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# Smartsediment Ecosystem services-tool manual

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# 1 Introduction

Sediment measures, going from dredging to nourishing areas, impact the environment by changing the system’s hydrological and morphological characteristics. These abiotic changes in their turn change the biotic environment and ecotopes. These do not only impact for example the macrobenthos availability and bird populations, they also have an impact on the provisioning of ecosystem services (ESS). With the Smartsediment ESS-tool, the user can calculate the provisioning of a selection of ecosystem services in an estuary and compare scenario’s with different sediment measures or developments. The end result gives an indication of how much (quantitatively, by calculations based on expert knowledge) and where (spatially explicit show in GIS maps) certain ecosystem services are provided.

We highly recommend reading De Swerdt et al. (2020) and Boerema et al. (2020) for a full understanding of methods, input and output while using the ESS-tool.

## 2 Installation procedure

The Smartsediment tool is a QGIS plug-in. It operates in Windows 7 and 10. Other operation systems are not tested. First, QGIS should be installed (step 1). Afterwards, the actual installation can be done by downloading the plug-in and database folders to the right places on your computer (step 2 & 3).

### 2.1 Step 1: Installing QGIS

QGIS is a free and open source geographic information system and can be downloaded from their website (<https://www.qgis.org/en/site/forusers/download.html>). The plug-in only works in QGIS 2, versions 2.8 – 2.18.

### 2.2 Step 2: Plug-in installation

The ESS-tool consists of two separate parts: the actual plug-in and the database (Figure 1). The plug-in part contains the scripts that build up the interface in QGIS.

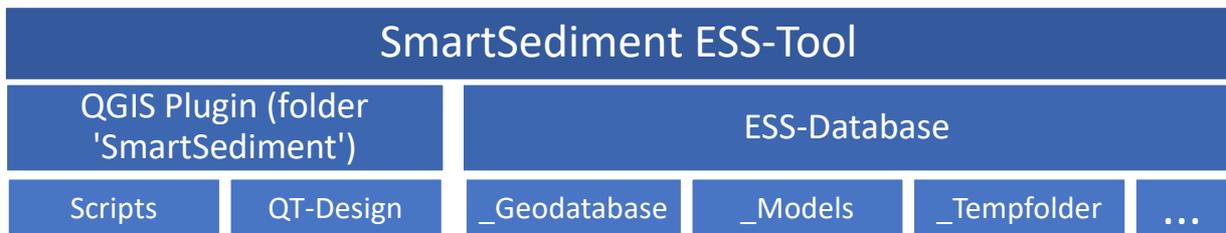


Figure 1: Composition of the ESS-Tool

To install the plug-in in QGIS, the folder ‘SmartSediment’ has to be placed in the QGIS plugin folder: C:\Users\user\.qgis2\python\plugins. It is thus required that the user can access the computer’s C-drive. When this is the first time a plug-in is installed in QGIS, the folder ‘plugins’ still has to be created by the user himself.

Now reopen QGIS. To make the plug-in visible in QGIS, follow the next steps:

- select in the menu bar ‘Plugins’ > ‘Manage and Install Plugins...’ (Figure 2)

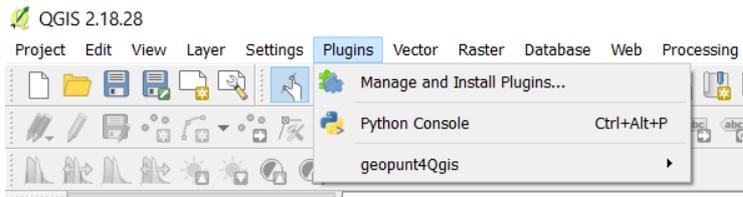


Figure 2: QGIS 'Plugins' menu

- look for 'SmartSediment' in the list of installed plugins and make sure the box in front of it is checked (Figure 3).

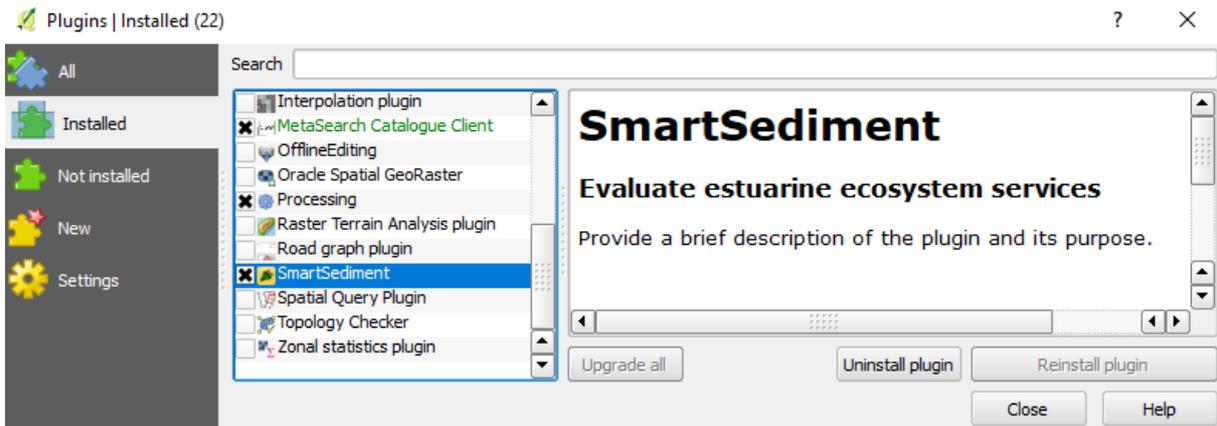


Figure 3: Activate installed 'SmartSediment' plug-in in QGIS

- Now a new tab 'Smartsediment' should be visible in the menu bar (Figure 4).



Figure 4: Smartsediment plug-in in QGIS menu bar

### 2.3 Step 3: Installing the ESS-Database

The second part of the plugin is the ESS-Database. Since this folder requires quite some space, it can be saved wherever the user wants. The database contains three folders:

- \_Geodatabase: Contains most important map layers of the Scheldt estuary, can be supplemented by the user
- \_Models: Contains data that is used during calculations
- \_Tempfolder: During calculations temporary files are stored here and are automatically deleted at the end of the calculations.

The names of these three folders should remain unchanged. Users can add files and folders to this ESS-Database in order to save different results and scenario's.

When all three steps are fulfilled, the plug-in is installed successfully.

### 3 Interface and data requirements

#### 3.1 Interface and ESS calculator use

The use of the QGIS plug-in is divided into three parts, as also shown in plug-in's menu (Figure 5).



Figure 5: Smartsediment menu with three submenu's

First, the user can prepare an ecotope map. This map is used in almost all calculations. One can also choose to use their own maps, but the coding should be the same as the one used by the tool (Chapter 4). It should also be noted that the calculation of ecotopes in the ESS-tool is based on quite basic calculations and for example no photograph data is used. Due to this, ecotope maps made by the ESS-tool are difficult to compare to other ecotope maps. The user should keep this in mind during the data selection and the interpretation of results.

The second menu-entry leads to the calculator for the different ESS (Figure 6). With the option '2.0 Overall analysis', the user can calculate all ESS at once. 2.1-2.8 give the calculators for the separate ESS (For example Figure 7).

