



Scheldt Estuary Evaluation Methodology

Phase 2



Evaluation methodology Scheldt estuary Phase 2

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December 2011

Commissioned by:



Project number Deltares: 1204407

Project number University of Antwerp: ECOBE report 011-R148



Project part-financed by the
European Union (European
Regional Development Fund)

The Interreg IVB
North Sea Region
Programme



This report contains the English translation of the summary of 'Evaluation methodology Scheldt estuary, Phase 2' for exchange in the framework of the Interreg IVB project 'Tidal River Development (TIDE)'.

November 2012

Summary

1 Introduction

1.1 Background

The Scheldt estuary is a complex system in the throes of change. For reasons of securing economic, safety and wildlife interests, the Netherlands and Flanders jointly designed an integrated approach, viz. the Long-Term Vision (LTV), from which developed the Scheldt Estuary Development Outline 2010. In this context it was decided to set up the joint monitoring programme MONEOS. The right parameters are to be monitored in the right location with the right frequency. Still, even all these data do not provide a ready-made answer for policy. This requires an evaluation methodology. The basic principles of this methodology are the policy objectives from the LTV and the proper functioning of the ecosystem. It is thus by no means based on a historical or 'unspoilt' reference. The evaluation should not be aimed at a unilateral consolidation of the current status, but at a properly functioning system. The estuary should be given the freedom to evolve within the boundaries of this proper functioning. The methodology should offer the possibility to duly recognise and evaluate various evolutions in support of an adaptive management. It will be used to carry out an evaluation of the Scheldt estuary every six years.

A first version of the evaluation methodology (Phase 1) was delivered in 2010, but was deemed not sufficiently practicable to carry out an objective and unambiguous evaluation of the Scheldt. A new version should be more coherent and concise and contain a limited set of indicators with clear criteria.

1.2 Work method

The methodology is built around the three main functions of the LTV: Safety, Accessibility and Naturalness. On the basis of these functions a limited set of communication indicators has been developed (Figure 1-1). For 'Safety' and 'Accessibility' a communication indicator ('Hydrodynamics' and 'Navigability') was selected which evaluates the impact of the functioning of the system on these functions. The evaluation of 'Safety' and 'Accessibility' in itself is not part of this methodology. To evaluate 'Naturalness' five communication indicators have been drawn up: 'Tidal flat and Channel Systems', 'Living Environment', 'Water Quality', 'Ecological Functioning', 'Flora and Fauna'.

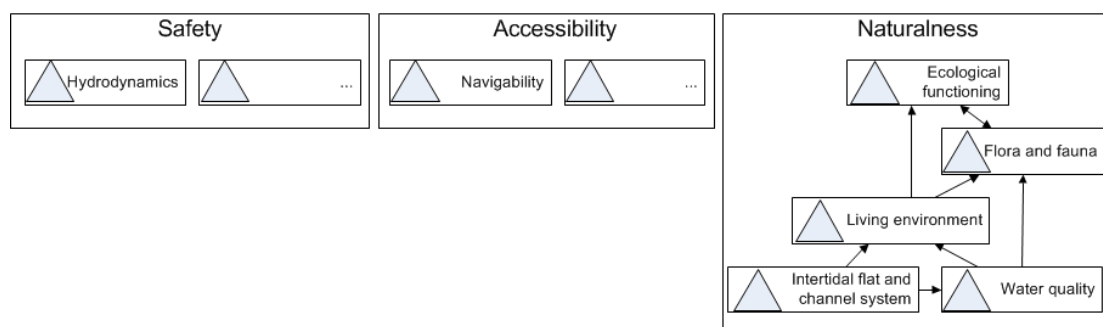


Figure 1-1: Diagram of the communication indicators (pyramids) per main function of the Long-Term Vision. NB. The functions 'Safety' and 'Accessibility' could later be extended to include communication indicators that are not directly related to the functioning of the system, but which do have an effect on the function.

Each communication indicator is discussed in a separate chapter and is evaluated on the basis of a tiered approach: the pyramid approach (Figure 1-2). At the top of the pyramid one can find the communication indicator. This indicator is evaluated by going through the lower levels.

Level 1: Directly below the communication indicator are the test parameters: a limited, yet complete set of parameters which can be used to evaluate the status or trend of the communication indicator in an unambiguous way.

Level 2: Each test parameter consists of one or more calculation parameters. A clear test criterion has been designed for each calculation parameter. All the calculation parameters combined determine whether the evolutions of a test parameter are favourable or unfavourable for the functioning of the system.

Level 3: At the bottom of the pyramid is a set of explanatory parameters. Explanatory parameters mainly help to understand the observed evolutions and to a lesser extent to evaluate the evolution. The reason for this is that the explanatory parameters themselves cannot be evaluated independently.

During the evaluation each of the levels is always completed. Explanatory parameters are always determined as well, since trends in explanatory parameters can point to underlying problems which in the long run can result in negative evolutions of a specific test parameter.

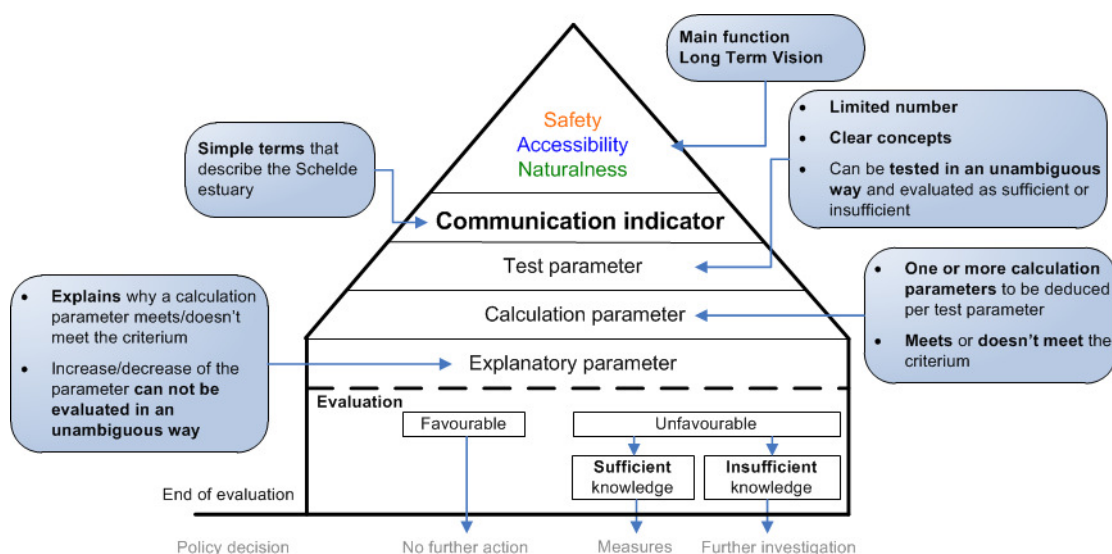


Figure 1-2: Diagram of the pyramid approach

However, the subdivision into different pyramids does not mean that no attention is paid to their mutual coherence. There is great mutual influence between pyramids, even though they have been developed with a minimum of redundancy. Still, test or calculation parameters from one pyramid can return as explanatory parameters in another pyramid. In this way the interrelation within the estuarine system is implicitly built-in in the methodology.

