during March to November; (2) Offshore fishery during December to February

2.8 fuel consumption fishing
DATA:
- Source: Personnal communication fishermen
- Data: 782 l/ 24hr or 38 l/hr

2.10 (&2.11) time fishing per trip (inshore and offshore fish grounds)
DATA:
- Data: inshore 9.5 hr/trip; offshore 16.4 hr/trip

<table>
<thead>
<tr>
<th>Year</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inshore fishery</td>
<td>9.41</td>
<td>9.72</td>
<td>9.49</td>
<td>9.54</td>
</tr>
<tr>
<td>Offshore fishery</td>
<td>15.23</td>
<td>16.65</td>
<td>18.08</td>
<td>16.44</td>
</tr>
</tbody>
</table>

(1) Inshore fishery during March to November; (2) Offshore fishery during December to February
2.12 fuel price
**DATA:**
- Data: in €/l

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.19</td>
<td>0.19</td>
<td>0.15</td>
<td>0.18</td>
<td>0.30</td>
<td>0.28</td>
<td>0.25</td>
<td>0.26</td>
<td>0.31</td>
<td>0.43</td>
</tr>
</tbody>
</table>

2.14 fuel consumption sailing
**DATA:**
- Source: Personnal communication fishermen
- Dataset: 2.3 l/km

2.15 & 2.16 average steamed distance per fish ground per trip
**DATA:**
- Source: Hans Polet - DVZ
- Dataset: inshore fish ground (18.5 km); offshore fish ground (46 km)

2.19 ratio turnover
**DATA:**
- Source: Ministry of the Flemish Community. Administration of the Agriculture and Horticulture. Department of Agriculture and Fishery Management – Sea Services Division (Period 2002)
- Data: (Estimation from data period 2002)

<table>
<thead>
<tr>
<th></th>
<th>Landings</th>
<th>Average shrimp price</th>
<th>Turnover</th>
<th>Personnel cost</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>84217</td>
<td>4.72</td>
<td>397504.24</td>
<td>88568</td>
<td>0.22</td>
</tr>
</tbody>
</table>

2.21 number of employees per vessel
**DATA:**
• Dataset: 3 employee/vessel

2.22 number of vessels in small fleet

**DATA:**
- Source: Ministry of the Flemish Community. Administration of the Agriculture and Horticulture. Department of Agriculture and Fishery Management – Sea Services Division
- Data: 7 vessels (subset of total)

2.24 ratio other costs

**DATA:**
- Source: Ministry of the Flemish Community. Administration of the Agriculture and Horticulture. Department of Agriculture and Fishery Management – Sea Services Division (based on year 2002)
- Dataset: ratio is 0.13

3 FIXED COST

3.3 monthly maintenance cost per vessel

**DATA:**
- Source: Ministry of the Flemish Community. Administration of the Agriculture and Horticulture. Department of Agriculture and Fishery Management – Sea Services Division (estimate based on year 2002)
- Dataset: 460 Eur/vessel

3.5 insurance rate

**DATA:**
- Source: Personnal communication Fortis Corporate Insurance nv
- Dataset: 0.0175 (=1.75%) estimate based on an investment cost of 800,000€ per vessel and the dimensions of the small fleet

3.6 investment cost per vessel

**DATA:**
- Source: Personnal communication fisher
- Dataset: 800000 EUR/vessel (based on the building cost of new shrimp vessel – traditional beam-trawler, 2006)

3.8 economic lifetime of a ship

**DATA:**
- Source: Expert judgement DVZ
• Data: 30 years

3.9 monthly interest rate

**DATA:** calculated but not verifiable

A one time investment cost can be expressed in **yearly costs** using the annuity formula:

\[ I_0 = \frac{r(1+r)^n}{(1+r)^n - 1} \]

- \( I_0 \) = One time investment
- \( r \) = yearly real interest rate (= nominal interest rate corrected for inflation)
- \( n \) = economic lifetime of the investment in years

Example: investment cost for a vessel of 10 million euro with an economic lifetime of 30 years and applying an interest rate of 10% => yearly investment cost = 1.06 million euro.

A one time investment cost can be expressed in **monthly costs** using the same annuity formula. Taking into account the following adaptations:
- \( n \) = economic lifetime of the investment in months (number of years * 12)
- \( r \) = real interest rate expressed per month

This monthly interest rate can be calculated starting from the yearly real interest rate:

\[ \left[\frac{(1+(\text{yearly real interest rate/12}))^{12}-1}{12}\right] \]

Example: investment cost for a vessel of 10 million euro with an economic lifetime of 30 years and applying a yearly interest rate of 10%  
- => monthly interest rate: 0.8726% 
- => monthly investment cost: 91259 euro

3.10 yearly real interest rate

**DATA:**
- Dataset: 0.1 (= 10%)
Part 2:
Global change, Ecosystems and Biodiversity

Annex 8

BALANS
BALANCING IMPACTS OF HUMAN ACTIVITIES
IN THE NORTH SEA

EV/21

Coordinator and promotor:
Prof. Dr. F. Maes, Maritime Institute, University Gent

Promotors:
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Prof. Dr. M. Vincx, Marine Biology Section, University Gent
Prof. Dr. Colin Janssen, Laboratory for Biological Research in Aquatic Pollution, University Gent
Ir. Serge Scory, Management Unit of the North Sea Mathematical Models
Ir. D. Leroy, Ecolas nv