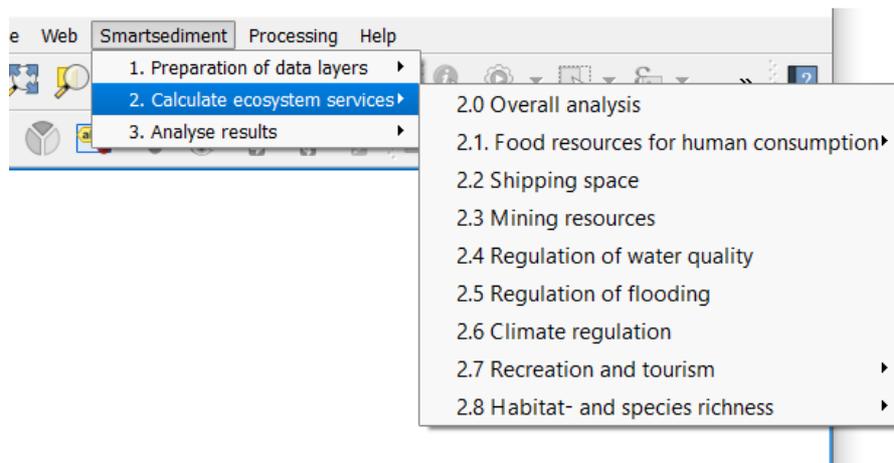


Figure 6: Submenu for calculation of ESS

To calculate an ESS four types of information are asked (Figure 7):

- 1) The location of the ESS-Database, that was explained in chapter 2.3 and the area of interest (as a shapefile). The area of interest can be as large or small as the user wants. The calculation of the ESS will cover this area.
- 2) The timestep(s) for which the calculation has to be performed. Four timesteps can be chosen: the current situation, one year later, 2 years later and 5 years later. The current situation can also be regarded as the reference situation, one year later as the situation right after the sediment measure and 2 & 5 years later as some time after the measure. The exact timespans depend on the data that is given by the user.
- 3) Data needed for the ESS calculation for the different timesteps. Sometimes a raster-file (.tiff format) or a single value can be given for a parameter. This enables the user to make more or less detailed calculations based on more or less accurate data.
- 4) The location where the results should be stored. Be aware that if no different folder is given, results will be overwritten when a second calculation of the same ESS and timestep is done.

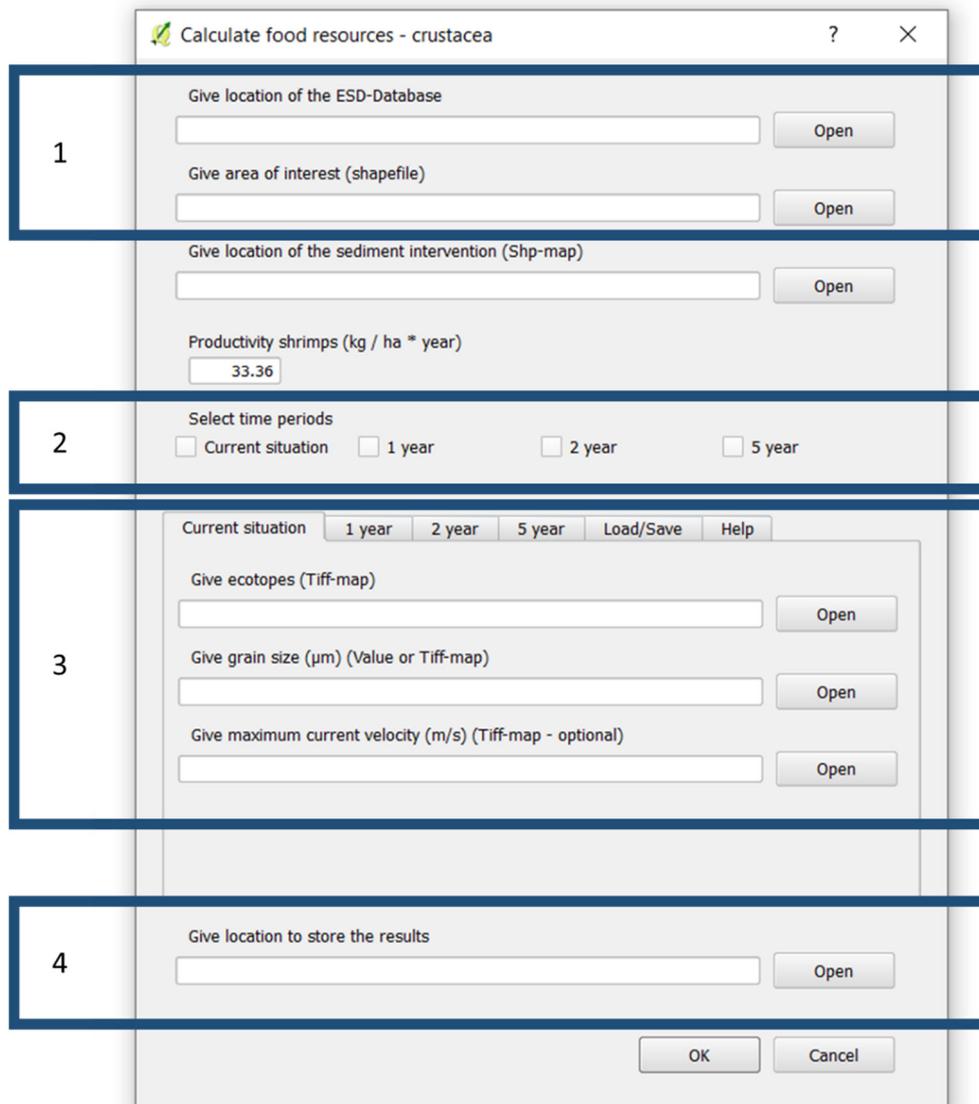


Figure 7: Example of an ESS calculator interface with the four types of information that are asked. Here the calculator interface for ESS food resources from crustaceans is shown.

When all required information is filled in, the calculation can be started by selecting 'OK'. When the calculation is finished, a pop-up window appears (Figure 8).

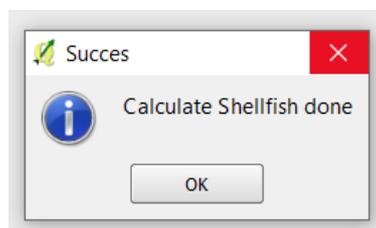


Figure 8: Example of a pop-up window appearing when a calculation is finished.

In the Load/Save tab the user has the possibility to save the data that he has filled in into a text file and load it in afterwards. This facilitates recalculations.

Dependent on the size of the study area and the complexity of the model, the calculations can take quite some time. In the QGIS Python Console the progress of the calculations can be followed (Figure

9). To open the Python console select 'Python Console' in the 'Plugins'-tab in the menu bar or use 'Ctrl-Alt-P'.

