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From past to present: biodiversity in a changing delta

K. Troost, M. Tangelder, D. van den Ende & T.J.W. Ysebaert

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From past to present: biodiversity in a changing delta

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WOt Working Document **317** presents the findings of a research project commissioned by the Netherlands Environmental Assessment Agency (PBL) and funded by the Dutch Ministry of Economic Affairs (EZ). This document contributes to the body of knowledge which will be incorporated in more policy-oriented publications such as the National Nature Outlook and Environmental Balance reports, and thematic assessments.

From past to present: biodiversity in a changing delta

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Abstract
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A large-scale coastal engineering project (the 'Delta works') changed large-scale, dynamic estuarine nature in the southwest of the Netherlands into a diverse mosaic of ecosystems with different characteristics. This led to a suite of ecological problems, which is why plans are made to restore estuarine dynamics. Until today the effect of the Delta works on biodiversity in the subsystems is still poorly understood. We combined long-term datasets on macrobenthos, fish, birds and key species and present reliable and factual information on changes in biodiversity in the Southwest Delta in the past decennia in relation to the Delta works and other developments. Effects of the Delta works on biodiversity are highly diverse and depend on many different factors and histories specific for the different water bodies. If connections are restored, effects on species richness and biodiversity will depend on the specific characteristics of the separate basins. Because restoration of estuarine dynamics likely occurs on a reduced scale, effects on biodiversity may only be modest. However, effects on the occurrence of rare species of the brackish and intertidal transition zones may be more significant. It is recommended to study this further.

Key words: biodiversity, restoration of estuarine dynamics, Delta works, long-term trends, species richness

Trefwoorden: biodiversiteit, zuidwestelijke Delta, Deltawerken, herstel estuariene dynamiek, lange termijn trends, soortenrijkdom

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Summary

A large-scale coastal engineering project (the 'Delta works') drastically changed the appearance, hydromorphology and ecology of the Rhine-Meuse and Scheldt delta in the southwest of the Netherlands. A formerly estuarine delta with multiple branches was fragmented by dams into several smaller areas of which many lost their estuarine character. Large-scale, dynamic estuarine nature changed into a diverse mosaic of ecosystems with different characteristics.

However, in recent years it became clear that there is also a downside to the Delta works. Reduced dynamics resulted in several ecological problems, such as erosion of tidal flats in the Oosterschelde estuary, blooms of cyanobacteria in Lake Krammer-Volkerak, and oxygen deficiency in Lake Grevelingen. To address these problems, as well as future effects of climate change and sea level rise, possibilities for restoring estuarine dynamics, salinity gradients and connectivity between water bodies are currently investigated (Deltaprogramma, Stuurgroep Zuidwestelijke Delta).

To be able to predict consequences for species biodiversity we need to know todays biodiversity, as well as how biodiversity of the different water bodies, and the delta area as a whole, changed due to the long-term effects of the 'Delta project'. This study addresses the question what will be gained and what will be lost if we restore estuarine dynamics. This question is answered in two reports, financed by the Ministry of Economic Affairs (EZ). The first of the two reports shows how the biodiversity of some main species groups (birds and fish) in each subsystem evolved into today's state, and how this relates to the biodiversity of the entire Delta area as a whole. Based on these results it is questioned whether restoration of estuarine dynamics will lead to an increase or decrease in biodiversity, species richness, and overall robustness (Tangelder *et al.,* 2012). The second report is the one presented here. The study was commissioned by the Netherlands Environmental Assessment Agency (Planbureau voor de Leefomgeving, PBL) with the goal to make a more detailed comparison possible between on the one hand an open delta with connections between the different water bodies and with the river systems and North Sea, and on the other hand a fragmented delta as was created by the Delta works. Water bodies studied in detail are the Oosterschelde estuary and the Lakes Grevelingen, Veere and Haringvliet. We combined available long-term datasets on macrobenthos, fish, birds, and key species (sea grass and sea mammals) with the aim to present reliable and factual information on changes in biodiversity in the Southwestern Delta in the past few decennia, and how the Delta works influenced it. In many cases there were no time series available that cover the period around, or just after, the construction of the Delta works. Before describing analysis results we therefore first give a literature overview of documented changes as a consequence of closing the Oosterschelde from riverine input, completion of the Oosterschelde storm surge barrier, and creation of the Lakes Grevelingen, Veere and Haringvliet.

The results clearly illustrate the main problems of the Delta works: almost no migration possibilities for fish, a loss in estuarine dynamics causing a reduction in pioneer vegetations and breeding habitats on bare grounds as well as bad water quality, and a loss in species strictly associated with the intertidal and brackish zones in estuarine salinity gradients. If connections are to be restored (even to some extent) between saltwater and freshwater systems, allowing for migration and salinity gradients as well as some tidal movement, this is likely to lead to a higher species richness locally. Overall biodiversity in the different water bodies and the Southwestern Delta as a whole may only change slightly. However, restoration of connections and estuarine gradients and dynamics is likely to occur on a scale that is much more reduced in comparison with the situation before the Delta works. The positive effects on biodiversity caused by these measures may therefore be modest. On the other hand, effects on the occurrence of species and communities exclusively occurring in the intertidal and brackish transition zones that have become more rare due to the Delta works, may be more significant. It is recommended to study this effect in more detail in a follow-up study.

Samenvatting

De zuidwestelijke Delta is als gevolg van de Deltawerken drastisch veranderd. De voorheen grootschalige estuariene natuur werd omgevormd in een gevarieerd mozaïek van verschillende, van elkaar gescheiden, waterbekkens met grote verschillen in abiotische en ecologische karakteristieken. Daarbij verloor een groot deel van de nieuwe gebieden het estuariene karakter.