February 2007
USER INPUTS
1. **SAND AND GRAVEL**

Table 1-1 Input parameters Sand and Gravel – General User Interface

<table>
<thead>
<tr>
<th>Name</th>
<th>Range or possible value</th>
<th>Default value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity of demand</td>
<td>[0.5; 10]</td>
<td>1</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Percentage of overlap</td>
<td>[0;1]</td>
<td>0</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Fuel price</td>
<td>[0;10]</td>
<td>0.54</td>
<td>EUR/l</td>
</tr>
<tr>
<td>Price of aggregates</td>
<td>[0;15] (for each zone)</td>
<td>4</td>
<td>EUR/m³</td>
</tr>
<tr>
<td>Manpower cost</td>
<td>[0;10,000]</td>
<td>4,583</td>
<td>EUR/person</td>
</tr>
</tbody>
</table>

Table 1-2 Input parameters for the Sand and Gravel thematic page ‘Driving Forces’

<table>
<thead>
<tr>
<th>Name</th>
<th>Range or possible value</th>
<th>Default value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quota over five years</td>
<td>[0;20,000,000]</td>
<td>15,000,000</td>
<td>m³</td>
</tr>
<tr>
<td>Critical Depth</td>
<td>[0;10]</td>
<td>4.0</td>
<td>m</td>
</tr>
<tr>
<td>Maximum number of trips per day and per vessel</td>
<td>[0;10]</td>
<td>2</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Regime of the zones</td>
<td>{0</td>
<td>1} for each of the zones, “1” means it is open for exploitation, 0 means it is closed</td>
<td>(1,1,0,1,1,1,0,0)</td>
</tr>
<tr>
<td>Extraction depth of gear</td>
<td>[0.1;1]</td>
<td>0.5</td>
<td>m</td>
</tr>
</tbody>
</table>
Table 1-3 Input parameters for the Sand and Gravel thematic page ‘Socio–economy’

<table>
<thead>
<tr>
<th>Name</th>
<th>Range or possible value</th>
<th>Default value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average loading capacity (×2)</td>
<td>[0;10,000]</td>
<td>1,266</td>
<td>m³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3,903</td>
<td></td>
</tr>
<tr>
<td>Fuel consumption while extracting (×2)</td>
<td>[0;1,000]</td>
<td>350</td>
<td>l/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Fuel consumption while sailing (×2)</td>
<td>[0;1,000]</td>
<td>0.05</td>
<td>l/m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.075</td>
<td></td>
</tr>
<tr>
<td>Time extraction per trip (×2)</td>
<td>[0;24]</td>
<td>1.0</td>
<td>h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Number of employees per vessel (×2)</td>
<td>[0;10]</td>
<td>4</td>
<td>person</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Monthly maintenance cost per vessel (×2)</td>
<td>[0;100,000]</td>
<td>37,500</td>
<td>EUR/mo</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50,000</td>
<td></td>
</tr>
<tr>
<td>Investment cost per vessel (×2)</td>
<td>[0;100,000,000]</td>
<td>10,000,000</td>
<td>EUR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13,000,000</td>
<td></td>
</tr>
<tr>
<td>Number of vessels in the fleet (×2)</td>
<td>[0;20]</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Investment ratio fleet B</td>
<td>[0;1]</td>
<td>0.02</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Maintenance ratio fleet B</td>
<td>[0;1]</td>
<td>0.02</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Insurance rate</td>
<td>[0;1]</td>
<td>0.075</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Economic lifetime</td>
<td>[0;50]</td>
<td>30</td>
<td>year</td>
</tr>
<tr>
<td>Yearly interest rate</td>
<td>[0;1]</td>
<td>0.1</td>
<td>Dimensionless</td>
</tr>
</tbody>
</table>

Table 1-4 Input parameters for the Sand and Gravel thematic page ‘Environment’

<table>
<thead>
<tr>
<th>Name</th>
<th>Range or possible value</th>
<th>Default value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth rate</td>
<td>[0;5]</td>
<td>0.36</td>
<td>Ind.m^2mo^-1</td>
</tr>
<tr>
<td>Mortality rate</td>
<td>[0;5]</td>
<td>0.05</td>
<td>Ind.m^2mo^-1</td>
</tr>
<tr>
<td>Density for competition</td>
<td>[0;10,000]</td>
<td>1,000</td>
<td>Ind.m^-2</td>
</tr>
</tbody>
</table>
2. SHRIMP FISHERIES

Table 2-1 Input parameters Shrimp Fisheries – General User Interface

<table>
<thead>
<tr>
<th>Name</th>
<th>Range or possible value</th>
<th>Default value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity of effort</td>
<td>[0;1.5]</td>
<td>1.0</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Mesh size</td>
<td>{20</td>
<td>30}</td>
<td>20</td>
</tr>
<tr>
<td>Fuel price</td>
<td>[0;10]</td>
<td>0.43</td>
<td>EUR/l</td>
</tr>
<tr>
<td>Discount on fuel price</td>
<td>[0;1]</td>
<td>0.0</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Fish price</td>
<td>[0;100]</td>
<td>4.43</td>
<td>EUR/kg</td>
</tr>
<tr>
<td>Subsidy on fish price</td>
<td>[0; 20.0]</td>
<td>0.0</td>
<td>EUR/kg</td>
</tr>
</tbody>
</table>