A first step in designing the various pyramids was to clearly outline concrete goals. The Long-Term Vision was used as the basis for this. Other existing policy frameworks were applied as well to define the goals. Suitable indicators and corresponding evaluation criteria were selected on the basis of these goals: which preconditions should the system meet in order to function within the margins of the set goals. Harmonisation with existing legal frameworks and criteria was aimed at. If, however, other yardsticks were reasoned

on the basis of the system's functioning than those used in the legal frameworks, the existing criteria are deviated from in this methodology.

The LTV mentions 'robustness' as an important feature of the Scheldt estuary. A robust system is able to withstand a (limited) disruption. The testing of 'robustness', and by extension the performance of a risk assessment, does not fall within the scope of this evaluation methodology. However, the methodology has been conceived in such a way that it can lend itself for such an approach later on.

2 Hydrodynamics

2.1 Introduction

The communication indicator 'Hydrodynamics' is mainly linked to the main function 'Safety', but is also important for the main functions 'Accessibility' (elaboration under the communication indicator *Navigability*) and 'Naturalness' (water level as explanatory parameter for the communication indicator *Living Environment*).

Both Flanders and Netherlands test their flood protection, using their own legal frameworks. Testing flood protection infrastructure, like embankments, against the legal safety standard is not part of the evaluation methodology. There are no legal standards, nor a policy framework for hydrodynamics.

For the system evaluation the indicator *Hydrodynamics* has been developed into two **test parameters**, High Tide and Waves (see Figure 2-1). Current velocity has not been included as a test parameter. Both test parameters only reflect the evolution, without any checks against safety standards.

No quantitative criteria have been drawn up for the calculation parameters because this indicator only reflects the evolution of trends, without valuing it to safety. It is indicated, however, whether an increasing or declining trend is positive or negative, from a systems perspective.

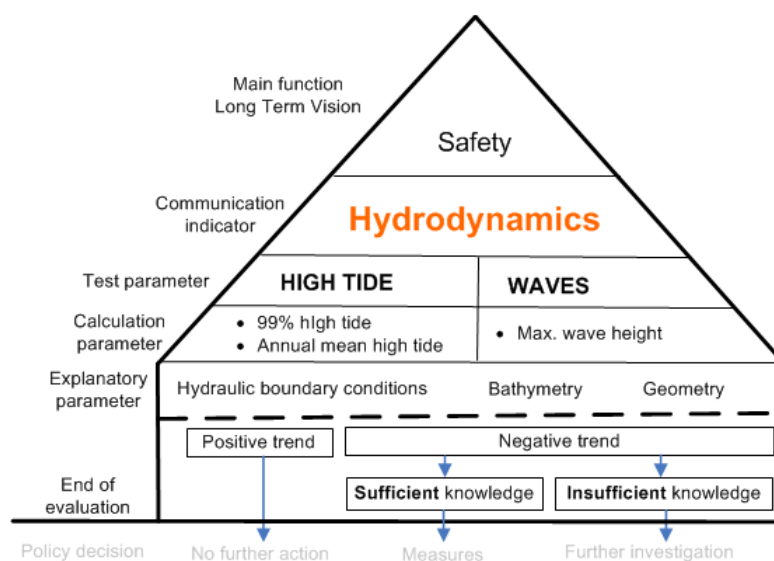


Figure 2-1: Diagram of the indicator *Hydrodynamics*

2.2 Test parameters

2.2.1 High Tide

The test parameter 'High Tide' is determined by two calculation parameters, viz. the **annual mean high tide** and the **99-percentile high tide** during the year. The annual mean high tide mainly relates to the astronomical tide and is a measure for the evaluation of the system in relation to the tidal propagation. The 99-percentile high tide during the calendar year is a proxy for the maximum water level and is mainly the result of a wind-driven surge combined with spring tide.

For the system's functioning an increase in relation to the expected trend evolution of the annual mean high tide and/or the 99-percentile high tide is evaluated as negative.

2.2.2 Waves

Waves are caused by wind and shipping. Shipping waves are not regarded as part of the test parameter *Waves*. The properties of wind waves depend on the wind speed and direction, the fetch, the bathymetry and the interaction with the tidal currents. There is a great natural variability in the incidence of storms. As a result, changes can be equally large year after year.

The purpose of the test parameter 'Waves' is to evaluate the effects of changes in the system, being the bathymetry, on wave action. This test parameter is determined by the calculation parameter **maximum annual wave height**.

For the system's functioning an increase in the maximum annual wave height in relation to the expected trend evolution is evaluated as negative.

3 Navigability

3.1 Introduction

The aim of the communication indicator *Navigability* is to provide insight into the functioning of hydrodynamics in relation to the main function 'Accessibility' of the Scheldt estuary. This means, for instance, that potential evolutions in ship types, channel stabilisation, wreck removal, external safety (transport of hazardous substances, risk contours), etc. are left out of consideration. Guaranteeing safe passage for ships in the Scheldt estuary is not part of the evaluation methodology, because this is done by the Common Nautical Administration.

The starting point for the evaluation of the navigability are the system aspects influencing navigability, i.e. the **test parameters** Navigable Depth and Tide Duration (see Figure 3-1). Strong cross currents are an impediment to shipping, but are not included as test parameter because these only occur in one specific location and ships handle it well. This means that the phenomenon hardly causes problems.

No quantitative criteria have been drawn up for the calculation parameters, because this indicator only reflects the evolution of trends without valuing it to accessibility. It is indicated, however, whether an increasing or declining trend is positive or negative, from a systems perspective.