Recent werd duidelijk dat er ook een schaduwzijde was aan de Deltawerken, in ieder geval wat betreft de ecologie. Gereduceerde dynamiek heeft geresulteerd in verschillende problemen, zoals de zandhonger in de Oosterschelde, de bloei van toxische blauwalgen in het Krammer-Volkerak en zuurstofloosheid in het Grevelingenmeer. Om iets aan deze problematiek te doen, en om toekomstige problemen als gevolg van klimaatverandering voor te zijn, worden momenteel mogelijkheden verkend voor het herstellen van estuariene dynamiek en verbindingen tussen bekkens (Stuurgroep Zuidwestelijke Delta).

Om de gevolgen van eventuele ingrepen voor de biodiversiteit van soorten in het mariene en aquatische milieu te kunnen voorspellen, moeten we eerst weten hoe het momenteel gaat met de biodiversiteit in de verschillende bekkens, en hoe de biodiversiteit in de verschillende gebieden en de delta als geheel is veranderd als gevolg van de Deltawerken. Deze studie houdt zich bezig met de vraag wat er gewonnen zal worden aan biodiversiteit en wat er verloren zal worden als de estuariene dynamiek wordt hersteld. Deze vraag wordt beantwoord door twee rapporten, gefinancierd door het Ministerie van Economische Zaken (EZ). Het eerste laat zien hoe de biodiversiteit van enkele belangrijke soortgroepen (vogels en vissen) in de verschillende Deltawateren zich heeft ontwikkeld tot de huidige situatie, en hoe zich dit verhoudt tot de biodiversiteit van de Zuidwestelijke Delta als geheel (Tangelder *et al.*, 2012). De resultaten worden gebruikt om te bediscussiëren of herstel van estuariene dynamiek zal leiden tot een toename, of juist een afname, van biodiversiteit, soortenrijkdom, en robuustheid. Het tweede rapport is het voorliggende. Deze studie werd uitgevoerd in opdracht van het Planbureau voor de Leefomgeving (PBL) met het doel om een meer gedetailleerde vergelijking mogelijk te maken tussen aan de ene kant een open Delta met verbindingen tussen de verschillende bekkens en met de rivieren en Noordzee, en aan de andere kant een gefragmenteerde Delta zoals ontstaan is door de Deltawerken.

We hebben beschikbare tijdseries van macrobenthos, vissen, vogels en sleutelsoorten (zeegras en zeezoogdieren) gecombineerd om zo betrouwbaar en feitelijk mogelijk de veranderingen in biodiversiteit in de Zuidwestelijke Delta gedurende de laatste decennia te beschrijven, en hoe de Deltawerken deze hebben beïnvloed. In veel gevallen waren er geen tijdseries beschikbaar van de periode rond, of vlak na, de vorming van de verschillende bekkens in hun huidige staat. Alvorens de resultaten van onze analyses te beschrijven, geven we daarom een literatuur overzicht van de gedocumenteerde effecten van de bouw van de Deltawerken die de bestudeerde bekkens hebben beïnvloed.

De resultaten illustreren heel duidelijk de belangrijkste problemen van de Deltawerken: nauwelijks migratiemogelijkheden voor vissen, begroeiing van kale gronden (pioniervegetaties en geassocieerde broedvogels) door een verlies aan estuariene dynamiek, slechte waterkwaliteit, en een verlies aan soorten dat alleen voorkomt in de brakwaterzone en de getijdenzone. Als verbindingen worden hersteld (zelfs in beperkte mate) zal dit waarschijnlijk leiden tot een hogere soortenrijkdom in de verschillende bekkens en de Delta als geheel, maar het effect op algehele biodiversiteit in de Zuidwestelijke Delta zal waarschijnlijk beperkt zijn. Herstelmaatregelen zullen echter waarschijnlijk op een gereduceerde schaal plaatsvinden in vergelijking met de situatie voor de Deltawerken, en daarom wordt verwacht dat effecten op biodiversiteit bescheiden zullen blijven. Gevolgen zouden echter wel groot kunnen zijn voor soorten gemeenschappen die uitsluitend in de overgangszones voorkomen en daarom zeldzamer zijn geworden door de Deltawerken. Aanbevolen wordt om dit in een vervolgstudie te onderzoeken.

1 Introduction

A large-scale engineering project, the 'Delta project', caused drastic changes in the ecosystems of the different estuaries of the Southwestern Delta (SW Delta) in the Netherlands. Estuarine ecosystems with extensive intertidal habitats (mud and sand flats, marshes) were changed into stagnant fresh, brackish and salt water lakes. Although the Delta Works provided protection and brought safety following the flood disaster of 1953, the Delta Works also have their downsides for the natural environment, water quality and the economy. While some environmental drawbacks were expected at the time, the Delta currently faces many ecological problems, indicating a lack in robustness. Examples are: erosion of tidal flats in the Oosterschelde estuary (Van Zanten and Adriaanse 2008) and oxygen deficiency in Lake Grevelingen (Lengkeek *et al.*, 2007), excessive growth of sea lettuce (*Ulva lactuca*) in Lake Veere (Malta and Verschuure 1997) and blooms of cyanobacteria (*Microcystis*) in Lake Volkerak and Zoommeer (Verspagen *et al.,* 2006). To address these problems, as well as future effects of climate change and sea level rise, possibilities for restoring estuarine dynamics, salinity gradients and connectivity between water bodies are currently investigated (Stuurgroep Zuidwestelijke Delta 2011).

To be able to predict consequences for species biodiversity we need to know todays biodiversity, as well as how biodiversity of the different water bodies, and the delta area as a whole, changed due to the long-term effects of the 'Delta project'. This project has led to a dramatic reduction of estuarine dynamics and to a fragmentation of large-scale estuarine nature into multiple, largely isolated systems. All of these systems developed in different directions into fresh-, brackish and saltwater ecosystems with varying characteristics (nutrient availability, degree of river influence, tidal/stagnant etc.). For the area as a whole, the overall species biodiversity seems to have increased. By restoring estuarine dynamics, what will be gained and what will be lost? Commissioned by the Ministry of Economic Affairs, IMARES conducted a study in which the development of overall biodiversity of the SW Delta area is compared to that of the separate water bodies (Westerschelde and Oosterschelde estuaries, the lakes Lake Veere, Lake Grevelingen, Haringvliet, Krammer-Volkerak, Zoommeer and Markiezaat) (project BO-11-015-004; Tangelder *et al.*, 2012). Discussed was how biodiversity of birds and fish in each subsystem evolved in the last decennia and how this relates to the total biodiversity of all subsystems for the Delta area as a whole. Results showed that the overall biodiversity is higher than in separate subsystems (2012). This was explained by the fact that every subsystem developed differently after isolation by the Deltaworks with their own specific conditions and species.