Table 2-2 Input parameters for the Shrimp fisheries thematic page ‘Driving Forces’

<table>
<thead>
<tr>
<th>Name</th>
<th>Range or possible value</th>
<th>Default value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swept escape rate</td>
<td>[0;1]</td>
<td>0.01</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Gear escape rate</td>
<td>[0;1]</td>
<td>0.01</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Cod end escape rate</td>
<td>[0;1]</td>
<td>0.01</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Discard rate</td>
<td>[0;1]</td>
<td>0.25</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Density intensity</td>
<td>[0;2]</td>
<td>1.00</td>
<td>Dimensionless</td>
</tr>
</tbody>
</table>

Table 2.3 Input parameters for the Shrimp fisheries thematic page ‘Socio-economy’

<table>
<thead>
<tr>
<th>Name</th>
<th>Range or possible value</th>
<th>Default value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trips per fish ground</td>
<td>[0;100]</td>
<td>65</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Fuel consumption while fishing</td>
<td>[0;100]</td>
<td>38.0</td>
<td>l/h</td>
</tr>
<tr>
<td>Fuel consumption while sailing</td>
<td>[0;100]</td>
<td>2.3</td>
<td>l/h</td>
</tr>
<tr>
<td>Average steamed distance per fish ground and per trip</td>
<td>[0;60]</td>
<td>18.5</td>
<td>km</td>
</tr>
<tr>
<td>Name</td>
<td>Range possible value</td>
<td>Default value</td>
<td>Unit</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>----------------------</td>
<td>---------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Time fishing per trip per fish ground</td>
<td>[0;24]</td>
<td>9.5</td>
<td>h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16.4</td>
<td></td>
</tr>
<tr>
<td>Number of employees per vessel</td>
<td>[0;10]</td>
<td>3</td>
<td>Person</td>
</tr>
<tr>
<td>Ratio turnover</td>
<td>[0;1]</td>
<td>0.22</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Ratio to other costs</td>
<td>[0;1]</td>
<td>0.15</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Monthly maintenance cost per vessel</td>
<td>[0;100,000]</td>
<td>460.00</td>
<td>EUR</td>
</tr>
<tr>
<td>Investment cost per vessel</td>
<td>[0;10,000,000]</td>
<td>800,000.00</td>
<td>EUR</td>
</tr>
<tr>
<td>Public help on investment</td>
<td>[0;10,000,000]</td>
<td>0.00</td>
<td>EUR</td>
</tr>
<tr>
<td>Insurance rate</td>
<td>[0;1]</td>
<td>0.0175</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Economic lifetime of a ship</td>
<td>[0;50]</td>
<td>30</td>
<td>Year</td>
</tr>
<tr>
<td>Yearly interest rate</td>
<td>[0;1]</td>
<td>0.1</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Number of vessels in small fleet</td>
<td>[1;25]</td>
<td>7</td>
<td>Dimensionless</td>
</tr>
</tbody>
</table>

Table 2-4 Input parameters for the Shrimp fisheries thematic page ‘Environment’
Part 2:
Global change, Ecosystems and Biodiversity

Annex 9

BALANS
BALANCING IMPACTS OF HUMAN ACTIVITIES
IN THE NORTH SEA

EV/21

Coordinator and promotor:
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Prof. Dr. Colin Janssen, Laboratory for Biological Research in Aquatic Pollution, University Gent
Ir. Serge Scory, Management Unit of the North Sea Mathematical Models
Ir. D. Leroy, Ecolas nv

February 2007
ANNEX 9: CONCEPTUAL MODEL SAND AND GRAVEL
Fig. 1. Sand and Gravel Conceptual Model for economic, social, environmental, and driving force aspects
The main goal of the socio-economical model is the calculation of the profit or loss due to the aggregate extraction activities. The general outlook of the socio-economical model is drawn in the figure below. It is a (mainly) demand driven business model. Starting from the driving forces components ‘demand’ and ‘quota’, the model calculates profit or losses for the whole sector. A description per component is given below.

Fig. 2. Sand and Gravel Conceptual Model for socio-economic model expanded
**AMOUNT OF SAND AND GRAVEL EXTRACTED (BLUE LINES)**

The amount of sand and gravel extracted is mainly driven by ‘demand’ and ‘quota’ (see ‘driving forces’). In the current market situation, the market price (compared with the variable cost on extracted sand and gravel) has no large influence on the amount of sand and gravel extracted. Price, variable cost and fee will only have an influence when importing sand and gravel from other areas (such as British CS) will be competitive (e.g. when Belgian fee should rise much).

**TOTAL COST (BLACK LINES)**

The total cost can be divided into variable costs, semi-fixed (or semi-variable) and fixed costs.