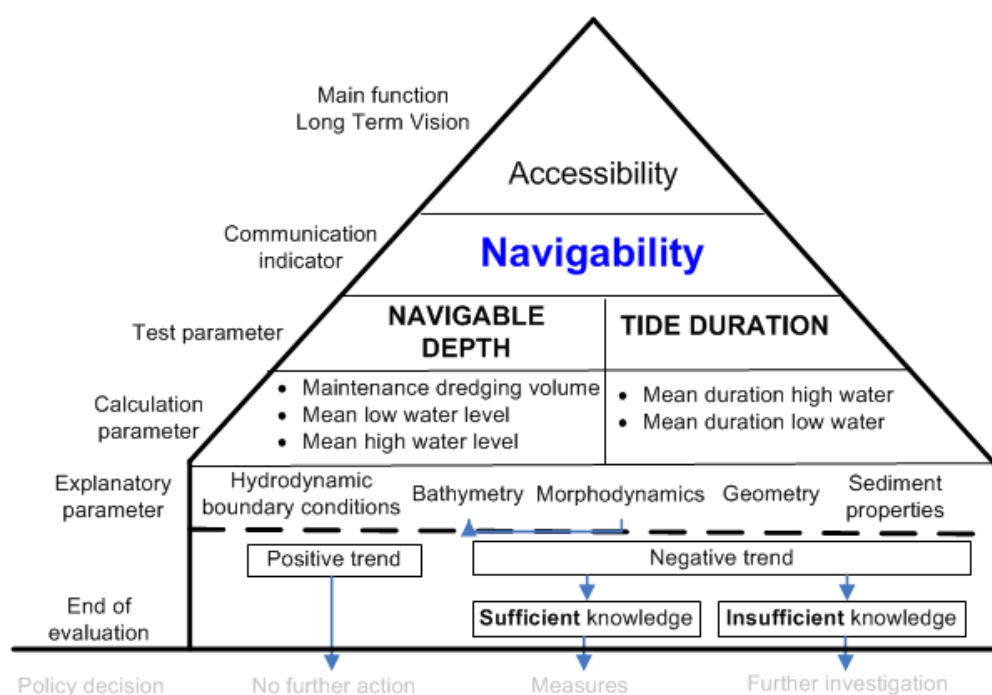


Figure 3-1: Diagram of communication indicator Navigability and underlying test, calculation and explanatory parameters

3.2 Test parameters

3.2.1 Navigable Depth

The test parameter *Navigable Depth* is defined as the minimum water depth in the fairway. For the Western Scheldt this is currently 14.7 m. Minimum water depths also exist for the Sea Scheldt.

Changes in **high and low water levels** lead to changes in water depth. For the evaluation of the high and low water levels the observations since 1900 are used. By first determining a 95% prediction interval it can be evaluated whether the new observations fall within these intervals. A decrease of the low water level (lower low water) and a decrease of the high water level (lower high water) in relation to the historical trend are regarded as an unfavourable evolution for the navigability. With statistical methods it can be determined whether the observed changes are significant.

The navigable depth and width are maintained through dredging. The **scale of the dredging effort** indicates whether the system is undergoing changes, supposing that there are no changes in the desired draught.

A distinction is made between dredged material that is predominantly sandy or silty and between dredging in channels or ports.

To evaluate the dredged volumes the observations are used that have been done since 2002 following the second deepening. Again, a 95% prediction interval can be applied to evaluate whether the new observations fall within these intervals. An increase in the maintenance volume for the fairway and/or in the ports in relation to the annual dredged volumes is regarded as unfavourable.

3.2.2 Tide Duration

Shipping bound by tide requires a water depth which is larger than the navigable depth and which is only available during part of the tide, i.e. the tidal window. A larger draught of a ship means a smaller tidal window.

The tidal window is determined by the duration of the tide, which is in its turn determined by the high and low water levels, the propagation speed of the high and low water levels, and the shape of the tidal curve. A higher propagation speed means a shorter duration of the tide and a smaller tidal window. This leads to a reduced navigability of the estuary¹.

The **duration of high and/or low water** between two stations is calculated by subtracting the time when high water occurs in the seaward station from the time when the high water occurs in the landward station. Again, a 95% prediction interval can be applied to evaluate whether the new observations fall within these intervals. A decrease in the duration of high and low water in relation to the historical trend is considered to be an unfavourable evolution for the navigability, especially for shipping bound by tide.

¹ Note that observed average changes per year are small, hence significant effects can only be noticed after a long period.

4 Intertidal flat and Channel System

4.1 Introduction

The indicator *Intertidal flat and Channel System* is part of the function 'Naturalness'. All indicators consist of three levels (Figure 4-1). The basis for this evaluation are hydro- and morphodynamics of the three subsystems in the Scheldt estuary: the mouth, the multiple channel system (Western Scheldt) and the single channel system (Sea Scheldt). This leads to three **test parameters**: Mouth, Multiple Channel System and Single Channel System.

Hydro- and morphodynamic naturalness is characterised by changes in patterns and processes in time (dynamics) and space (gradients). For each of the test parameters this results in the following scales of time and space:

1. **Large-scale dynamics**: The size, shape and hydro- and morphodynamic processes of the morphological cells and the channel system as a whole;
2. **Macro-scale dynamics**: The size, shape and hydro- and morphodynamic processes of individual large channels;
3. **Meso-scale dynamics**: The size, shape and hydro- and morphodynamic processes of smaller morphological elements.