In addition to, and to complement, the above mentioned project, the PBL Netherlands Environmental Assessment Agency (Planbureau voor de Leefomgeving) commissioned a more detailed study on changes in biodiversity, species richness, functional groups and key species and habitats in a subset of water bodies in the SW Delta. The goal is to make a more detailed comparison possible between on the one hand an open delta with connections between the different water bodies and with the river systems and North Sea, and on the other hand a fragmented delta as was created by the Delta works. This project is also funded by the Ministry of Economic Affairs (project WOT-04-011-007).

We combined available long-term datasets on macrobenthos, fish, birds, and key species (sea grass and sea mammals) with the aim to present reliable and factual information on changes in biodiversity in the SW Delta in the past few decennia, in relation to large scale human impacts such as the Delta project. We study four water bodies with a different history of development in detail: the Oosterschelde estuary, Lake Grevelingen, Lake Veere and Lake Haringvliet.

2 Materials and Methods

2.1 Data collection and availability

Data on species occurrence and abundance of birds, fish, benthic macrofauna, sea mammals and surface area of seagrass and salt marshes used in this study originated from several datasets. Data were largely collected or commissioned by Rijkswaterstaat (RWS) and kindly made available for this study by RWS Waterdienst.

We mainly included species groups that are related to the marine/aquatic habitat. We did not take into consideration terrestrial flora and fauna. A major consideration leading to this decision was the (apparent) lack of long-term data series representing entire waterbodies. In the marine/aquatic environment we did not take into account macrobenthos of hard substrates. Apart from seagrass we did not consider macro-algae. We also did not look at long-term changes in plankton communities.

Birds

Numbers of water birds are counted monthly in the saltwater bodies of the Southwestern Delta (including the Oosterschelde estuary, Lake Veere, and Lake Grevelingen) since 1978/1979. Since 1990 this is part of the biological monitoring programme of the salt water bodies in the Netherlands (MWTL: "Monitoring van de Waterstaatkundige Toestand des Lands"), since 1990 commissioned by Rijkswaterstaat (presently Rijkswaterstaat Waterdienst, part of the Ministry of Infrastructure and Environment). The results are reported annually (e.g. Strucker *et al.*, 2010a). Data for the period 1987 – 2008 were available to us. Data of the period before 1987 is not checked and corrected for missing data. We digitized data of the Oosterschelde for the period 1975/76 – 1983/84 from reports by Meininger *et al.* (1984; 1985) as a reference to the period before the storm-surge barrier. Data for Lake Haringvliet were provided by SOVON (Dutch Centre for Field Ornithology).

Shorebird numbers are counted once per month, during a series of high tides. During high tide, the birds are concentrated on high tide roosts, where they are relatively easy to count. The entire shore of the Oosterschelde estuary is split up into smaller areas, that cover all high tide roosts. The large intertidal flats of Roggenplaat and Neeltje Jans are counted from a boat. Gulls were counted in January only.

Fish

The Dutch Demersal Fish Survey (DFS) covers the coastal waters from the southern border of the Netherlands to Esbjerg, including the Wadden Sea, the outer part of the Ems-Dollard estuary, and the Westerschelde and Oosterschelde estuaries (Van Beek *et al.*, 1989). This survey has been carried out in September-October since 1970 by IMARES, commissioned by the Ministry of Economic Affairs. In this study, data of the Oosterschelde estuary and Lake Grevelingen were used. Both are sampled with a 3 meter beam trawl. Fishing is restricted to the tidal channels and gullies deeper than 2 meter because of the draught of the research vessel.

Benthic macrofauna

Within the monitoring programme MWTL, the benthic macrofauna of the Oosterschelde estuary, Lake Veere and Lake Grevelingen have been monitored since 1990, and data were available for the period 1992 – 2010. Sampling is carried out each spring and autumn by the Monitor Taskforce of NIOO-CEME (Netherlands Institute of Ecology – Centre for Estuarine and Marine Ecology), commissioned by the Ministry of Infrastructure and Environment. Methods are described by Escaravage *et al.* (2003b). MWTL data for Lake Haringvliet were provided by Rijkswaterstaat Waterdienst. We used data from a report by Weeber (1980) to compare biodiversity indices in the MWTL dataset with the period before decoupling from the North Sea. These data were collected in 1962 and 1963.

Sea mammals

Numbers of sea mammals in the Oosterschelde, Grevelingen and Westerschelde were counted yearly in June - July since 1996 until present by Rijkswaterstaat Waterdienst (Strucker *et al.*, 2010a). Sea mammals in the Oosterschelde estuary and Lake Grevelingen include seals (Common seal *Phoca vitulina* and Grey seal *Halichoerus grypus*) and Harbour porpoises (*Phocaena phocoena*). The Harbour porpoise was left out of the analysis because not enough data were available.

Seagrass

Mapping of seagrass was done by Rijkswaterstaat using false colour aerial photography (scale 1:10,000 and 1:20,000 and GPS/INS scale 1:2500). Field measurements included mapping in the field and subsequent analysis using GIS. Data were collected in the Oosterschelde in 1977-2003 and in Lake Grevelingen in 1973-2003. Data of 2008-2009 were extracted from studies by Damm (2009; 2010).

Saltmarshes

We refer to Van der Pluijm and De Jong (1998) for a description of changes in saltmarsh area.

2.2 Functional groups

Benthos, birds and fish were subdivided into different functional groups. We chose for an allocation to trophic groups ('feeding guilds') as shown in Table 1.