Variable costs vary directly with the activity (in this case the amount of sand and gravel extracted). Fixed costs (in the short term) stay equal when the activity changes. Semi-fixed components are partly variable and partly fixed.

The variable costs consist only of fuel cost and are driven by the total amount sand and gravel extracted, the extraction area and the characteristics of the vessel (loading capacity, etc.). The fuel cost per amount of sand and gravel extracted (unit cost) is influenced by the extraction area. The further the extraction area is from the port, the higher the unit cost price (fuel cost per m³ sand and gravel extracted). *Fuel price can be changed depending on the scenario.*

In this model the semi-fixed costs consist of personnel costs and maintenance costs. Since we have no data on how these semi-fixed costs vary with the amount extracted, in the model we assume them to be fixed.

In this model the fixed costs consist of investment costs and insurance costs. Investment costs can be expressed in equal annual costs using the annuity formula. The annual investment cost consists of depreciation and interest.

**TURNOVER (GREEN LINES)**

The turnover is calculated by simply multiplying the amount extracted with the price. *Sand and gravel price can be changed depending on the scenario.*

**FEE**

The fee is calculated by multiplying the unit fee with the amount extracted. *Unit fee can be changed depending on the scenario.*
PROFIT/LOSS (RED LINES)

The profit or loss is calculated by decreasing the turnover with the total cost and fee. When turnover is higher then the sum of total costs and fee, then there is a profit, when lower, then there is a loss.
Part 2:
Global change, Ecosystems and Biodiversity

Annex 10

BALANS
BALANCING IMPACTS OF HUMAN ACTIVITIES
IN THE NORTH SEA

EV/21

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Ir. D. Leroy, Ecolas nv

February 2007
ANNEX 10:
CONCEPTUAL MODEL
SCHRIMP FISHERIES
Fig. 1. Shrimp Fisheries Conceptual Model for economic, social, environmental, and driving force aspects

Flowchart fishery

- **Input**
  - Air pollution
  - Water pollution
  - Seafloor disturbance

- **Output**
  - **Swept area**
  - Animals in swept area
  - GS (gear selection)
  - Animals entering gear
  - NS (net selection)
  - Gross catch
  - FS (fishermen's selection)
  - Retained catch M
  - o/b Proc
  - Landings
  - Waste

- **Management**
  - TM (technical measures)
  - MLS (minimum landing size)
  - MMS (minimum mesh size)
  - Sel dev
  - Gear

- **Other driving forces**
  - Environment

- **Economics & employment**
  - Removals due to NM
  - NM
  - Im
  - influx
  - Im
  - SRR
  - SRR

- **E: effort**
  - GS: gear selection
  - FO: fishing gear operation
  - M: fishery
  - N: natality
  - NM: predation etc.; natural mortality
  - Gr: growth
  - MMS: minimum mesh size
  - MLS: minimum landing size
  - TM: technical measures

- **Perception of biomass**
  - OD: on board processing

- **Dead biomass**

**Legend**
- XXX: effect
- XXX: fluctuates randomly between most likely values
- ×: process

**Abbreviations**
- N: natality
- NM: predation etc.; natural mortality
- Gr: growth
- MMS: minimum mesh size
- MLS: minimum landing size
- TM: technical measures
- E: effort
- GS: gear selection
- FO: fishing gear operation
- SRR: stock recruitment relationship

SPSD II – Part 2 – Global change, ecosystems and biodiversity – North Sea
The socio-economical model calculates the profit or loss made by the local shrimp fisheries. The general outlook of the model is drawn in the figure below. The shrimp business is driven partly by availability and partly by the market price (which can be influenced by external parameters such as public help and the international price\(^1\)). Starting from the driving forces components ‘availability’ and ‘effort’ the model calculates profit or loss for the whole sector. A description per component is given below.

![Shrimp Fisheries Conceptual Model for socio-economic model expanded](image)

---

\(^1\) In the BALANS project the influence of the international market was not taken into account.
**Total Cost (Black Lines)**

The total cost is the summation of the variable and the fixed costs. The variable costs consist of fuel cost (sailing, fishing), personnel cost and other variable costs. The fuel cost is determined by the steamed distance (dependent on the fish ground), time fishing and the fuel price (inclusive public help). Fuel price can be changed depending on the scenario. Due to a lack of detailed information, both the personnel cost and the other variable costs are expressed as a certain percentage of the turnover. Other costs consist of fish gear, loading and unloading, ice, etc.

In this model the fixed costs consist of investment costs, maintenance cost and insurance costs. Investment costs can be expressed in equal annual costs using the annuity formula. The annual investment cost consists of depreciation and interest.

**Turnover (Green Lines)**

The turnover is calculated by simply multiplying the fish landings with the price. The fish price on the local market is determined by the fish landings (offer) and the public help (subsidies). The model does not include the influence of the international market on the local fish price.