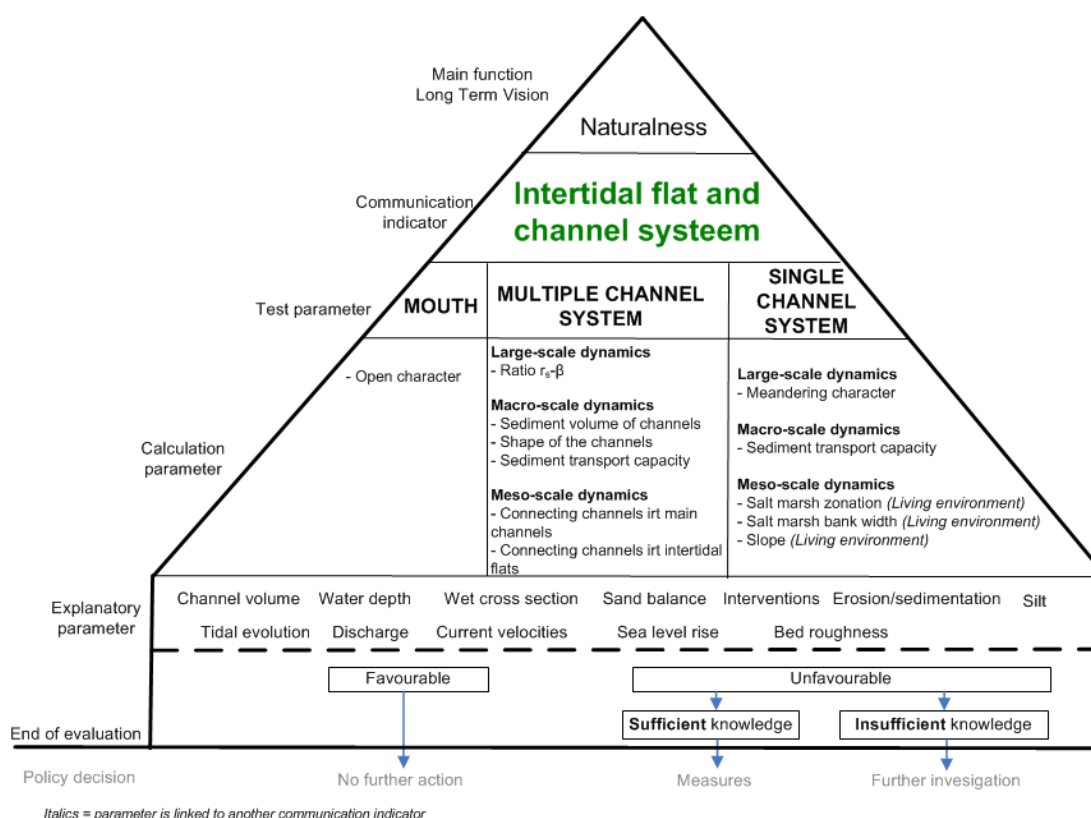


Figure 4-1: Diagram of communication indicator *Intertidal flat and Channel System* and underlying test, calculation and explanatory parameters

A lot of monitoring data and explanatory parameters are required for both the indicator '*Intertidal flat and Channel System*' and the indicator '*Living Environment*'. However, a clear choice was made to consider these two communication indicators separately. *Intertidal flat and Channel System* reflects the abiotics of intertidal flats and channels as a whole, often on longer time scales. *Living Environment* considers the development of the habitats that occur on the intertidal flats and channels with a breakdown into specific

quality characteristics, such as high- and low-dynamic areas (due to current velocities), high and low lying areas (duration of flooding) and the location along the fresh/salt water gradient.

4.2 Test parameters

4.2.1 Open Mouth

Both the “Scheldt Estuary Development Outline 2010” and the Long-Term Vision oppose any (large-scale) interventions in the mouth. Up till now no more specific indicators have been determined besides a qualitative test of the open character. For the qualitative test of the open character it is examined whether:

- a change has occurred in the vastness and openness of the area
- its role as transition area is impeded
- interventions have been made which affect the natural morphology of the estuary.

4.2.2 Multiple Channel System

The multiple channel system is characterised by a system with multiple channels that have gradual transitions to the intertidal flats. This system of channels and intertidal flats manifests itself in the Western Scheldt as a regular pattern of six so-called morphological cells. Each of these cells consists of a large curved ebb channel and a straight flood channel, separated by a long stretch of intertidal flats and connected by connecting channels.

The large-scale dynamics is considered on the basis of the calculation parameter '**ratio between the water surface area at high tide and low tide (r_s)**', as characterisation of the (relative) area of intertidal flats of the morphological cell, and the '**width-depth ratio of a morphological cell (β)**' in relation to the average sea level.

The macro-scale dynamics is determined by the large ebb and flood channels. Together, they form the backbone of a morphological cell. Besides this, most of the dredging and relocation activities take place in these channels. These channels are evaluated using the calculation parameters **Changes in the Volume and shape of the Channels** and the **Gross Sediment Transport Capacity**.

The connecting channels determine the meso-scale dynamics. They can exist because of the presence and geometry of the large ebb and flood channel in the morphological cell and the resulting water level differences. Due to this dependence and their shorter response time, changes in the dynamics of connecting channels can be a sign of changes in the larger channels which may not be measurable yet. Dynamics of connecting channels is to be understood as the presence of connecting channels (size, pattern) and their behaviour (whether or not quasi-cyclical with channel migration). Two calculation parameters have been drawn up with regard to connecting channels: the '**Dynamics of connecting channels in relation to the main channels**' and the '**Dynamics of connecting channels in relation to the intertidal flats**'.

4.2.2.1 Evaluation of the multiple channel system

To evaluate and assess the indicator 'Intertidal flat and Channel System' the calculation parameters on the different scale levels must be assessed in mutual coherence. For instance, in the morphological cell 4, the evolution in the 'Middelgat' (ebb channel) will always have to be considered in the light of the changes that took place with the 'Overloop van Hansweert' (flood channel). No generic, quantitative standards are available for what is favourable and unfavourable for the intertidal flat and channel system on the scale of the estuary. It is possible, however, to classify observed

evolutions per area (macro-scale) as favourable or unfavourable, from the point of view of 'hydro- and morphodynamic naturalness'. This is one spatial level lower than the scale of the entire multiple channel system and the single channel system. The areas on the macro-scale each need their own reference for morphological naturalness. This requires a good knowledge of the area. A step-by-step scheme has been drawn up for the evaluation of the multiple channel system which includes this morphological coherence.

4.2.3 Single Channel System

The evolution of the geometry (meandering character), the sediment transport and the evolution of the river banks are important for the single channel system. Again, the three scales of time and space are significant.

The meandering character is an essential element of the large-scale dynamics of the single channel system. The number of bends and the length of the thalweg determine the **extent of meandering**. This is the calculation parameter on the basis of which the large-scale dynamics of the single-channel system is described.

The macro-scale dynamics is evaluated on the basis of the **sediment transport capacity** of the single-channel system.

Generally, the channel width of a river increases faster downstream than the channel depth. Therefore, the width to depth ratio increases. This feature determines the dynamics on the meso-scale. The development of the width to depth ratio manifests itself in the evolution of the habitats (**salt marsh zonation, salt marsh bank width, slope**) which have been worked out under the indicator '*Living Environment*'.

5 Water Quality

5.1 Introduction

The communication indicator '*Water Quality*' includes both physicochemical aspects and aspects of biological water quality. The evaluation is not based on pristine or reference situations, but resolutely on the functioning of the ecosystem. This implies that boundaries are set in which a limited set of test parameters may fluctuate, so as not to impede the proper functioning of the ecosystem and to ensure the achievement of certain ecological quality features.