Table 1. Benthic macrofauna, birds and fish species were allocated to different trophic groups. Per trophic group a few examples of abundant species are given.

Group	Feeding guild	Referred to as:	Example of species
Benthic macrofauna	Suspension feeder, filter feeder	Filter feeder	Cockle (*Cerastoderma edule*), slipper limpet (*Crepidula fornicata*)
	Interface-, surface deposit- and facultative suspension feeder	Surface deposit feeder	Baltic tellin (*Macoma balthica*), the polychaete *Aphelochaeta marioni*
	Subsurface deposit feeder, grazer	Subsurface deposit feeder	the polychaete *Capitella capitata*, Mud snail (*Hydrobia ulvae*, grazer)
	Omnivore, predator, scavenger	Omnivore/predator/ scavenger	Crabs (*Carcinus* sp., *Hemigrapsus* sp.), shrimp (*Crangon* sp.)
Birds	Benthivores		Oystercatcher (*Haematopus ostralegus*), Knot (*Calidris canutus*)
	Carnivores		Common kestrel (*Falco tinnunculus*), Buzzard (*Buteo buteo*)
	Herbivores		Wigeon (*Anas penelope*), Brent Goose (*Branta bernicla*), Mallard (*Anas platyrhynchos*)
	Omnivores		Herring gull (*Larus argentatus*), Black-headed gull (*Larus ridibundus*)
	Piscivores		Great cormorant (*Phalacrocorax carbo*), Great crested grebe (*Podiceps cristatus*)
Fish	Benthivores		Plaice (*Pleuronectes platessa*), Common dab (*Limanda limanda*), Sole (*Solea solea*)
	Bentho-piscivores		European eel (*Anguilla anguilla*), Shorthorn culpin (*Myoxocephalus scorpius*)
	Piscivores		Whiting (*Merlangius merlangus*), Cod (*Gadus morhua*)
	Planktivores		Gobies (*Pomatoschistus* sp.), Herring (*Clupea harengus*)

For the benthic trophic guilds we used the same allocation to trophic groups as was used by Lavaleye *et al.* (2007) for the North Sea macrobenthos. Note that epibenthic grazers are included in the larger group of 'subsurface deposit feeders and grazers'. Not all species could be allocated to a trophic guild, based on our current knowledge (Oosterschelde and Lake Grevelingen 14%, Lake Veere 17%).

When considering trophic guilds of fish, detritivores were left out of the analysis because only one taxa (*Mugilidae*) was recorded in three years only (1973, 1977 and 2001).

2.3 Data processing, statistics and presentation

Datasets were checked for synonyms in species names. Accepted names according to the World Register of Marine Species (WoRMS; www.marinespecies.org) were used. Incomplete determinations were either deleted or scaled back to a higher taxonomic level. In the bird dataset, missing values were replaced by modelled values through imputing (Underhill & Prys-Jones, 1994, in Strucker *et al.*, 2008b). We used the dataset from 1987/1988, when the closure of the Oosterschelde estuary was completed. From this year on, all data have been checked, validated, and missing data imputed.

Each species or taxonomic endpoint level of birds (including breeding birds), fish and macrobenthos were categorized in feeding guilds (Table 1). A list of determined species and their classification in feeding guilds can be found in Appendix 1.

Indices

We used three indices to assess biodiversity: diversity (a combination of species richness and evenness), evenness (numerical equality of species groups), and species richness (the total number of species). Diversity is expressed by the "Shannon Wiener index for biodiversity", which is one of several diversity indices used to measure diversity in categorical data. Typically the value of the index ranges from 1.5 (low evenness and species richness) to 3.5 (high evenness and species richness), though values beyond these limits may be encountered. Because the Shannon Wiener Index (H) gives a measure of both species numbers and the evenness (J) of their abundance, the resulting figure does not give an absolute description of a site's biodiversity. It is particularly useful when comparing similar ecosystems or habitats, as it can highlight one example being richer or more even than another. Equations used for calculating the Shannon Wiener index and evenness are:

Shannon Wiener index $$H=-\sum_{i=1}^{S} Pi*\ln Pi$$

Evenness $$J=\sum_{i=1}^{S} \frac{H}{\ln S}$$

n_i = The number of individuals in species i; the abundance of species i
N = the total number of individuals
Pi = Number of Pilou. The relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals in the community: n_i/N
S = the number of species (species richness).

In this report we will refer to the Shannon Wiener index as biodiversity. In this report biodiversity and evenness were determined for birds, fish and macrobenthos data. 'Richness' refers to the species richness, and 'abundance' to the total number of individuals.

Statistical analysis

Time series were analysed for species groups and feeding guilds in the Oosterschelde using TrendSpotter version 6.4. This is a programme that is based on structural time series analysis in combination with the Kalman filter. The program identifies periods with significant increases or decreases from annual fluctuations, by estimating smoothed population numbers for a time series with equidistant measurements over time. TrendSpotter also estimates the standard deviations of the smoothed population numbers. Finally, it estimates the standard deviations of the differences between consecutive timepoints. The estimation of confidence intervals is based on the deviations of time point values from the smoothed line. A more detailed description of the method can be found in Visser (2004) and Soldaat *et al.,* (2007). The advantage is that this method takes account of serial correlation and provides confidence limits that enable to test changes in abundance, richness, Shannon-diversity and evenness. R (version 2.13.1) was used for batch processing and for the statistical analyses and production of graphs.

Calculated indices were analysed in TrendSpotter and modelled values were plotted together with the measured values. Confidence intervals of the modelled values are not given as this would crowd the graphs too much. Significance of year-to-year trend changes are given in Appendix 2.

3 Overview of water bodies and major changes

3.1 Oosterschelde

Description

The Oosterschelde estuary (SW Netherlands) is nowadays a tidal system of 350 km^2 with intertidal flats (110 km^2), deep gullies, artificial rocky shores for coastal defence, and shallow water areas (Figure 1). A storm surge barrier between the estuary and the North Sea protects the area from flooding but the valves in the dam are normally open, allowing a tidal range varying from 2.5 m at the entrance to 4 m at the eastern boundaries. The system has an average freshwater load of 25 m^3/s and is mesotrophic with an average salinity of 30 ppt; there are no untreated waste water discharges (Nienhuis and Smaal, 1994).