**Profit/ Loss (Red Lines)**

The profit or loss is calculated by decreasing the turnover with the total cost. When turnover is higher then the total costs, then there is a profit, when lower, then there is a loss.
Annex 11

BALANS
BALANCING IMPACTS OF HUMAN ACTIVITIES
IN THE NORTH SEA

EV/21

Coordinator and promoter:
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Promotors:
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Prof. Dr. M. Vincx, Marine Biology Section, University Gent
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Ir. D. Leroy, Ecolas nv

February 2007
ANNEX 11: ECOTOXICOLOGY

Scientific report:
Summary of main results and conclusions

Laboratory of Environmental Toxicology and Aquatic Ecology

Vincent Dufour and Colin Janssen
1 INTRODUCTION

As stated in the introduction of this report, the BALANS project is the first attempt to create an instrument that allows science-based policy choices to be made when assessing the impact of human activities on the Belgian part of the North Sea. In the context of this tool development, the project concentrated on what drives two human activities (1) sand and gravel extraction and (2) shrimp fisheries, and how they affect the environment and trigger the socio-economic system.

Starting from the flowchart analysis the major aspects were identified that are relevant for the development of the conceptual model. The model developed for sand and gravel extraction is given in Fig. 1.

![Conceptual model](image)

**Fig. 1 Conceptual model used for the assessing sand and gravel extraction in the BALANS project.**

This overall conceptual model was used for the developments of a quantitative simulation model Stella which is the systems thinking instrument that shapes the step between conceptual modeling and final simulation and calculation (see main report).
Within the BALANS project the general tasks of the Laboratory of Environmental Toxicology and Aquatic Ecology were:

- Selection and development of relevant ecotoxicological indicators reflecting the impact of various industrial activities in the Belgian part of the North Sea (fisheries, sand- and gravel extraction and resulting emission of contaminants);
- Selection of representative indicators of the ecological status of the marine environment, based on the chemical properties of the water column and the sediment, including ecological indicators of the effects of pollutants on the marine ecosystem;
- Support of the actions taken in the context of the policy development.

Based on literature, previous projects, and the extensive discussion among the partners and the user committee the following indicators were selected as relevant environmental indicators of potential impact through human activity:

- Pollution (air and water)
- Physical impact
- Depletion of resources
- Ecosystem health
- Hydrodynamics

Within the tasks assigned to the Laboratory of Environmental Toxicology and Aquatic Ecology, the main research activities developed were aimed at assessing the importance and magnitude of pollution caused by the selected human activities: i.e. (shrimp) fisheries and gravel (and sand) extraction and the resulting effects on resource depletion and ecosystem health.

The following gives an overview of the methods used to perform these assessments and summarize the main results and conclusions obtained.

## 2 METHODS AND RESULTS

### 2.1 Sand and gravel extractions: selection and evaluation of potential ecotoxicological indicators associated with the extraction itself

All extraction techniques result in the re-suspension of the sediment in the water column forming a temporary sediment plume. Additionally sediment plumes can be also formed through onboard release of sediment rejected by the means of overflow. The re-suspended sediment can result in the following potential impact: (1) adverse
effects on filter feeding organisms and/or phytoplankton (through decrease the light availability), and (2) remobilization of sediment-associated pollutants, nutrients and organic matter.

The envisaged methodology to be developed was to quantitatively link adverse effects on biota caused by extraction-associated re-suspension events to the duration and turbidity level of the plume. However, the extensive literature searches performed in the context of this project demonstrated that although some reports are available on the duration and intensity of re-suspension events in Belgian coastal water, no to very little information is available linking this information to (potential) impacts on marine organisms. Some papers report both negative, toxic effects on the benthos and positive effects on the primary production, however, the type of data presented does not allow to quantitatively assess the impact of increased turbidity or locally increased contaminant concentration of the resident biota. From this literature (and as reported in progress report 2003) it was (qualitatively) concluded that considering the local occurrence of the plume and short duration of the extraction associated re-suspension events the impact of this physical disturbance to pelagic organisms is probably negligible.

Extraction and re-suspension may also potentially re-mobilize sediment associated contaminants. Considering that in some areas of the Belgian Continental Shelf (BCF, mainly east of Ostend towards the Western Scheldt) the sediments are contaminated with a various chemicals (metals and organic compounds), we attempted to assess the magnitude of contaminant remobilisation and their potential effect on marine biota. Based on the type and concentration of chemicals present in the sediments occurring in Belgian coastal waters and using the equilibrium partitioning approach (combined with the SEM/AVS approach for metals, i.e. metal associated sulphides in reduced sediments) we simulated how much of the sediment associated chemicals would partition into the water phase during an extraction event. Results indicated that for the model chemicals considered (benzoapyrene, Cd and Cu) the expected increase in local Predicted Environmental Concentration in the water column was less than 1%. Given these simulation results, the results from the laboratory simulation experiments (performed by the contractor in the context of other projects), the local nature and known short re-suspension periods and the high dilution factor occurring in Belgian coastal water, it is concluded remobilisation of contaminants due to extraction events will not lead to significant increases in chemicals/contaminants concentrations in the water phase and as such does not pose as additional risk to pelagic communities.
2.2 Sand and gravel extractions: selection and evaluation of potential ecotoxicological indicators associated with the shipping & transport at sea