The set of test parameters is limited to 'Oxygen', 'Nutrients', 'Algae' and 'Toxic Substances', for which clearly quantifiable calculation parameters and criteria were drawn up (Figure 5-1). These 4 test parameters determine the 'Water Quality'. Parameters such as 'salinity', 'light climate', 'temperature' or 'residence time' are also inextricably linked with water quality. They will be used as explanatory parameters in the evaluation.

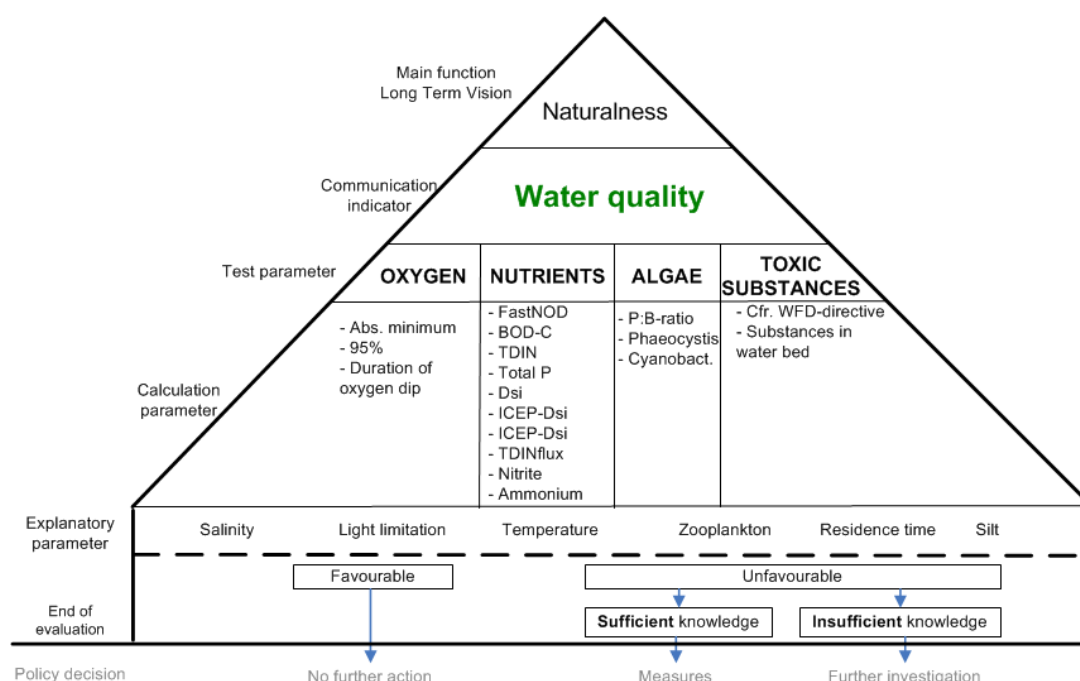


Figure 5-1: Diagram of communication indicator 'Water Quality'

5.2 Test parameters

5.2.1 Oxygen

Oxygen is of vital importance for all animal life, ranging from small plankton to large fish. If something is wrong with the oxygen level, the whole ecosystem will bear the consequences of this. Therefore, oxygen is an essential test parameter for Water Quality. For this reason it was examined how much oxygen each of the different parts of the aquatic ecosystem requires, in order to deduce the minimum levels. These minimum levels may vary in time and space. For instance, the oxygen criterion will be higher during periods of fish migration.

The oxygen requirements were translated into three calculation parameters. These can be applied throughout the estuary thanks to the monthly monitoring programmes.

Moreover they can be checked on a 24-hour basis thanks to a network of permanent monitoring stations. First, a threshold value of 5 mg/l is proposed in the summer half-year. In the winter half-year this lower limit is increased to 6 mg/l, among other things in view of the migration and spawning of certain fish species. Since oxygen fluctuations may take place naturally in an estuary, a 95 percentile is used. Oxygen dips may occur in the estuary without causing any damage to the ecosystem, provided they are limited in scale and duration. This brings us to the second and third calculation parameters: the oxygen level must never decrease below 2.5 mg/l and the dip must never last longer than 5 hours.

5.2.2 Nutrients

This test parameter examines whether the nutrient load which passes through the Scheldt does not impede the achievement of the good ecological status. This applies to the good ecological status in both the Scheldt itself and in the estuary. After all, we cannot give the Scheldt a positive evaluation if we know that it causes problems for the North Sea.

Apart from nutrients, this test parameter also takes into account the organic carbon load. Together they form the basis of the eutrophication issue. This resulted in the selection of 10 calculation parameters which we can subdivide into eutrophication in the estuary and eutrophication in the coastal area.

In the case of eutrophication in the estuary we focus on three phenomena. First, an excess biodegradable carbon load and excess ammonium may lead to too large oxygen consumption which jeopardises the criteria for oxygen. On the other hand, excess nutrients in a wrong ratio (silicium plays an essential role in this) can lead to shifts in the algae community. Also, some nutrients may have a direct toxic effect. The necessary calculation parameters have been defined for each of these aspects.

Finally, the effects on the coastal area are also considered, with the focus on shifts in the algae community.

5.2.3 Algae

Algae, and more in particular diatoms, form the basis of the food chain and are therefore essential for the estuarine ecosystem. However, excess algae may cause a problematic oxygen demand when they die. The ideal algae concentration and the threshold value at which problems may start occurring depend on a number of factors. Therefore, it is impossible to develop an unambiguous criterion for the algae concentration. Simplified, we can state that algae do not cause any problems as long as they are readily eaten. To this end the P/B ratio was selected as calculation parameter. This ratio indicates the relationship between primary production and algae biomass. A high ratio is ideal, because this means that the algae are very productive, but still limited in terms of biomass. This is only possible when they are readily eaten.

In the estuary a number of toxic algae species may also occur. For this reason, the density in *Phaeocystis* and *Cyanobacteria* is evaluated as a separate calculation parameter.

5.2.4 Toxic Substances

The test parameters 'Oxygen', 'Nutrients' and 'Algae' have a direct influence on the functioning of the ecosystem, which in its turn has an important impact on these parameters. Consequently, interventions in the estuary and the estuarine functioning may have a bearing on these test parameters. This interaction is much less present for toxic substances. Toxic substances may thoroughly disturb the functioning of the ecosystem, whereas the influence of the estuarine management is limited here.