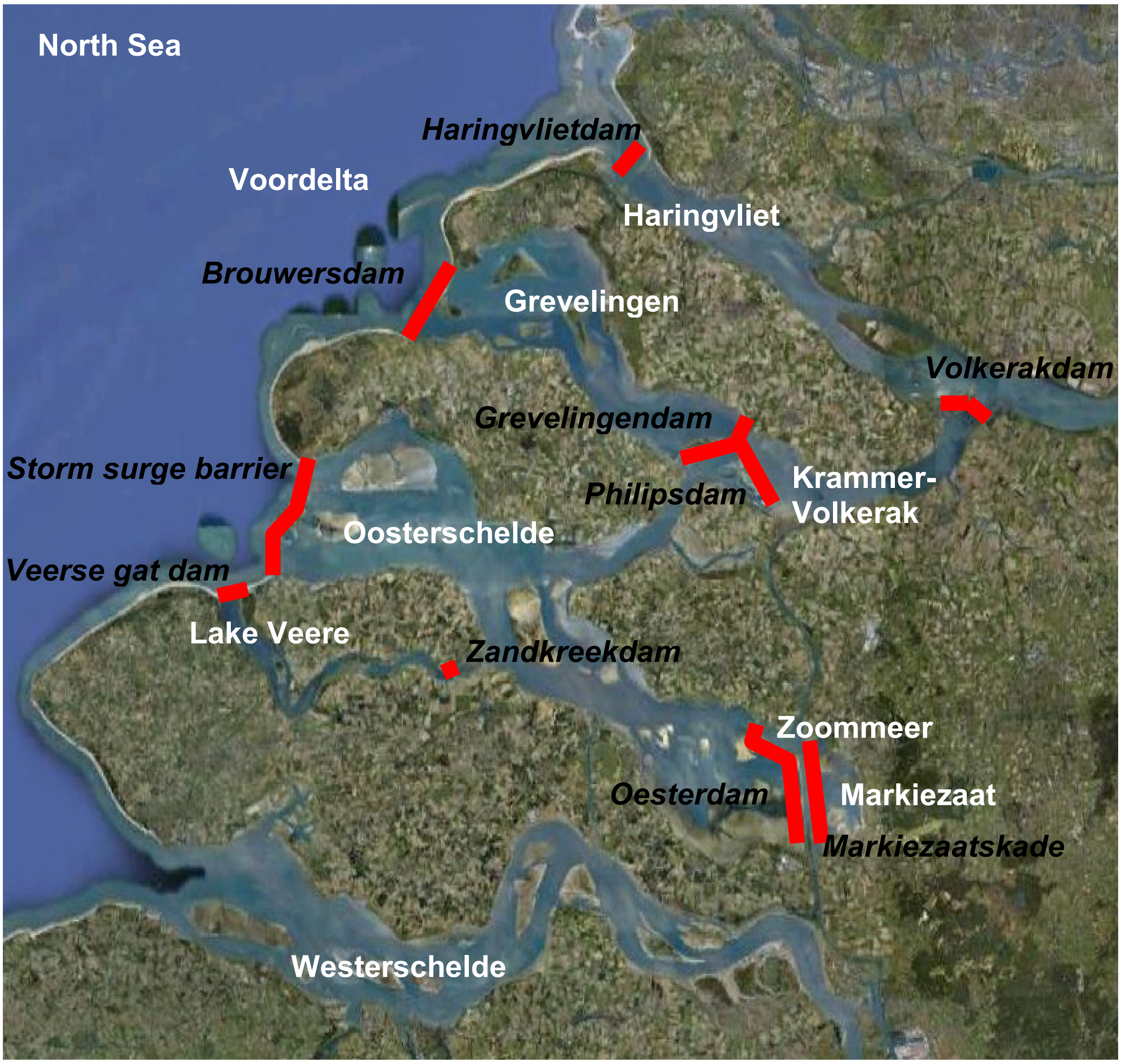


Figure 1. An overview of the South-Western Delta, showing the different water basins (white text) and coastal engineering works (red with black text) that are part of the Delta project.

The Oosterschelde is important as nature conservation area and of particular relevance for wader birds such as Oystercatcher, Dunlin, Grey Plover and Curlew that overwinter in large numbers (Troost and Ysebaert, 2011). The Oosterschelde is protected under the international Ramsar convention as wetland of international importance and is part of the Natura 2000 network under the European Birds and Habitats Directive. The area is extensively used for shellfish bottom culture and cockle fishery. There are 1,550 hectares of oyster culture plots, all located in the Eastern part.

The construction of the Delta works (Figure 2) started to affect the Oosterschelde estuary in 1959 with the separation of Lake Veere. The Grevelingen was closed off by the construction of the Grevelingen dam (1958-1965) and the Krammer-Volkerak was closed off by the Volkerakdam (1957-1969). These constructions cut off the freshwater discharge into the Oosterschelde. The original plan was to close off the Oosterschelde estuary completely from the North Sea, so it would become a freshwater basin. Soon, a campaign started to keep the Oosterschelde open, to maintain the unique intertidal saltwater environment. The Dutch government agreed to an alternative plan. Instead of closing the Oosterschelde estuary, an open barrier would be built. This barrier (Figure 3) would be closed during storms and high water levels. As a consequence of the debate on the design of the dam, the construction of the storm surge barrier from start to completion covers a long period of time with years of no action.