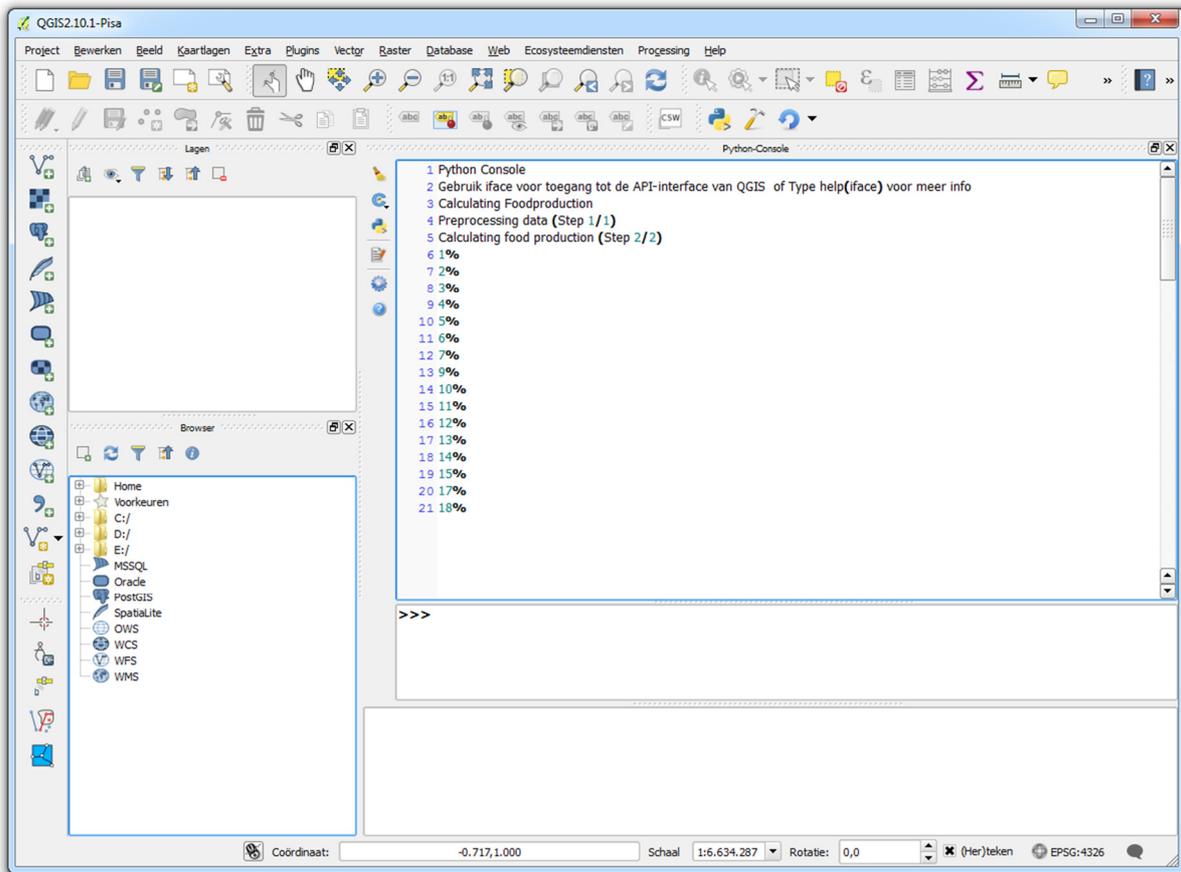


Figure 9: Example of calculation progress shown in the QGIS Python console.

Due to the way in which the ESS-Database is built, only one calculation can be done at the time. If the user wants to perform multiple calculations at the same time, the ESS-Database has to be copied entirely to another location. By opening a second QGIS session, parallel calculations can be performed by the plug-in referring to the other ESS-Database location.

### 3.2 Data requirements

For the calculation of the different ES, the user needs to provide data of multiple parameters representing the scenario that he wants to screen. For the Scheldt estuary, some of the data layers are already available in the ES-Database.

Table 1: Input data needed to calculate all ESS in the Smartsediment ES-tool

| Input variables ESS-tool              |              |                  |
|---------------------------------------|--------------|------------------|
| Variable                              | Unit         | Data type        |
| Area of interest                      | -            | vector (polygon) |
| Location of the sediment intervention | -            | vector (polygon) |
| Bed level                             | m NAP        | raster           |
| Maximum current velocity              | m/s          | raster           |
| Dry period                            | %            | raster           |
| Ecotope map                           | class (1-10) | raster           |
| Mean high water during springtide     | m NAP        | value            |

|  |  |                   |
|--|--|-------------------|
| Location mussel plots  | -                                      | vector (polygon)  |
| Mussel productivity  | kg/(ha*year)                           | value             |
| Sediment type  | "sandy" or "silt"                      | value             |
| Sedimentation rate   | cm/year                                | value or raster   |
| SPM  | mg/l                                   | value or raster   |
| Shrimp productivity  | kg/(ha*year)                           | value             |
| Sole productivity  | kg/(ha*year)                           | value             |
| Benthic recovery   | %                                      | value             |
| Grain size   | µm                                     | value or raster   |
| Waterways  | -                                      | vector (polyline) |
| Width waterways  | m                                      | value             |
| Mean low water   | m NAP                                  | value or raster   |
| Sailing depth thresholds (safety limit & critical limit)           | m                                      | value             |
| Maximum stream velocity  | m/s                                    | value or raster   |
| Stream velocity thresholds (safety limit & critical limit)         | m                                      | value             |
| Maximum lateral stream velocity                                    | m/s                                    | value or raster   |
| Lateral stream velocity thresholds (safety limit & critical limit) | m                                      | value             |
| Locations for raw material extraction                              | -                                      | vector (polygon)  |
| Amount of extraction   | m <sup>3</sup> /year                   | value             |
| Salinity   | class (1: fresh; 2: brackish; 3: salt) | value or raster   |
| Mean high water  | m NAP                                  | value or raster   |
| Maximum wave height  | m NAP                                  | value or raster   |
| Sedimentation rate   | cm/year                                | value or raster   |
| Soil density   | kg/m <sup>3</sup>                      | value or raster   |
| POC  | mg/l                                   | value or raster   |
| Walking-, horseback riding & cycling paths                         | -                                      | vector (polyline) |
| Swim locations   | -                                      | vector (point)    |
| Minimum stream velocity  | m/s                                    | raster            |
| Sand-silt map  | sand/silt                              | value or raster   |
| Slope  | %                                      | value or raster   |
| Recreational waterways   | -                                      | vector (polyline) |
| Amount of passages   | /year                                  | value             |
| Reference water depth recreational shipping                        | m NAP                                  | value             |

All data layers that are used should fulfil following requirements:

- .shp (vector data) or .tiff (raster data) format
- Reference system ETRS\_1989\_LEAR (EPSG:3035)
- Resolution 5m x 5m
- Extent: Except for the creation of an ecotope map, the extent may differ between data layers, but all should cover the defined area of interest.