The evaluation of toxic substances is a complex matter, even more so because the list of toxic substances constantly changes. Within this evaluation methodology the logic from the VLIZ-SDI (Sustainable Development Indicators for the Scheldt Estuary) report and the Water Framework Directive is maintained. The VLIZ-SDI report proposes the following measurements for the indicator 'Pressure due to Environmental Pollutants'.

- Emissions of nutrients into the surface water of the Scheldt estuary
- Waterbed quality in the Scheldt estuary
- Swimming water quality in the Scheldt estuary
- Environmental pollutants in the food web of the Scheldt estuary

For this evaluation methodology the last 3 measurements are indicated as calculation parameters for toxic substances. Nutrients are a separate test parameter. For a description of the calculation parameters and the assessment thereof, we refer to the existing legal frameworks.

6 Living Environment

6.1 Introduction

The communication indicator '*Living Environment*' is part of the main function 'Naturalness' in the Scheldt estuary. In the chapter 'Living Environment' the term 'habitats' is used because it mainly concerns habitats for flora and fauna. The boundaries between the different habitats are determined on the basis of physical characteristics which are largely dictated by the presence of flora and fauna.

The Scheldt estuary is constantly subject to changes and is characterised by a large variation of habitats. This variation is caused by the salinity gradient, the height gradient and the internal gradient of a cyclical variation in habitats in a specific location. In addition, a lot of changes are effected by human interventions with morphological changes that are reflected in the absence or presence of habitats.

Many habitats have an important function in the ecological functioning of the Scheldt estuary. Higher trophic levels, such as fish, birds and sea mammals need these habitats as staging, pawning or feeding grounds.

The basic principle for the evaluation of '*Living Environment for flora and fauna*' is that the Scheldt estuary functions naturally, if the **surface area** is divided between different habitats in a balanced way, if the existing habitats are of a sufficient **quality** (both abiotically and biotically) and if there is stability in the habitats. By the latter is meant that habitat **turnover** does not occur too often in a specific location. These three aspects constitute the test parameters of the '*Living Environment*' indicator.

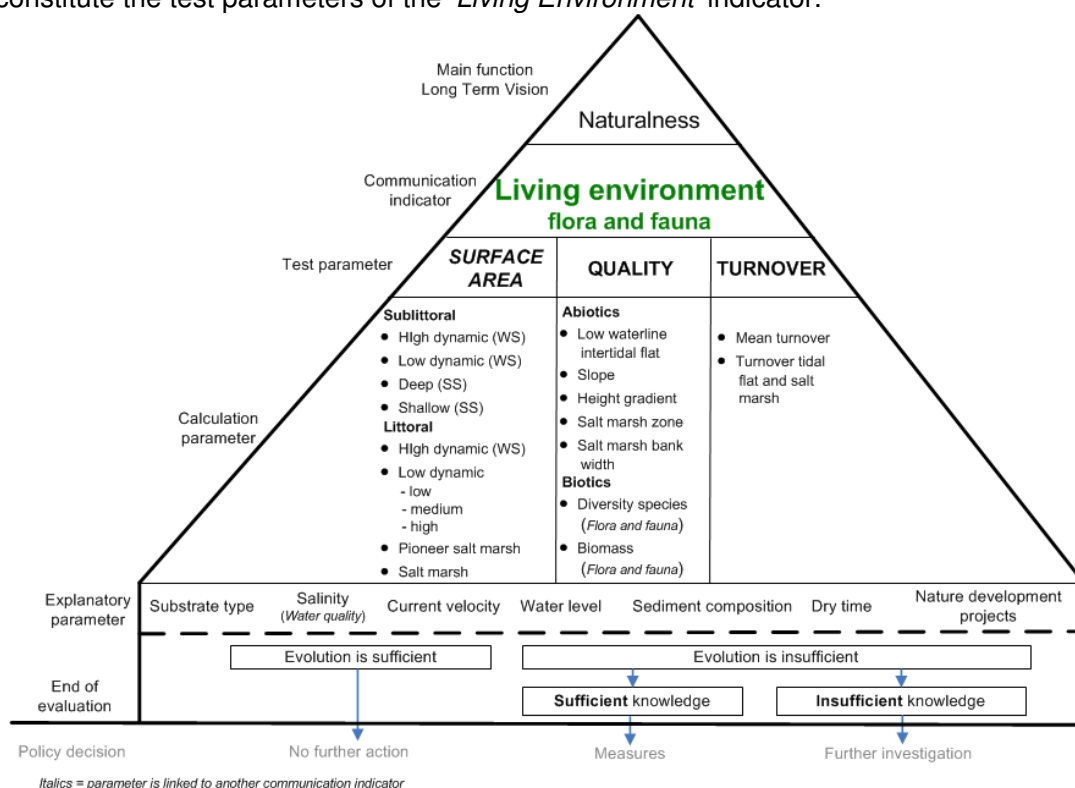


Figure 6-1: Diagram of communication indicator '*Living Environment*', for flora and fauna

6.2 Test parameters

6.2.1 Surface Area

In order to guarantee the ecological functioning, not only the area of the most important habitats is important, but also their mutual relationships and spatial spread. For instance, high dynamic littoral habitats are less interesting for many bird species than low dynamic littoral habitats where birds can easily follow the waterline when feeding.

Under the test parameter 'Surface Area' the (aggregated) habitats are defined which constitute the calculation parameters and jointly provide a picture of the Scheldt estuary as a whole. It concerns the high and low dynamic sublittoral habitats, high dynamic littoral habitats, low dynamic low, medium and high littoral habitats, pioneer salt marsh and salt marsh.

Because in the Sea Scheldt no distinction is made (yet) in terms of dynamics, it has been decided to subdivide the sublittoral in the fresh water segments (Sea Scheldt) in terms of deep and shallow water instead of dynamics. Furthermore, the high dynamic littoral is not distinguished in the littoral and the surface areas of the low, medium and high littoral habitats are determined irrespective of the dynamics.

6.2.2 Quality

The quality of the habitat is of the utmost importance for the ecological functioning of the Scheldt estuary. Although the surface areas may be available, the system will function not at all or insufficiently if the quality does not suffice.

The test parameter 'Quality' is determined by the structure (abiotic quality) and the existing flora and fauna (biological quality). The structure is defined by the existing dynamics in combination with the morphology of the habitat (length of low waterline and slope), the presence of height gradients, the space for banks (bank width) and the presence of salt marsh zones. The biological quality is determined by the diversity and biomass of the existing flora and fauna for higher trophic levels.