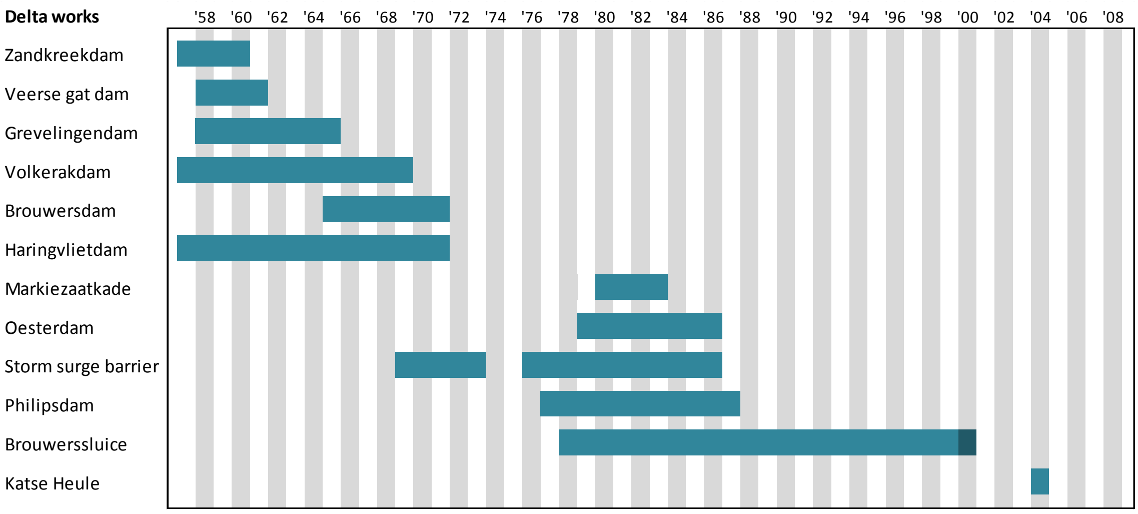


Figure 2. An overview of the construction periods of the different Delta works that (may have) affected the four systems studied: Oosterschelde estuary, Grevelingen, Lake Veere, Haringvliet.

The Delta works changed the hydrodynamic characteristics of the Oosterschelde. The construction of the storm surge barrier diminished the cross sectional area of the channels of the inlet of the Oosterschelde from 80,000 m^2 in 1984 to approx. 17,900 m^2 in 1987. During the construction works of this barrier, the tidal volume, tidal current velocities and the tidal range gradually decreased. Later on, the closure of the Oesterdam (1986) and the Philipsdam (1987) led to a decrease of tidal volume of almost 30%, but led to an increase in tidal range. Due to the decrease in the tidal volume the current velocities in the Oosterschelde are reduced by about 30%. In total, the tidal range is reduced by about 12%. As a consequence of this tidal reduction, wave energy dissipation is concentrated on a smaller part of the intertidal flats and salt marshes.

Despite the Oosterschelde remained an open, tidal ecosystem, the geomorphology of the area is still changing as a result of the infrastructural works of the Delta project. The compartmentalisation dams and the storm surge barrier decreased the tidal water volume going in and out the Oosterschelde, as well as the tidal currents. As a result, the gullies are too wide and too deep for the reduced water volume. During storm events, sediment of the tidal flats is eroded away, whereas tidal currents are too weak to bring back the sediments on the tidal flats. As a consequence the sediments are transported from the intertidal zone into the gullies, and many tidal flats are slowly eroding. This process is known as the 'sand starvation' problem of the Oosterschelde. Until 2001, on average 0.5 km^2 of the intertidal permanently eroded per year (Van Zanten and Adriaanse, 2008). According to Jacobse *et al.* (2008), between 1990 and 2007, 6 km^2 of intertidal flats was lost. Each year, an estimated total of 1 million m^3 sand is disappearing into the gullies. More than 50% of the entire intertidal of the Oosterschelde estuary is predicted to have disappeared by 2045 (Van Zanten and Adriaanse, 2008). Jacobse *et al.* (2008) mention an expected loss of 40 km^2 in the coming century.

Figure 3. The Oosterschelde storm surge barrier.

The Oosterschelde estuary is the centre of Dutch shellfish culture. Pacific oysters (*Crassostrea gigas*) and blue mussels (*Mytilus edulis*) are cultured on subtidal bottom plots (respectively 1550 and 2250 ha). The Pacific Oyster was introduced to the Oosterschelde in 1964 by fishermen for culture purpose, but started to expand in the wild since 1976. Since then a rapid expansion of the Pacific Oyster was observed, but the increase appears to have stabilised (Troost *et al.,* 2009). The percentage of the intertidal area covered by oyster beds increased to around 9% in 2011 (Brummelhuis *et al.*, 2011).

Documented initial effects of the Delta works

The construction of the storm surge barrier and compartmentalisation dams directly resulted in a reduction of 33% of intertidal area and a reduction in salt marsh area from 17.3 to 6.4 km^2. Already in 1994, a further loss of intertidal area 15% was predicted for the following decades (Nienhuis and Smaal, 1994). The tidal volume was reduced by 30% and the tidal range by 13% (Vroon, 1994). Due to the isolation from riverine input, the salinity increased slightly, brackish areas disappeared, and the average nutrient concentration decreased by 20 – 60%. In general, the Delta Works turned the Oosterschelde estuary from a turbid estuary into a tidal bay, but the system still retained its well-mixed, non-stratified character. The estuary retained most of its abiotic boundary conditions for a high quality estuarine system.

Due to the Delta works the visibility in the Oosterschelde increased.Therefore the contribution of microphytobenthos to the total primary production was estimated to have increased. The net import of organic matter from the North Sea was insignificant before closure, and remained so after closure. The Oosterschelde estuary remained a self-sustaining ecosystem in terms of organic matter and food availability. No changes in macrobenthic fauna could be directly attributed to the Delta works.

Although the total number of waterbirds in a post-barrier study period (1987 – 1990) was similar to a pre-barrier / construction period (1978 – 1982), significant shifts in the composition of the bird community were observed (Schekkerman *et al.*, 1994). In general, species dependent on intertidal areas for foraging decreased while species feeding on open water remained stable or increased. Loss in feeding habitat seemed primarily responsible for significant declines in winter numbers among Shelduck, Pintail, Teal, Shoveler, Oystercatcher, Avocet, Kentish plover, Grey plover, Dunlin and Redshank. However, the relatively short study period and the occurrence of two cold winters in the pre-barrier / construction period and three mild winters in the post-barrier period have complicated the analysis. Still, the fact that the loss of feeding area was not compensated by higher bird densities in the remaining part of the estuary suggests that the number of intertidal foragers was close to carrying capacity in the period before the Delta Works, and also in the study period after completion of the Delta Works.