### 3.3 Errors

When the calculations are interrupted, in some cases a clear message is shown in a pop-up window to inform the user about what went wrong:

- **Error 1: 'Select time period(s)'**  
At least one of the four possible time periods has to be selected, to enable the tool make the right calculations.
- **Error 2: 'Deleting temporal files failed'**  
During calculations temporary files are loaded into the \_Tempfolder. At the start and at the end of each calculation, the tool tries to empty this folder. When a calculation fails, it is possible that one of these files is still stuck in QGIS and thus cannot be deleted. This can be solved by restarting QGIS.  
Also when the program ArcGIS is running at the same time, this can also block the emptying of \_Tempfolder and thus closing ArcGIS might also help to solve the problem.
- **Error 3: 'Data layer in the wrong EPSG'**  
All data layers should be in the reference system ETRS\_1989\_LEAR (EPSG:3035), otherwise this error message is shown.
- **Error 4: 'Data layer has the wrong resolution'**  
All data layers should be in the resolution 5mx5m, otherwise this error message is shown.
- **Error 5: 'Data layer has the wrong extent'**  
If one of the data layers has an extent that does not cover the area of interest, this error is shown and the data layer has to be enlarged.
- **Error 6: 'Creation of results map failed'**  
The tool is not able to create the results map. It is possible that the given location does not exist or you do not have the rights to the location. If a former results map has to be overwritten and this is blocked by QGIS or another program (e.g. ArcGIS), this error is also shown. It can be solved by closing the program that blocks the action.
- **Error 7: 'The different maps have a different extent'**  
When creating an ecotope map, the three input layers have to have the same extent, otherwise this error is shown.

## 4 Making Ecotope maps

When the user does not have an ecotope map of the study area, it is possible to create one with the QGIS plugin. The ecotope maps are calculated following a simplified version of the methodology for the salt ecotope system used for the ecotope maps of the Western and Eastern Scheldt (Bouma et al., 2005; Rijkswaterstaat 2016). The original method results in more detailed maps because it also uses photograph material. To keep the tool user friendly, the creation of ecotope maps is based on only four variables: bed level, maximum current velocity, dry period and mean high water during spring tide. Based on these variables, ten different ecotopes are defined each with a number from 1 to 10. If the user wants to use its own ecotope maps, the same coding should be used (Table 2) and when comparing own maps with the ecotope maps created with the tool, this inaccuracies should be kept in mind and the same classification should be used.

Table 2: Ecotope classification based on bed level, current velocity and dry period.

| Class | Ecotope                                      | Bed level (m NAP) | Max. current velocity (m/s) | Dry period (%)       |
|-------|--|-------------------|-----------------------------|----------------------|
| 1     | Deep subtidal                                | ≤ -7              | -                           | -                    |
| 2     | Shallow, low dynamic sublitoral              | > -7              | ≤ 0.70                      | < 4                  |
| 3     | Low dynamic low litoral/mudflat              |                   |                             | 4 - 25               |
| 4     | Low dynamic middlehigh litoral/ mudflat      |                   |                             | 25 - 75              |
| 5     | Low dynamic high litoral/ mudflat            |                   |                             | 75 - 85              |
| 6     | Low dynamic supralitoral/pioneer high marsh  |                   |                             | 85 - 99              |
| 7     | Shallow, high dynamic sublitoral             |                   |                             | < 4                  |
| 8     | High dynamic litoral                         |                   | > 0.70                      | 4 - 85               |
| 9     | High dynamic supralitoral/pioneer high marsh |                   | 85 - 99                     |                      |
| 10    | High marsh                                   |                   | -                           | ≥ 99<br>(below MHWS) |

### INPUT:

| Variable                          | Unit  | Data type |
|-----------------------------------|-------|-----------|
| Bed level                         | m NAP | raster    |
| Maximum current velocity          | m/s   | raster    |
| Dry period                        | %     | raster    |
| Mean high water during springtide | m NAP | value     |

### OUTPUT:

Map with ecotopes following the classification of Table 2 with the same extent as the given input maps.

## 5 Calculating ecosystem services

### 5.1 Food resources for human consumption

#### 5.1.1 Shellfish (mussel, oyster) biomass yield

##### INPUT:

| Variable                              | Unit              | Data type        |
|---------------------------------------|-------------------|------------------|
| Area of interest                      | -                 | vector (polygon) |
| Location of the sediment intervention | -                 | vector (polygon) |
| Location mussel plots                 | -                 | vector (polygon) |
| Mussel productivity                   | kg/(ha*year)      | value            |
| Sediment type                         | "sandy" or "silt" | value            |
| Sedimentation rate                    | cm/year           | value or raster  |
| SPM                                   | mg/l              | value or raster  |
| Maximum current velocity              | m/s               | raster           |

By default, the average shellfish productivity of the Scheldt estuary is given.

##### SPATIAL & TEMPORAL CONTEXT:

The QGIS plug-in only calculates local effects for existing mussel plots. For more enhanced analysis, the user can also indicate potential mussel plot locations and add it to the vector input in the calculator.

The calculator only accounts for a one-time nourishment that has no direct effects anymore after one year. Due to instability, the nourishment can still affect the environment for a longer time and indirectly affect mussel plots due to changing sedimentation rate and currents. This is reflected by the current and sedimentation data given by the user.

##### EFFECT CHAINS AND CALCULATION RULES:

The most important effects on shellfish biomass yield from sediment measures are related to hydromorphological changes:

- Direct burial of the mussel plots by the nourishment
- Indirect burial due to erosion of a nearby nourishment and increasing sedimentation rates
- Changing current velocities due to a change in bathymetry (a small increase means more food availability, a too big increase can detach and flush away shellfish)

| Effect relation  | Input maps  | Effect:<br>changing<br>variable "IF ...,"                               | Outcome:<br>effect on ESS<br>"... THEN ..." | Timeframe               | Spatial<br>boundary |
|--|---|---|---|-------------------------|---------------------|
| Δ bathymetry →<br>burying of plots   | - Nourishment<br>location<br>- Location &<br>productivity of<br>mussel plots                  | IF nourishment<br>on top of<br>mussel plot,                             | THEN 100% loss<br>of biomass yield.         | 1 year after<br>measure | Mussel plots        |
| Δ bathymetry →<br>erosion &<br>sedimentation →<br>Δ sedimentation<br>rate on mussel<br>plots | - Sedimentation<br>rate<br>- Location &<br>productivity of<br>mussel plots<br>- Sediment type | IF<br>sedimentation<br>rate > 2.5 cm/y<br>(silt) or > 5 cm/y<br>(sand), | THEN 100% loss<br>of biomass yield.         | Permanent               | Mussel plots        |

|  |   |   |  |           |              |
|--|---|---|--|-----------|--------------|
| Δ current velocity<br>→ flush away     | - Location & productivity of mussel plots<br>- Max current velocity | IF max. current velocity > 70 cm/s; > 116 cm/s; 143 cm/s, | THEN loss of biomass yield of respectively 4%; 13.5%; 100%, following a linear function. | Permanent | Mussel plots |
| Δ current velocity<br>→ food provision | - Location & productivity of mussel plots<br>- Max current velocity | IF max. current velocity < 5cm/s,                         | THEN 100% loss of biomass yield.   | Permanent | Mussel plots |
| Δ SPM → shellfish growth               | - Location & productivity of mussel plots<br>- SPM                  | IF SPM > 250 mg/l; > 1220 mg/l,                           | THEN loss of biomass yield between respectively 0 & 100% following a linear function.    | Permanent | Mussel plots |

### OUTPUT:

Map showing biomass yield values at mussel plots in kg/year for the area of interest.