6.2.3 Turnover

Habitat turnover is the conversion dynamics from one habitat to another in a specific location. In a healthy and dynamic system there is always habitat turnover to some extent. However, there must also be stability of the habitat in a specific location.

When evaluating the test parameter 'Turnover' the average turnover in each segment is considered as well as the turnover of sandbars, intertidal mudflats and salt marshes. Systematic changes can be observed on the basis of this. These systematic changes may be a local phenomenon, but they can also be steered by physical powers on a macro- and mega-scale.

6.3 Reference values

Not all the exact reference values per segment are available yet for the calculation parameters under the three test parameters. Exact values under the test parameter 'Surface area' are available for the calculation parameters high dynamic sublittoral and littoral, the shallow sublittoral and the pioneer vegetation. For the test parameter 'Quality' exact values are available for the calculation parameters the slope across the entire profile, the existing height gradient, the bank width and the zoning of the salt marsh habitat. No exact values are available yet for the calculation parameters under the test parameter 'Turnover'.

Although legal frameworks have provided values for the surface of some habitat types defined under the test parameter 'Surface Area', these do not sufficiently correspond in terms of definition and spatial extent with the evaluation methodology. For the test parameters 'Quality' and 'Turnover' the legal frameworks do not provide any values for the calculation parameters.

In the short term the lacking exact reference values will have to be deduced.

7 Flora and Fauna

7.1 Introduction

The communication indicator '*Flora and Fauna*' encompasses the evaluation of biodiversity in the estuary. Biodiversity is one of the basic characteristics of each ecosystem. Within this communication indicator we limit ourselves to the diversity of species. Apart from its intrinsic value, diversity is important to mankind both directly and indirectly. Its direct importance as food and material, among other things, is clear. The indirect importance of biodiversity is the role it plays in the functioning of ecosystems. There is a clear connection between biodiversity and function. In other words, the functionality of a system (for instance primary production, nutrient cycling,...) correlates positively with the number of species. Therefore, an evaluation of the diversity is required. It is difficult to determine how much diversity is exactly needed. Since much diversity has already been lost, each further loss is evaluated negatively.

7.1.1 Determination of diversity

There are different ways to determine diversity, but usually this is done via indices. Overall, diversity indices can be subdivided into 2 large groups: those which only take into account the presence of species and those which also consider the evenness (the distribution of the number of individuals among the species). Such indices are very useful for giving a global assessment. However, in most cases no account is taken of the species themselves. As a result, traditional diversity indices do not respond when all the species in a community are replaced but the number of species remains the same. An intactness index on the other hand compares species against a reference matrix and is consequently susceptible to oppression of original species by exotic ones.

The work method for '*Flora and Fauna*' is based on a threefold approach. First, the diversity is considered using intactness indices. To that end reference matrices are to be drawn up for all groups of species we wish to evaluate: lists of species that belong in a healthy system.

Secondly, all species within the intactness index are equally important. However, some species fulfil keystone functions within the estuary or enjoy special protection. That is why a quantitative evaluation is also carried out for these keystone species. For various species, amongst others migratory birds, the trend in numbers strongly depends on what goes on outside the estuary. For this reason, the trends will be evaluated in function of the global trend of the Delta or Northwest European population.

Thirdly, additional attention is paid to the exotic species. The arrival of an invasive exotic species can have a detrimental effect on other organisms or functions. That is why exotic species are evaluated quantitatively (trend) as well. Species which move their distribution area as a result of global warming, i.e. the so-called shifters, are not counted among the exotic species. The reason for this is that the policy that is implemented in the estuary cannot put an end to these evolutions. This contrasts sharply with the actual exotic species where regulations on ballast water, for instance, can play an important role in preventing exotic species from becoming established.

7.2 Test parameters

One of the goals in this evaluation methodology is to work with the smallest possible set of test parameters. However, under '*Flora and Fauna*' the diversity of various organisms is to be evaluated. There is no point in classifying organisms that differ too much from each other under one single index. Therefore the following 7 test parameters have been selected within the communication indicator '*Flora and Fauna*': 'Birds', 'Mammals', 'Fish', 'Benthos', 'Zooplankton', 'Phytoplankton' and 'Vegetation' (Figure 7-1). Each test

parameter will be evaluated through 3 calculation parameters: intactness, key species and exotic species.

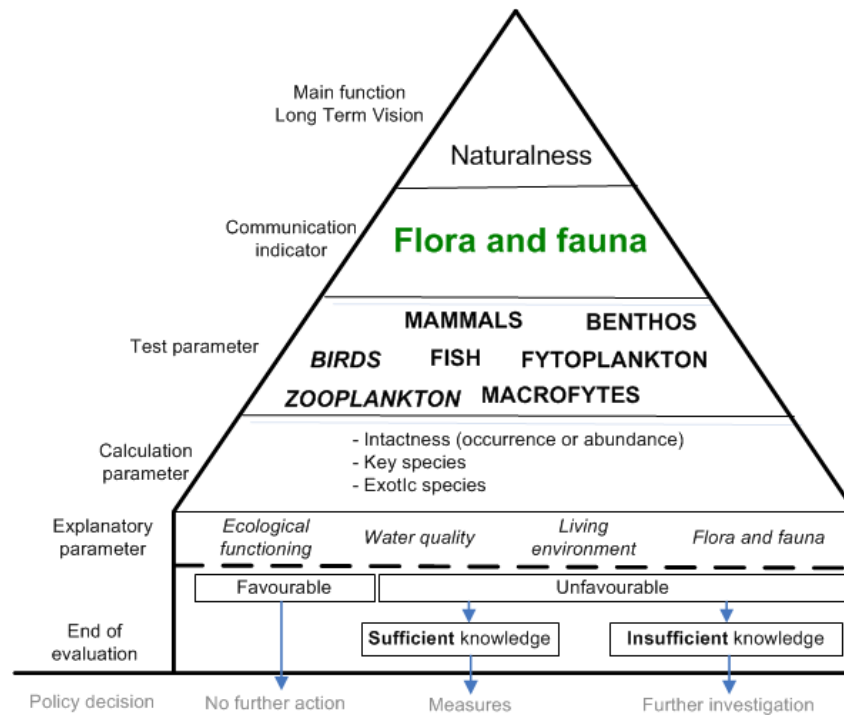


Figure 7-1: Diagram of communication indicator 'Flora and Fauna'

8 Ecological Functioning

8.1 Introduction

Ecological functioning is a title that covers a broad content ranging from biochemical aspects such as nutrient cycling to completing the life cycle of various organisms. Evaluating all these aspects within the Ecological Functioning chapter is neither possible nor desirable. In fact, because the evaluation methodology starts from the LTV goals and looks for test parameters on the basis of the functioning of the ecosystem, many aspects of the ecological functioning are already embedded in other pyramids. These do not evaluate the ecological functioning itself, but monitor the preconditions for proper functioning.