After having established that environmental risks of the release of chemicals from sediments and the potential effects of turbidity is low we focused on the assessment of the potential impact of extraction related shipping activity on the marine environment in Belgian coastal waters. In this project we assessed the quantity of contaminants released by (extraction) dredging and transport in coastal waters as established if these concentrations pose a risk to ecosystem health. We did not assess harbour associated pollution. From literature we established that three main types of contaminants are emitted by the dredging ships: copper and tributyltin leaching from the ship’s hull, zinc released from the sacrificial anodes used to prevent corrosion and a mixture of contaminants released via the air and resulting from the combustion of fossil fuels (air pollution). Although extensively explored (see progress report 2003-2004), the latter was not further developed in this project as (1) there were no quantitative data (as a function of distance traveled) available on the type and concentration of the emitted air pollutants and (2) the effects of this type of local contribution of this source to the overall potential air pollution at sea are indistinguishable form transboundary and land-borne sources. For the two former contaminants identified (local) risk assessments and risk simulations were performed to evaluate the contribution to the potential risk to the health of the marine ecosystem in Belgian coastal waters.

The risk assessment procedures applied in this project are in accordance with EU requirements and described in detail in the EU technical guidance document. For clarity this methodology is briefly described hereunder. In a first step the Predicted No Effect Concentration for the marine environment (PNECmarine) is established. This is done through the use of acute and chronic toxicity data for marine organisms. The PNEC may be calculated using an assessment factors or statistical extrapolation models, both of which account for degree of uncertainty in extrapolation from test data to the real environment. In a second step the Predicted Environmental Concentration (PEC) for the selected toxicants is calculated/estimated. In this project the PECs in the coastal waters resulting from extraction and shrimp fishing associated shipping was calculated using a modified version of the computer model MAMPEC (see below). This model calculates the contaminant emissions from the vessels in combination with chemical speciation. The last step in the risk assessment procedure is to evaluate the possible risks by comparing the PEC and PNEC. Its should be noted that extensive simulations of possible PEC values, depending on shipping scenario’s, were performed.
Based on an extensive literature review and recently performed EU risk assessments of Cu and Zn, a PNEC for both the sediment and pelagic compartment of the marine environment was established. A PNEC should be viewed as that concentration (or lower) at which no long-term adverse effects on marine biota are expected. The PNEC for Cu for example is based on ecotoxicity data of 19 species of marine algae, 11 species of marine invertebrates and one marine fish species. A graphical representation of the sensitivity distribution of these species is given in Fig. 2. For metals and other natural substances one needs to consider that anthropogenic and natural sources contribute to the environmental concentration of the metal. Considering the natural background it was, using statistical extrapolation models, calculated that the PNEC_{total, marine water} is 0.3 µg Cu/l\textsuperscript{1}. A similar approach was to derive the PNEC for the sediment compartment, a value of 79.5 mg Cu/kg dw was derived and used in this study. It should be noted that because of the lack ecotoxicity data with benthic species, this PNEC was derived from tests with freshwater benthic species. It should be stressed that for both compartments the metal bioavailability may change as a function of environmental characteristics. In the present project we assumed the worst case scenario: i.e. the total metal concentration being bioavailable.

In general terms, the PNECs for TBT was derived in a similar way and are 0.01 ng/l and 0.25 mg/ kg dw for the water and sediment compartment, respectively. For Zn – again through the lack of sufficient marine toxicity data – PNECs were based on freshwater data and were 15 µg/ and 78 mg/kg dw for these compartments.

![Species sensitivity distribution for Cu (expressed as added Cu, i.e. without background concentrations) based on the chronic ecotoxicity data with marine species.](image)
To derive the PEC in marine environments for active substances used in antifouling products in water column and sediment compartments the computer model MAM-PEC PEC (Marine anti-fouling model to predict environmental concentrations) is used. This model allows us to derive PEC values for a number of generalised environmental scenarios relevant to European Union waters, i.e.:

- yachting marina
- commercial harbour
- shipping Lane
- estuary, and
- open sea.

Fig. 3 Generalized scheme of the Marine anti-fouling model to predict environmental concentrations (MAMPEC) used in this project to predict environmental concentrations of chemicals leaching from ship hulls treated with antifouling products.

These standard environments can be adapted and customized scenarios can be introduced. The environmental scenarios have the flexibility to account for differences in: water temperature, salinity, pH, water movement (tide) and volume.

Emissions of antifouling products emissions are quantified as the product of a leaching rate (ug / cm2 / day) and the total underwater area treated with antifouling product (i.e. ship's hull). The leaching rate depends on the type of compound, characteristics and age of paint matrix and velocity of the ship. The total antifouling treated (underwater) area depends on shipping intensities, dimensions of the various categories of ships, and many other factors such as cargo load and residence time of the various ships.
After extensive literature searches and frequent contacts with the stakeholders we were able to collect the relevant data (i.e. for the Belgian coastal zone and the gravel extraction and transport vessel) required to run MAMPEC. Briefly the following data were compiled:

- product parameters: type of paint and antifouling agent
- ship parameters such as size, underwater hull area, number of active vessels per time unit, distance travelled/vessel, routes, and average cruising speed;
- environmental parameters: salinity, temperature, wave speed and size.

A summary of the numerous simulations performed to derive the current and possible future emissions of Cu and TBT originating from the use of extraction and transport vessel in Belgian coastal water is given in Table 1.