#### 5.1.2 Crustacea (shrimp) biomass yield

### INPUT:

| Variable                                     | Unit         | Data type        |
|--|--------------|------------------|
| Area of interest                             | -            | vector (polygon) |
| Location of the sediment intervention        | -            | vector (polygon) |
| Shrimp productivity                          | kg/(ha*year) | value            |
| Ecotope map                                  | class (1-10) | raster           |
| Grain size                                   | μm           | value or raster  |
| Maximum current velocity ( <b>optional</b> ) | m/s          | raster           |
| Benthic recovery                             | %            | value            |

To be able to differentiate in more detail between current dynamics, the user has the option to provide current velocities. If this is not given, the calculation will be solely based on the ecotope map with 100% loss of biomass yield in high dynamic area.

By default, the average shrimp productivity of the Scheldt estuary is given.

### SPATIAL & TEMPORAL CONTEXT:

Commercial shrimp fishing does not occur everywhere in an estuary. By limiting the area of interest to the commercial areas, the user can more accurately evaluate the effect of a sediment measure.

Since adult shrimp can move easily when they are buried, only the effect on juveniles and larvae is taken into account due to a loss of suitable habitat.

Macrobenthos communities that are covered by a nourishment die off. Over time, recolonization occurs on the nourishment area. By taking into account a recovery percentage, effects of the nourishment on benthos can be accounted for after several years.

## EFFECT CHAINS AND CALCULATION RULES:

The most important effects on shrimp biomass yield from sediment measures are related to changes in suitable habitat due to a change in turbulence, current velocity and grain size. Due to a lack of data about the turbulence thresholds, current velocity is taken here as an indicator for turbulence.

| Effect relation   | Input maps   | Effect: changing variable "IF ...,"  | Outcome: effect on ESS "... THEN ..."   | Timeframe |
|---|--|--|---|-----------|
| $\Delta$ grain size preference $\rightarrow$ $\Delta$ habitat     | - Ecotope map<br>- Grain size<br>- Optional: Max. current velocity | IF grain size within preferred ecotopes < 125 $\mu\text{m}$ or > 710 $\mu\text{m}$ , | THEN 75% loss of biomass yield.   | Permanent |
| $\Delta$ low dynamic area $\rightarrow$ $\Delta$ nursery function | - Ecotope map<br>- Optional: Max. current velocity                 | IF area preferred ecotope changes,   | THEN between 0 (until 50 cm/s) and 100 % ( $\geq$ 70 cm/s) loss of biomass yield following a linear function. | Permanent |

## OUTPUT:

Map showing shrimp biomass yield values in kg/year for the area of interest.

### 5.1.3 Fish (sole) biomass yield

## INPUT:

| Variable                              | Unit          | Data type        |
|---------------------------------------|---------------|------------------|
| Area of interest                      | -             | vector (polygon) |
| Location of the sediment intervention | -             | vector (polygon) |
| Sole productivity                     | kg/(ha*year)  | value            |
| Ecotope map                           | class (1-10)  | raster           |
| Grain size                            | $\mu\text{m}$ | value or raster  |
| Benthic recovery                      | %             | value            |

By default, the average sole productivity of the Scheldt estuary is given.

## SPATIAL & TEMPORAL CONTEXT:

By limiting the area of interest to the commercial areas, the user can more accurately evaluate the effect of a sediment measure.

Macrobenthos communities that are covered by a nourishment die off. This limits sole food resources. Over time, recolonization occurs on the nourishment area. By taking into account a recovery percentage, effects of the nourishment on benthos can be accounted for after several years.

## EFFECT CHAINS AND CALCULATION RULES:

| Effect relation   | Input maps                    | Effect: changing variable "IF ...," | Outcome: effect on ESS "... THEN ..." | Timeframe |
|---|-------------------------------|-------------------------------------|---------------------------------------|-----------|
| $\Delta$ grain size preference $\rightarrow$ $\Delta$ habitat | - Ecotope map<br>- Grain size | IF grain size within preferred      | THEN 75% loss of biomass yield.       | Permanent |

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ecotopes < 130  
µm or > 390 µm,

---

**OUTPUT:**

Map showing sole biomass yield values in kg/year in the area of interest.

## 5.2 Shipping space

**INPUT:**

| Variable   | Unit  | Data type         |
|--|-------|-------------------|
| Area of interest   | -     | vector (polygon)  |
| Waterways  | -     | vector (polyline) |
| Width waterways  | m     | value             |
| Bed level  | m NAP | value or raster   |
| Mean low water   | m NAP | value or raster   |
| Sailing depth thresholds (safety limit & critical limit)           | m     | value             |
| Maximum stream velocity  | m/s   | value or raster   |
| Stream velocity thresholds (safety limit & critical limit)         | m     | value             |
| Maximum lateral stream velocity                                    | m/s   | value or raster   |
| Lateral stream velocity thresholds (safety limit & critical limit) | m     | value             |

**EFFECT CHAINS AND CALCULATION RULES:**

The ESS plug-in provides a method to identify problems along the waterways with three factors important for shipping: the shipping depth, the stream velocity and the lateral stream velocity.

For each of the factor shipping depth, the user gives bed level, low water and two thresholds. When the difference between low water and bed level at one point along the waterway is lower than the safety limit, there is a possible problem for shipping. When it is lower than the critical depth (the shipping depth without safety margin), the ESS plugin will identify a problem at that point.

A similar approach is taken for (lateral) stream velocity. The user gives a map or value of the maximum (lateral) stream velocity and two thresholds. When the (lateral) stream velocity is higher than the safety limit, there is a possible problem for shipping. When it is higher than the critical limit, the ESS plugin will identify a problem at that point.

**OUTPUT:**

Three maps showing areas with problem (value = 3), a possible problem (value = 1) and without (value = 0) problem for shipping depth, stream velocity and lateral stream velocity in the area of interest.

## 5.3 Mining resources

**INPUT:**

| Variable                              | Unit                 | Data type        |
|---------------------------------------|----------------------|------------------|
| Area of interest                      | -                    | vector (polygon) |
| Locations for raw material extraction | -                    | vector (polygon) |
| Amount of extraction                  | m <sup>3</sup> /year | value            |

## EFFECT CHAINS AND CALCULATION RULES:

There are no underlying calculations for this ESS. The tool here serves as a presentation tool to show the possible amounts and areas of raw material extraction in m<sup>3</sup>.

### OUTPUT:

Map showing the amount of possible raw material extraction in m<sup>3</sup> per year for the area of interest.

## 5.4 Regulation of water quality

### INPUT:

| Variable                              | Unit                                   | Data type        |
|---------------------------------------|--|------------------|
| Area of interest                      | -                                      | vector (polygon) |
| Locations for raw material extraction | -                                      | vector (polygon) |
| Ecotope map                           | class (1-10)                           | raster           |
| Salinity ( <b>optional</b> )          | class (1: fresh; 2: brackish; 3: salt) | value or raster  |

For the Scheldt estuary, a salinity map is already embedded in the tool. Salinity should thus only be given when an area outside the Scheldt estuary is studied.

## EFFECT CHAINS AND CALCULATION RULES:

Based on expert knowledge, for each type of ecotope is decided how much it contributes to enhancing water quality by the storage of nitrate and phosphorus, by denitrification and by dissolution of silica. Each ecotope's contribution, combined with salinity, leads to certain mean values (Appendix A).