The starting point for the communication indicator '*Ecological Functioning*' is the flow of energy in the food chain: which parameters are suitable for evaluating the functioning of the food chain, viz. passing on energy from primary products to higher trophic levels. However, the success of the highest trophic levels is determined by many factors, such as habitat quality, water quality or predation. For this reason they are less suitable for evaluating the flow of energy. Here we want to provide a picture of the entire chain.

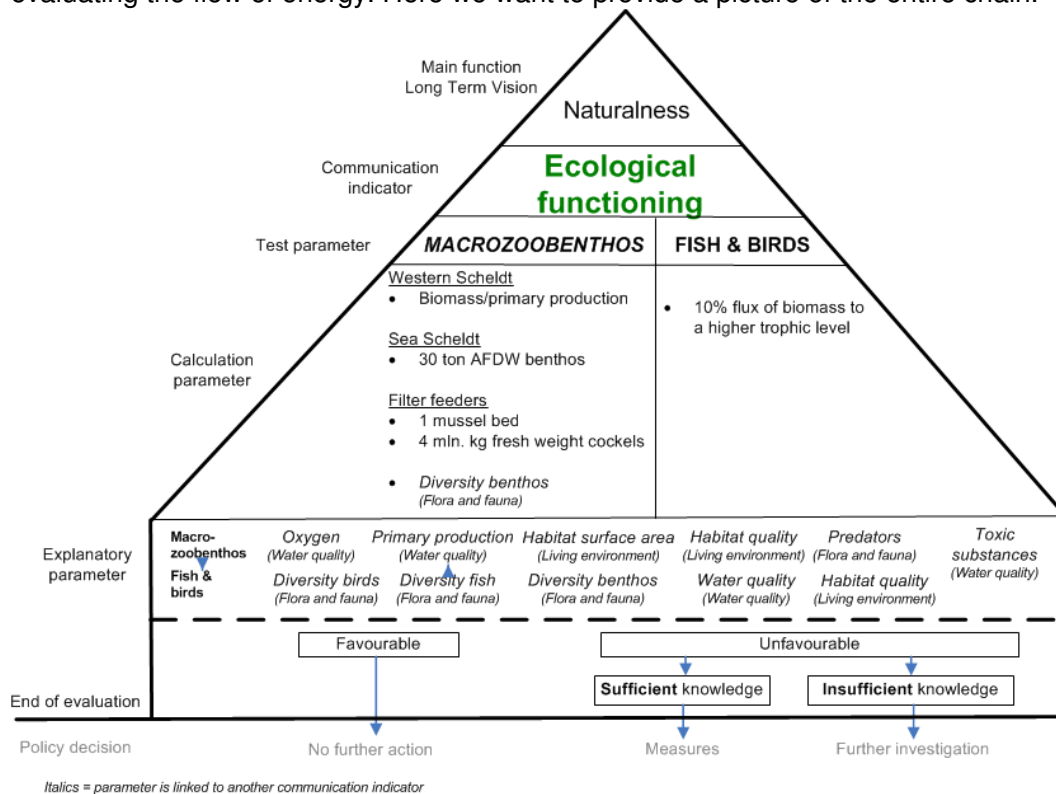


Figure 8-1: Diagram of communication indicator 'Ecological Functioning'

Retaining solar energy by means of pelagic algae and the transfer to zooplankton is evaluated in the test parameter '*Algae*' ('*Water quality*'), because of the interaction between this algal bloom and the physicochemical water quality. Benthic algae come under '*Living Environment*'. The flow from primary producers to the macrozoobenthos is the first test parameter within '*Ecological Functioning*'. The further flow of energy from the secondary producers, both benthic and pelagic, to higher trophic levels is a very complex matter which cannot be grasped in just a few parameters. Therefore, this pyramid considers the total flow from secondary producers to all the higher levels combined. These higher levels are limited to certain fish and bird species, elaborated in the test parameter '*Fish and Birds*' (Figure 8-1).

8.2 Test parameters

8.2.1 Macrozoobenthos

There is a dynamic balance between macrobenthic biomass production (per unit of surface area) and system average primary production. This ratio can be easily applied to the Western Scheldt, resulting in the following calculation parameter: in the Western Scheldt the macrobenthic biomass density (ADWmb, in g AFDW.m⁻²) must relate to the primary production density (PP, in g C.m⁻².j⁻¹) according to the equation $ADWmb = 1,5 + 0,105 \cdot PP$. Any deviations from this trend suggest problems. Because of the different character this cannot be directly applied to the Sea Scheldt. This reasoning is used, however, to calculate the benthos requirements for the Sea Scheldt: how many tonnes of benthos are required to achieve a good capacity for higher levels. This results in a criterion of 30 tonnes, which may possibly be further refined when better data are available.

Sufficient benthos alone is not enough because a proper ecological functioning also requires the necessary diversity. For the evaluation thereof this calculation parameter refers to the communication indicator '*Flora and Fauna*'.

Within this chapter special attention is devoted to an important ecological function of benthic organisms, namely the filtering function. Evaluating the filtering function itself is not possible, but in order to maintain the filtering function the following criteria have been defined: a minimum of 1 permanent mussel bed and a minimum of 4 million kg wet weight of cockles present in the Western Scheldt.

8.2.2 Fish and Birds

Whereas the flow of energy from the primary to the secondary level is still relatively easy to assess, it is much more complicated to determine the flow to higher levels. For fish and birds, the estuary is rather an open system. On a system scale the ratio between secondary production and higher trophic functioning can be assessed on the basis of ecological relationships. These indicate that predator/prey relationships amount to a flow of roughly 10% of the energy to the next level. However, in this respect there is 'noise' between the communities: A specific fish species can eat benthos but also hunt other fish species, or have a different menu as a juvenile than as an adult fish. Energy from Benthos flows on to waders, but also to fish and crab. The proposed connection must be broad enough to include the main share of the exchanged energy. Therefore, the following criterion is proposed: On a system scale, 10% of the biomass of all the benthos, hyperbenthos and zooplankton combined should flow to the higher trophic level consisting of fish, birds and crab. Moreover, the ratio between the trophic levels should not decrease.