The following data were used: distances from the port of Zeebrugge to the eight Zagri extractions zones ranges between 14.5 and 53.5 km with an average of 36 km. Of the total of 12 (Ecolas nv. (2006): Environmental Impact Assessment for the extraction of marine aggregates on the BPNS. 194 pp. + Annexes) available extraction vessels only 3 are active on the BCP on a regular basis resulting in a maximum of 1 ship at berth and 1 ship moving at any time of the day (= normal operation). Simulations of the three scenario are presented here:

Scenario 1: normal operation and vessels active in only one extraction zone (minimal dilution).
Scenario 2: normal operation and vessels active in all 8 extraction zones (maximal dilution).
Scenario 3: Worst case, doubling activity (maximal emission).

The main parameters used in the calculations and reflecting the current situation in the Belgian coastal zone are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silt concentration</td>
<td>35.0 g/m³</td>
</tr>
<tr>
<td>Particular organic carbon conc</td>
<td>1.0 g Organic Carbon/m³</td>
</tr>
<tr>
<td>Dissolved organic carbon conc</td>
<td>2.0 g/m³</td>
</tr>
<tr>
<td>Temperature</td>
<td>15.0 °C</td>
</tr>
<tr>
<td>Salinity</td>
<td>3.40E+01 :s.e.</td>
</tr>
<tr>
<td>Depth well-mixed sediment top layer</td>
<td>1.00E-01 :m</td>
</tr>
<tr>
<td>Sediment density</td>
<td>1.000E+03 :kg/m³</td>
</tr>
<tr>
<td>Fraction organic carbon in sediment</td>
<td>3.00E-02 :kg/m³</td>
</tr>
<tr>
<td>Nett sedimentation velocity</td>
<td>2.00E-01 :m/d</td>
</tr>
<tr>
<td>pH</td>
<td>8.0 :(-)</td>
</tr>
<tr>
<td>Length shipping lane</td>
<td>max 36000 :m</td>
</tr>
</tbody>
</table>
Table 1. Predicted environmental concentrations of Cu and TBT in water and sediment originating from extraction and transport vessels (treated with antifouling products) operating in Belgian coastal waters.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Contribution to the PEC of Cu in water phase (ng/l)</th>
<th>Contribution to the PEC of Cu in sediment phase (ng/g dw)</th>
<th>Contribution to the PEC of TBT in water phase (ng/l)</th>
<th>Contribution to the PEC of TBT in sediment phase (ng/g dw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>6.77E-1</td>
<td>2.23</td>
<td>5.41E-2</td>
<td>2.91E-3</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>5.99E-2</td>
<td>1.98E-1</td>
<td>4.78E-3</td>
<td>2.57E-4</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>3.24</td>
<td>10.7</td>
<td>2.58E-1</td>
<td>1.39E-2</td>
</tr>
</tbody>
</table>

In the **risk characterisation phase** of the project, the PEC and PNECs for the two aquatic compartments were subsequently combined to assess the potential risk to the marine environment of Cu and TBT leaching from extraction and transport vessels operation in the Belgian coastal zone. The **PEC/PNEC ratio** is used as an **indicator of risk**:

- **PEC/PNEC < 1**: so no adverse effects are anticipated
- **PEC/PNEC = 1**: indicating that adverse effects may occur.
- **PEC/PNEC > 1**: meaning that adverse effects are likely to occur.

A summary of the risk quotients calculated for Cu and the main scenarios studied is given in Table 2.
Table 2. Ecotoxicological indicator: risk quotients for Cu and TBT in water and sediment originating from extraction and transport vessels (treated with antifouling products) operating in Belgian coastal waters.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>RQ for Cu in water phase</th>
<th>RQ for Cu in sediment phase</th>
<th>RQ for TBT in water phase</th>
<th>RQ for TBT in sediment phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>2.25E-3</td>
<td>2.80E-5</td>
<td>5.41</td>
<td>1.16E-5</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>1.99E-4</td>
<td>2.49E-6</td>
<td>0.478</td>
<td>1.03E-6</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>1.08E-2</td>
<td>1.35E4</td>
<td>25.8</td>
<td>5.56E-5</td>
</tr>
</tbody>
</table>

Conclusions:

- The additional risk to both benthic and pelagic communities posed by copper released – through leaching – from extraction vessels can be considered very low to negligible. Indeed the risk quotients indicate that the PEC are 2 to 4 and 4 to 6 orders of magnitude lower that the PNEC.

- Similarly, the additional risk posed by TBT to the benthic community can be classified as negligible, i.e. PECs were 5 to 6 orders of magnitude lower that the PNEC. For the pelagic compartment, however, PEC/PNEC ratio's higher than 1 were obtained indicating a potential risk and thus adverse effects on species in this community. This is not surprising since it has been extensively demonstrated that the TBT concentrations measured in Belgian coastal water are close to those known to adverse affect marine organisms. Additional TBT specific effects have been observed in organisms collected in Belgian coastal waters. It should be noted that the use of TBT is now banned and environmental concentration are expected to decrease in the future.