### OUTPUT:

Four different maps showing the potential for storage of nitrate & phosphorus, denitrification and the amount of dissolved silica at the area of interest in kg N/year, kg P/year and g DSi/year.

## 5.5 Regulation of flooding

### INPUT:

| Variable            | Unit  | Data type        |
|---------------------|-------|------------------|
| Area of interest    | -     | vector (polygon) |
| Mean high water     | m NAP | value or raster  |
| Maximum wave height | m NAP | value or raster  |

## EFFECT CHAINS AND CALCULATION RULES:

To decide whether more or less effort has to be done to prevent flooding, the mean high water and maximum wave height are compared to the values that are given by the user for the current situation (this is used as the reference situation and should always be filled in). Following calculation rules are applied by the ESS-tool:

- If the mean high water after the sediment measure (year 1, 2 or 5) is lower/higher than the reference mean high water (current), then there is less/more effort needed to prevent flooding.
- If the maximum wave height after the sediment measure (year 1, 2 or 5) is lower/higher than the reference maximum wave height (current), then there is less/more effort needed to prevent flooding.

## OUTPUT:

A map showing whether more (value = 3), less (value = 2) or as much (value = 1) effort has to be done to prevent flooding, compared to the reference situation.

## 5.6 Climate regulation

### INPUT:

| Variable                     | Unit                                   | Data type        | Method 1 | Method 2 |
|------------------------------|--|------------------|----------|----------|
| Area of interest             | -                                      | vector (polygon) | x        | x        |
| Ecotope map                  | class (1-10)                           | raster           | x        | x        |
| Salinity ( <b>optional</b> ) | class (1: fresh; 2: brackish; 3: salt) | value or raster  | x        | x        |
| Sedimentation rate           | cm/year                                | value or raster  |          | x        |
| Soil density                 | kg/m <sup>3</sup>                      | value or raster  |          | x        |
| POC                          | mg/l                                   | value or raster  |          | x        |
| SPM                          | mg/l                                   | value or raster  |          | x        |

For the Scheldt estuary, a salinity map is already embedded in the tool. Salinity should thus only be given when an area outside the Scheldt estuary is studied.

### EFFECT CHAINS AND CALCULATION RULES:

The ecosystem service climate regulation by sediment measures is mainly the storage of carbon due to sedimentation and primary production at mudflats and marshes. With the ESS-tool, two calculation methods are available:

#### Method 1: mean values for carbon storage based on expert knowledge and literature

Based on the different ecotopes and their average carbon storage values, a total amount of carbon storage for the area of interest is calculated. Also the salinity is taken into account. For the Scheldt estuary, a salinity map is already added to the underlying model and should thus not be added by the user. For other areas the user can choose to add a salinity map that fits the area of interest.

#### Method 2: calculation of carbon storage based on sediment storage, soil density and emissions

---

|   |  |
|---|--|
| <b>TOTAL CARBON STORAGE (tonC/year)</b> | <b>= Change in carbon storage via sedimentation (tonC/year)</b>              |
|   | = Change in area mudflat and marshes (ha)                                    |
|   | * average sediment accumulation per year (cm/year)                           |
|   | * soil density (kg/m <sup>2</sup> )  |
|   | * POC (mg/l)   |
|   | * SPM (mg/l)   |
|   | * 10   |
|   | <b>- Change in carbon storage due to emissions from sediment (tonC/year)</b> |
|   | = Change in area mudflat and marshes (ha)                                    |
|   | * average greenhouse gas emissions (tonC/ha*year)                            |

---

## OUTPUT:

Map showing the amount of carbon storage per year for the area of interest in tonC/year.

## 5.7 Recreation and tourism

### 5.7.1 Coastbound recreation (walking, cycling, horseback riding, bird watching)

#### INPUT:

| Variable                                   | Unit         | Data type         |
|--|--------------|-------------------|
| Area of interest                           | -            | vector (polygon)  |
| Location of the sediment intervention      | -            | vector (polygon)  |
| Walking-, horseback riding & cycling paths | -            | vector (polyline) |
| Dry period                                 | %            | value or raster   |
| Ecotope map                                | class (1-10) | raster            |
| Benthic recovery                           | %            | value             |

#### SPATIAL & TEMPORAL CONTEXT:

Macrobenthos communities that are covered by a nourishment die off. This limits foraging resources for waders what negatively impacts wader appearance and thus the suitability of the area for bird watching. Over time, recolonization occurs on the nourishment area. By taking into account a recovery percentage, effects of the nourishment on benthos can be accounted for after several years.

#### EFFECT CHAINS AND CALCULATION RULES:

In a range up to 200 m from walking, horseback riding & cycling paths, the area of habitat that is suitable for birds and thus bird watching is calculated by, for each ecotope, taking the dry period (the percentage of time a bird can forage in the area) and correct it for the available biomass (Appendix B).

#### OUTPUT:

Map showing an indicator for habitat suitability for recreation going from 0 (not suitable at all) to 1 (perfect habitat).

### 5.7.2 Swimming

#### INPUT:

| Variable                | Unit         | Data type        |
|-------------------------|--------------|------------------|
| Area of interest        | -            | vector (polygon) |
| Swim locations          | -            | vector (point)   |
| Ecotope map             | class (1-10) | raster           |
| Minimum stream velocity | m/s          | value or raster  |
| Mean low water          | m NAP        | value            |
| Mean high water         | m NAP        | value            |
| Sand-silt map           | Sand/silt    | value or raster  |
| Bed level               | m NAP        | value or raster  |
| Slope                   | %            | value or raster  |

#### SPATIAL CONTEXT:

Users can calculate what the potential is for new beach areas by adding potential swimming locations to the map.

## EFFECT CHAINS AND CALCULATION RULES:

The tool starts from the swimming locations indicated in the given map and calculates the amount of visitors (with a reference of 310 per day) in a 50 m radius around the closed point on the low water line:

- If the minimum stream velocity is higher than 50 m/s, the swimming location is not suitable for 100% → no visitors
- If the slope in sublittoral area is > 20 %, the swimming location is not suitable for 100% → no visitors
- If silt area or ecotope mudflat (class 3, 4 or 5) appears within the 50 m radius, the swimming location is not suitable for 100% → no visitors
- The percentage change of the distance between the closest point on the high and low water line is applied to the % change in the amount of visitors, compared to the reference of 310/day

## OUTPUT:

Map (vector) with amount of visitors for each swimming location

### 5.7.3 Recreational shipping

#### INPUT:

| Variable                                    | Unit  | Data type         |
|---|-------|-------------------|
| Area of interest                            | -     | vector (polygon)  |
| Recreational waterways                      | -     | vector (polyline) |
| Amount of passages                          | /year | value             |
| Reference water depth recreational shipping | m NAP | value             |
| Bed level                                   | m NAP | raster            |
| SPM   | mg/l  | value or raster   |

#### SPATIAL & TEMPORAL CONTEXT:

Users can calculate what the potential is for new recreational waterways by adding potential routes to the map.

#### EFFECT CHAINS AND CALCULATION RULES:

The suitability of recreational waterways is presented as the amount of passages per year. The calculation of the change in number of passages is based on the clarity of the water (depends on SPM & photic depth) and the possibility of getting stuck (depends on bed level).