The Delta works had a limited effect on the occurrence of fish in the Oosterschelde estuary. The only impact seemed to be the decrease in a number of anadromous fish species, due to the decoupling from the rivers. The variety of habitats, and the different habitats present, did not change due to the Delta works although the natural tidal water movement and morphological balance (erosion and sedimentation) disturbed. This resulted in the 'sand starvation' problem as explained earlier.

3.2 Grevelingen

Description

Lake Grevelingen is presently the largest saltwater lake in Europe. It has a total surface area of 140 km^2, and a water surface area of 108 km^2. Before the Delta works it was an estuary in the mouth of the Rhine-Meuse river system. The former tidal flats became islands that were rapidly overgrown by vegetation. The isolated island in Lake Grevelingen are important for the Tundra Vole (or Root Vole) *Microtus oeconomus* (Dutch: Noordse Woelmuis). The lake is furthermore of great importance as a breeding area for international populations of shorebirds, and as a foraging and wintering area for piscivore birds (Wetsteyn, 2010).

The former Grevelingen estuary was closed off from riverine inputs together with the Oosterschelde estuary and present Lake Krammer-Volkerak with the construction of the Grevelingendam in 1965 (Figure 2). A side-effect of the decoupling from the river systems was that the Grevelingen was unaffected by the extreme pollution of the 1970s (Bijlsma and Kuipers, 1989). It was closed off from the North Sea in 1972, and became a stagnant tide-free saltwater lake. To prevent ongoing desalination and water quality deterioration a sluice connection with the North Sea was made in 1978 (Brouwerssluice). The sluice was opened during the entire year 1979, but was closed in the period April – September during the years 1980 – 1999. From April 1999 onward, the sluice is opened year round except for 30 days between September and December to prevent silver eels from leaving to benefit eelfisheries. From 2006 onward the sluice is opened year round. The sluice allows for water exchange with the North Sea but has hardly an effect on mixing in the lake. A water level of -20 cm relative to NAP is maintained throughout the year.

When the lake became a stagnant system, the entire intertidal disappeared. Tidal flats became islands that were rapidly overgrown with vegetation, and are now actively managed with large grazers. With tides and natural sedimentation absent, the islands were foreseen with low embankments to prevent shoreline erosion by waves.

The Grevelingen is the only area in the Netherlands where European flat oysters *Ostrea edulis* are still cultured, together with Pacific oysters *C. gigas.* About 500 hectares of bottom culture plots are in use here.

Documented initial effects of the Delta works and Brouwerssluice

After closure of the Brouwersdam (Brouwerssluice) in 1971 the residence time of the water changed from a few days to a few years. The chloride concentration decreased from 17‰ in 1971 to 12 ‰ in 1978 due to evaporation, precipitation and discharge of brackish polderwater. In 1978 the Brouwerssluice was opened to allow mixing with North Sea water. Already in 1979 a salinity at the level of 1971 was reached again. In 1979 the Brouwerssluice was open during the whole year. The saline water from the North Sea remained underneath the brackish Grevelingen water, leading to stratification from the end of May to the end of September. An overdemand of oxygen in the locked up saline watermass led to deoxygenation of 10% of the bottom surface area. This caused mass mortality among benthic fauna and flora. In subsequent years the Brouwerssluice was only opened during October-March to avoid this situation (Bannink and Van der Meulen, 1984). Nevertheless, oxygen deficiency in the deeper areas remains a problem today (Wetsteyn, 2010).

The import of organic matter from the North Sea was completely cut off. Overall yearly production of the phytoplankton was, however, not notably influenced by the closure although production started earlier and stopped later in the period 1971 - 1978 than before the closure (Nienhuis 1978). Food available for benthic filter feeders was reduced by a factor two due to the closure in 1971, because of a reduction in the amount of particulate organic carbon in the water column. This was a direct effect of the disappearance of tidal current. Phytobenthos production increased considerably. After construction of the Grevelingendam in 1964 common eelgrass (*Zostera marina*) developed in the eastern part of the Grevelingen. After construction of the Brouwersdam the area of eelgrass cover increased strongly to a maximum of over 4600 hectares in 1978. After that, the eelgrass beds decreased until none were left in 2000 (Wetsteyn, 2010).

The tidal amplitude (formerly 2.5 – 3.0 m) and tidal currents disappeared completely, leading to a high mortality of benthic macrofauna and flora. Above the water level, all tidal animals and vegetation dried up and died. Shortly after the closure in 1971 also below the water level many animals died because of a sudden lack of tidal currents. Mortality of many animals led to oxygen deficiency which again led to more mortality. Macrobenthic filter feeder production was reduced by a factor 2 due to a reduction in the available food. Within a number of plant and animal groups (sea-anemones, bristle worms, lobsters and crabs, molluscs, echinoderms, fish, macro-algae and some plankton groups) the overall number of species decreased with 24%. Species with a broad ecological tolerance against changes in environmental factors generally remained, but for others it was not possible anymore to complete their life cycle in the lake. In the period until 1978 only few immigrants were found that are characteristic for stagnant brackish waters (the crustacean *Idotea chelipes*, the molluscs *Nassarius reticulatus* and *Cerastoderma glaucum*, and the fish *Gobius niger*) (Nienhuis 1978).

No bird species disappeared due to the closure, but there were large shifts in the relative abundance of the different species. In general, piscivores (Great crested grebe *Podiceps cristatus*, Great cormorant *Phalacrocorax carbo*) showed a strong increase, as did herbivores (Mallard *Anas platyrhynchos*, Wigeon *Anas Penelope*, Mute Swan *Cygnus olor*, Black Coot *Fulica atra*). Zoobenthos feeders showed a strong decrease because of the disappearance of tidal flats (Oystercatcher *Haematopus ostralegus*, Grey Plover *Pluvialis squatarola*, Knot *Calidris canutus*, Dunlin *Calidris alpina*).