- Considering that (1) the risk posed by both contaminants - released from extraction vessel activity – to the sediment compartment is very low to negligible, (2) that similar conclusions can be drawn for Cu in the water phase, and (3) that the TBT concentrations (leading to a potential risk) were expected, the consortium concluded that these risk indicators should not be included in the Stella model as their impact will be very low.

Next to the chemicals leaching for the ship’s hull, we identified that zinc dissolving for the sacrificial anodes used to protect the ship hull against corrosion might be a possible source of additional contaminant concentrations in the study area.
From literature we estimated that for the three vessels that are active on the BCP on a regular base, a total amount of 480 kg Zn is sacrificed per year.

Table 3. Predicted environmental concentrations of Zn in water and sediment originating from extraction and transport vessels (with sacrificial anodes) operating in Belgian coastal water

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Contribution to the PEC of Zn in water phase (ng/l)</th>
<th>Contribution to the PEC of Zn in sediment phase (ng/g dw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>2.79</td>
<td>16.1</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>1.73</td>
<td>10.0</td>
</tr>
</tbody>
</table>

For both compartments the PECs obtained for Zn originating from sacrificial anodes are at least 4 orders of magnitude lower that the PNEC, indicating that the additional risk posed by this source is very low.

2.3 Shrimp fisheries: selection and evaluation of potential ecotoxicological indicators associated with the fishing vessels

This part of the project used the same methods (cf. above) to assess the potential impact of contaminants released from shrimp fishery vessels on water and sediment biota.

From (grey) literature and consultation with the stakeholders we were able to collect the relevant data (i.e. for the Belgian coastal zone and the shrimp vessels) required to make estimations on the contaminant quantities and resulting concentrations of contaminants emitted from this type of activity. A summary of the numerous simulations performed to derive the current and possible future emissions of Cu and TBT originating from the activities of shrimp vessel in Belgian coastal water is given in Table 4

On average approximately 8 vessels are fishing shrimp at any time of the day. The following scenarios were assessed:

**Scenario 1**: normal operation and vessels active in limited fishing zone (minimal dilution).
Scenario 2: normal operation and vessels active in a larger fishing zone (maximal dilution).

Scenario 3: Worst case, doubling activity (maximal emission)

Predicted environmental concentrations of Cu and TBT in water and sediment originating from shrimp vessels (treated with antifouling products) operating in Belgian coastal waters.

Table 4. Predicted environmental concentrations of Cu and TBT in water and sediment originating from shrimp vessels (treated with antifouling products) operating in Belgian coastal waters.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Contribution to the PEC of Cu (ng/l)</th>
<th>Contribution to the PEC of Cu in sediment phase (ng/g dw)</th>
<th>Contribution to the PEC of TBT (ng/l)</th>
<th>Contribution to the PEC of TBT in sediment phase (ng/g dw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>2.85E-2</td>
<td>9.42E-2</td>
<td>1.66E-2</td>
<td>8.92E-4</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>2.16E-2</td>
<td>7.12E-2</td>
<td>1.25E-2</td>
<td>6.71E-4</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>4.16E-1</td>
<td>1.37</td>
<td>3.32E-2</td>
<td>1.78E-3</td>
</tr>
</tbody>
</table>

As for the sand and gravel extraction vessels, a summary of the risk quotients calculated for the main scenarios studied for the shrimp vessel is given in Table 5.

Table 5. Ecotoxicological indicator: risk quotients for Cu and TBT in water and sediment originating from shrimp vessels (treated with antifouling products) operating in Belgian coastal waters.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>RQ for Cu in water phase</th>
<th>RQ for Cu in sediment phase</th>
<th>RQ for TBT in water phase</th>
<th>RQ for TBT in sediment phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>8.60E-5</td>
<td>1.12E-7</td>
<td>1.66</td>
<td>3.57E-6</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>7.2E-5</td>
<td>9.12E-8</td>
<td>1.25</td>
<td>2.68E-7</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>1.38E-3</td>
<td>1.75E-5</td>
<td>3.32</td>
<td>7.12E-5</td>
</tr>
</tbody>
</table>
Conclusions:

- In general the additional (or absence of) risks occurring from Cu and TBT releases due to shrimp fisheries are similar to those observed for the gravel extraction vessel. I.e. risks are very low to negligible for both contaminants and compartments, except for TBT in the pelagic compartment for which a potential additional was identified.
- Like for the gravel extraction vessel activity, the research consortium deemed that the inclusion of these risk indicators on Stella was not needed.

3 GENERAL CONCLUSIONS

This sub-project aimed at the selection and development of relevant ecotoxicological indicators for identifying and quantifying the impact of two human activities in the Belgian part of the North Sea (fisheries, sand- and gravel extraction and resulting emission of contaminants). After extensive literature searches and consulting with stakeholders a number of potential physical and chemical stressors were identified and their potential impact was evaluated. Because of the lack of relevant quantitative data for some stressors only a qualitative assessment could be made. Quantitative ecotoxicological indicators were developed for shipping activity (of extraction and fishing vessels) using the risk assessment paradigm. In general (except TBT in water phase) the risk indicators showed that the impact of stressors caused by the studied two human activities had very little to no impact on the ecological status of the studied area. As such, the consortium partners concluded that these indicators should not be included in the Stella model.