- A linear relationship is assumed between the amount of SPM and the suitability for recreative shipping. The change in clarity because of SPM concentration is accounted for 17.61 % of the change in passages.
- A linear relationship is assumed between the amount places where there is a possibility of getting stuck and the suitability for recreative shipping. The possibility of getting stuck (0: no possibility or 1: possibility) is accounted for 5.67 % of the change in passages.
- Other factors that are possibly affecting suitability for recreational shipping (e.g. construction works, near touristic activities,...) are assumed to be not affected by the sediment measures.

The calculation is done for each waterway segment separately.

## OUTPUT:

Shapefile with recreational waterways and the amount of passages per year

## 5.8 Habitat- and species richness

### 5.8.1 Seals

#### INPUT:

| Variable         | Unit              | Data type        |
|------------------|-------------------|------------------|
| Area of interest | -                 | vector (polygon) |
| Bed level        | m NAP             | raster           |
| Mean low water   | m NAP             | value or raster  |
| Sediment type    | "sandy" or "silt" | -                |
| Ecotope map      | class (1-10)      | raster           |
| Dry period       | %                 | value or raster  |

#### SPATIAL & TEMPORAL CONTEXT:

Rest area for seals is typically between 100 and 200 m away from the low water line. Only changes in intertidal area within this range and with a dry period  $\geq 16$  % will possibly have an impact on seal populations.

#### EFFECT CHAINS AND CALCULATION RULES:

The calculation happens in two steps. The user also has to go through two modules (Figure 10).



Figure 10: Two modules to calculate seal habitat

With the first module the user gives input (bed level and mean low water) for the delineation of the low water line. This results in a shapefile representing the low water line. Since this is a calculation that would require extensive data and modelling to make it applicable in all situations, it is chosen to keep the calculation simple with limited data input but give the user the possibility to change the shapefile if it is not correct. It can for example be the case that the tool calculates a low water line in the middle of an intertidal flat if there is a more shallow area, but this is not accessible for seals and should thus not be in the shapefile that is used to calculate seal habitat.

The second module calculates the suitability as seal habitat for each point in intertidal ecotopes, also taking into account the effect of sediment composition (silty area reduces the suitability with 50%).

#### OUTPUT:

Map showing an indicator for suitability as seal habitat going from 0 (not suitable at all) to 1 (perfect habitat).

### 5.8.2 Birds

#### INPUT:

| Variable         | Unit | Data type        |
|------------------|------|------------------|
| Area of interest | -    | vector (polygon) |

|                                       |              |                  |
|---------------------------------------|--------------|------------------|
| Location of the sediment intervention | -            | vector (polygon) |
| Ecotope map                           | class (1-10) | raster           |
| Dry period                            | %            | value or raster  |
| Benthic recovery                      | %            | value            |

**SPATIAL & TEMPORAL CONTEXT:**

Macrobenthos communities that are covered by a nourishment die off. This limits foraging resources for waders. Over time, recolonization occurs on the nourishment area. By taking into account a recovery percentage, effects of the nourishment on benthos can be accounted for after several years.

**EFFECT CHAINS AND CALCULATION RULES:**

The area of suitable habitat is calculated based on the dry period (the time a bird can forage in the area) and corrected for the available biomass (Appendix B). This results in a value of suitability for each point. In the years after the sediment measure, benthos recovery is also taken into account.

**OUTPUT:**

Map showing an indicator for suitability as bird habitat going from 0 (not suitable at all) to 1 (perfect habitat).

## 6 Making an evaluation using the Quickscan function

In order to aggregate all results and to evaluate and compare different scenario's regarding the provision of ESS, the user can use the Quickscan function, following these steps:

- 1) Make sure all maps that were created with the tool are in one folder and still have their original name.
- 2) In the Smartsediment QGIS-menu, go to '3. Result analysis' -> '3.1 Quickscan table'. A similar window opens as for the calculation of ESS (Figure 11).

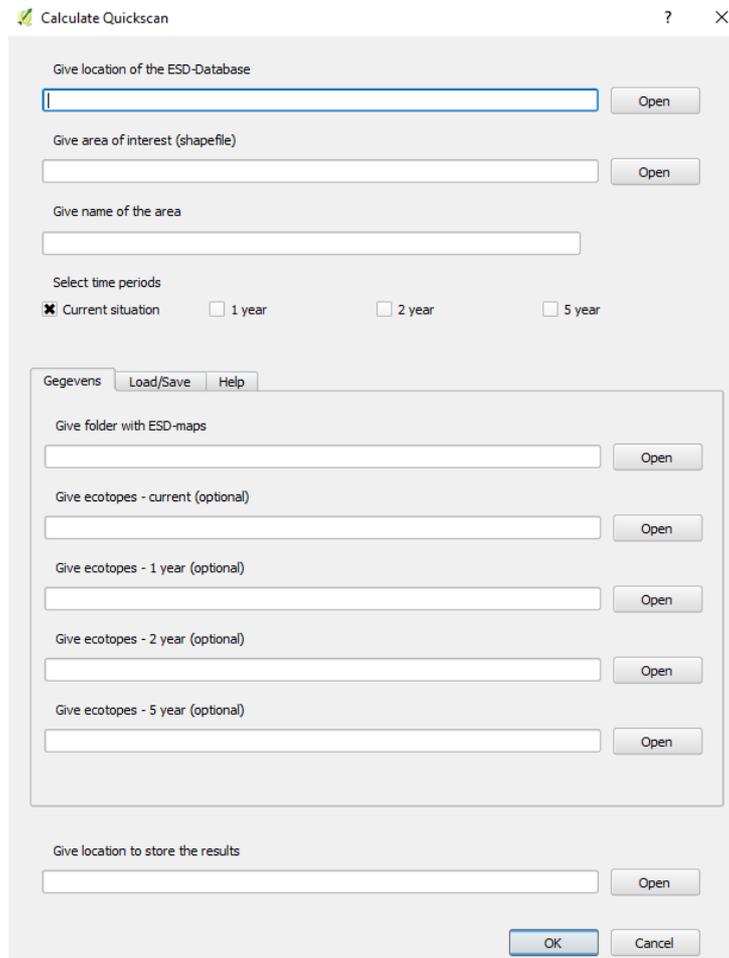


Figure 11: Interface for the Quickscan function of the SmartSediment QGIS plugin

- 3) After filling in all required information, two text files, named 'Ecotopes' and 'Ecosystem services', are created in the folder you selected.
- 4) Copy the text of both text files into the corresponding tab ('Input\_Ecotopes' and 'Input\_EcosystemServices') of the Quickscan excel file that is located in the ESS-database (Figure 12). Make sure excel interprets the decimal separator '.' in the right way (not as a thousands separator) and all columns are filled in.

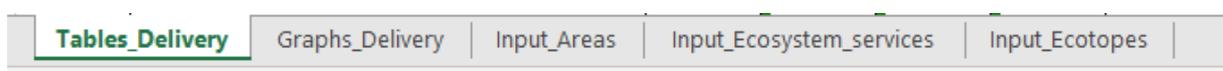


Figure 12: Five Tabs of the Quickscan excel file.

- 5) In the tab 'Input\_Areas' fill in the name of the area. This is also the name that was given in the QGIS plugin in step 2 (Figure 12) and is now shown in the columns 'Area' in the tabs 'Input\_Ecotopes' and 'Input\_EcosystemServices'.
- 6) Via the dropdown menu (Figure 13) in the tab 'Tables\_Delivery' you can now select two areas from the areas you named in tab 'Input\_Areas' to show and compare the provided ecosystem services and ecotopes.

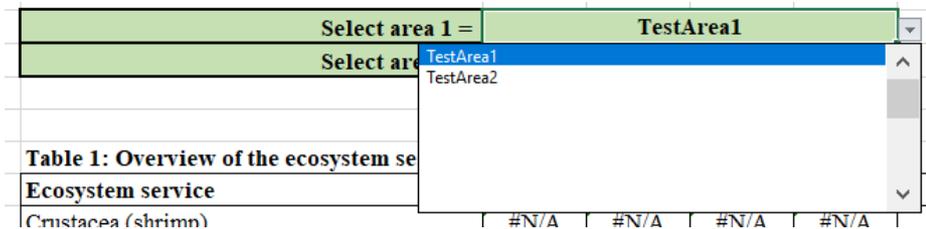


Figure 13: Dropdown menu to choose an area in the tab 'Tables\_Delivery' of the Quicksan excel file

- 7) The tab 'Graphs\_Delivery' gives a graphical representation of the results shown in 'Tables\_Delivery'.

## 7 Interpretation of the results

The values given for the provision of ecosystem services are no exact representation of reality. They are meant to give an insight and an overall view of the areas added value in terms of ecosystem services. They are also meant to make it more easy to compare different scenario's.

The reliability of the results represented by the maps and Quicksan is highly dependent on the reliability and precision of the input data. Therefore the results should always be interpreted by an expert with knowledge about the area of interest.

It should also be noted that the effect of different ecosystem services on each other is not taken into account. Here, also expert knowledge is recommended.

## 8 References

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## 9 Appendices

### 9.1 Appendix A – Expert knowledge regulation of water quality

| Salinity | Ecotope                                      | Denitrification<br>(kgN/ha/j) | Nitrogen<br>storage<br>(kgN/ha/j) | Phosphorus<br>storage<br>(kgP/ha/j) | Silicium<br>dissolution<br>(kgDSi/ha/j) |
|----------|--|-------------------------------|-----------------------------------|-------------------------------------|---|
| Salt     | Deep subtidal                                | 0                             | 0                                 | 0                                   | 0                                       |
| Salt     | Shallow, low dynamic sublitoral              | 0                             | 0                                 | 0                                   | 0                                       |
| Salt     | Low dynamic low litoral/mudflat              | 60                            | 1091                              | 70                                  | 200                                     |
| Salt     | Low dynamic middlehigh litoral/ mudflat      | 60                            | 1091                              | 70                                  | 200                                     |
| Salt     | Low dynamic high litoral/ mudflat            | 60                            | 1091                              | 70                                  | 200                                     |
| Salt     | Low dynamic supralitoral/pioneer high marsh  | 107                           | 1091                              | 70                                  | 400                                     |
| Salt     | Shallow, high dynamic sublitoral             | 0                             | 0                                 | 0                                   | 0                                       |
| Salt     | High dynamic litoral                         | 107                           | 1091                              | 70                                  | 200                                     |
| Salt     | High dynamic supralitoral/pioneer high marsh | 107                           | 1091                              | 70                                  | 400                                     |
| Salt     | High marsh                                   | 107                           | 273                               | 18                                  | 400                                     |
| Brackish | Deep subtidal                                | 0                             | 0                                 | 0                                   | 0                                       |
| Brackish | Shallow, low dynamic sublitoral              | 0                             | 0                                 | 0                                   | 0                                       |
| Brackish | Low dynamic low litoral/mudflat              | 289                           | 106                               | 30                                  | 200                                     |
| Brackish | Low dynamic middlehigh litoral/ mudflat      | 289                           | 106                               | 30                                  | 200                                     |
| Brackish | Low dynamic high litoral/ mudflat            | 289                           | 106                               | 30                                  | 200                                     |
| Brackish | Low dynamic supralitoral/pioneer high marsh  | 289                           | 1044                              | 30                                  | 400                                     |
| Brackish | Shallow, high dynamic sublitoral             | 0                             | 0                                 | 0                                   | 0                                       |
| Brackish | High dynamic litoral                         | 289                           | 106                               | 30                                  | 200                                     |
| Brackish | High dynamic supralitoral/pioneer high marsh | 289                           | 1044                              | 30                                  | 400                                     |
| Brackish | High marsh                                   | 70                            | 200                               | 20                                  | 400                                     |
| Fresh    | Deep subtidal                                | 0                             | 0                                 | 0                                   | 0                                       |
| Fresh    | Shallow, low dynamic sublitoral              | 0                             | 0                                 | 0                                   | 0                                       |
| Fresh    | Low dynamic low litoral/mudflat              | 200                           | 106                               | 30                                  | 200                                     |
| Fresh    | Low dynamic middlehigh litoral/ mudflat      | 200                           | 106                               | 30                                  | 200                                     |
| Fresh    | Low dynamic high litoral/ mudflat            | 200                           | 106                               | 30                                  | 200                                     |
| Fresh    | Low dynamic supralitoral/pioneer high marsh  | 200                           | 1044                              | 30                                  | 400                                     |
| Fresh    | Shallow, high dynamic sublitoral             | 0                             | 0                                 | 0                                   | 0                                       |
| Fresh    | High dynamic litoral                         | 200                           | 106                               | 30                                  | 200                                     |
| Fresh    | High dynamic supralitoral/pioneer high marsh | 200                           | 1044                              | 30                                  | 400                                     |
| Fresh    | High marsh                                   | 176                           | 200                               | 20                                  | 400                                     |

Ref.: Struyf et al. 2005; Struyf et al. 2006; Struyf et al. 2007; Boerema et al. 2016a; Boerema et al. 2016b; Van der Biest et al. 2017

## 9.2 Appendix B – Values used for calculating bird habitat

| <b>Ecotope</b>                               | <b>Dry period</b> | <b>Benthos biomass</b> | <b>Factor suitability as waders foraging area</b> |
|--|-------------------|------------------------|---|
| Low dynamic low litoral/mudflat              | 4 – 25 %          | 33 %                   | 0,0132 – 0,0825                                   |
| Low dynamic middlehigh litoral/mudflat       | 25 – 75 %         | 100 %                  | 0,2500 – 0,7500                                   |
| Low dynamic high litoral/ mudflat            | 75 – 85 %         | 69 %                   | 0,5175 – 0,5865                                   |
| Low dynamic supralitoral/pioneer high marsh  | 85 – 100 %        | 37 %                   | 0,3145 – 0,3700                                   |
| High dynamic litoral                         | 4 – 25 %          | 25 %                   | 0,0100 – 0,0625                                   |
|  | 25 – 75 %         | 25 %                   | 0,0625 – 0,1875                                   |
|  | 75 – 85 %         | 25 %                   | 0,1875 – 0,2125                                   |
| High dynamic supralitoral/pioneer high marsh | 85 – 100 %        | 25 %                   | 0,2125 – 0,2500                                   |

Ref.: Ysebaert, T. et al., 2016