Out of 28 fish species regularly found in the Grevelingen estuary, 21 were marine migratory species of which 11 have disappeared after the closure. Marine migratory species include species that migrate between fresh and saltwater or vice versa to complete their life cycle (= 'diadromous' species), or that migrate between full marine and estuarine conditions, e.g. for nursery of the juveniles. The rest of the migratory species comprised an aging population of flatfish species without recruitment (Nienhuis, 1978). The fish fauna in the estuary consisted mainly of marine migratory predators that used the estuary as spawning or hatchery area, nursery of feeding ground. In the period 1971 – 1976 about 40% of these species disappeared gradually. In general a shift was observed from larger pelagic predators to smaller bottom fish that complete their life cycle within the lake. We analysed a long-term time series of fish observations for the period 1970 – 1986. The development of the fish fauna after 1978 will be discussed in the results and discussion chapters of this report.

Salt marshes disappeared abruptly when the estuary became a lake. The former salt marshes dried up and the vegetation changed due to the absence of inundation with salt water and due to ongoing desalination because of precipitation. Also other estuarine benthic habitats disappeared, such as sand- and mudflats, beaches, the littoral zone on rocky shores, and the sublittoral coarse sand habitat with relatively strong tidal currents. Nienhuis (1978) stated that no really new habitats were created and that spatial heterogeneity therefore decreased. Above the water level however, the vegetation developed in different directions due to differences in management. For example, the northern part of the former salt marshes Slikken van Flakkee is not managed at all, which has led to development of a forest. This would have happened in the entire Grevelingen, if not for active management of the former salt marshes and tidal flats, where grass lands are maintained by large grazers.

3.3 Lake Veere

Description

Lake Veere was the first water body to be dammed off. The Zandkreekdam separated it from the Oosterschelde estuary in the East in 1960, and the Veerse Gat dam closed it off from the North Sea in 1961. Both dams were completely closed and did not allow for water exchange. The initial plan was to turn the area into a freshwater lake. However, when in 1976 the decision was made to keep the Oosterschelde estuary open, it was also decided to keep Lake Veere brackish.The water level was kept at a level of -70 cm relative to NAP in winter to increase the drainage capacity for superfluous water from the surrounding polders, and at a level around NAP in summer to sustain the recreational function of the area (Wijnhoven *et al.*, 2010). In order to ameliorate water quality, a sluice was built in the Zandkreekdam for tidal water exchange with the Oosterschelde estuary. The sluice, the 'Katse Heule', was opened in 2004. After opening of the Katse Heule the water level was adjusted to –0.6 m NAP in winter and –0.1 m NAP in summer (fluctuation range of 0.2 m). In 2008 the winter water level was adjusted to -0.5 m NAP (Wijnhoven *et al.*, 2010).

As would happen later in Lake Grevelingen, closing the system off from the tides resulted in the former tidal flats getting overgrown with vegetation. The lake is a nature reserve with high importance as a resting and foraging area for water birds, particularly in winter (references in Wijnhoven *et al.*, 2010).

Documented initial effects of the Delta works and Katse Heule

After the closure of the Veerse Gatdam, the salinity sharply dropped from almost 29 to 18 (Coosen *et al.*, 1990). During the 1970s and 1980s salinity varied between 14.4 and 21.7, respectively between winter and summer. The lake turned into a brackish eutrophicated system. Anoxic conditions occurred in the deeper water layers. During the period 2000 – 2004 the water quality reached its worst condition with a minimum salinity of 10.6. Because of this low salinity the mussel *M. edulis* disappeared from Lake Veere and massive blooms of green and blue-green algae developed. Because of the sudden disappearance of the tides, especially birds feeding on macrozoobenthos decreased whereas herbivores increased (Nijhof *et al.*, 2002).

The area of eelgrass *Zostera marina* decreased and macroalgae such as (predominantly) sea lettuce *Ulva lactuca* increased. Large quantities of sea lettuce washed onto beaches and piled up in stinking mats. Massive plankton blooms occurred in the period after closure. After a sharp decline in the number of macrozoobenthic species just after the closure, the number of species gradually increased during the late 1960s, 1970s and 1980s (Coosen *et al.*, 1990). However, due to the water quality problems the macrozoobenthic communities deteriorated again. Therefore, plans were made to reconnect Lake Veere to the Oosterschelde estuary.

The Katse Heule directly led to improved water quality. The salinity and transparency of the water increased. Density, biomass and species richness did not directly follow the increasing water quality (Wijnhoven *et al.*, 2010).

3.4 Haringvliet

Description

The Haringvliet estuary was the common outlet of the rivers Rhine and Meuse. It was changed from a brackish tidal inlet into a stagnant freshwater lake by the Delta works. Before closure in 1971 the estuary was bounded at the seaward side by a very shallow sill with a maximum depth of 4 m at low tide. Due to this sill the seawater intruded only over a limited distance into the estuary. Before closure of the Krammer-Volkerak (Figure 2**Fout! Verwijzingsbron niet gevonden.**), salt and brackish water from the Volkerak was pumped by tidal movements into the Haringvliet upstream of its theoretical freshwater limit. This salt and brackish water was mixed with fresh water and discharged into the Voordelta. This resulted in an extensive oligo-mesohaline brackish water area. The Haringvliet also had a relatively large freshwater tidal area. The oligo-mesohaline brackish and freshwater tidal areas of the Haringvliet were among the largest of this type in Europe (Ferguson and Wolff, 1984).

The present Lake Haringvliet was dammed off from the North Sea in 1971, but remained its open connection with the rivers. The Haringvliet is the extension of the water body Hollands Diep and both water bodies are part of the Rhine-Meuse river system. The Haringvliet was not completely closed off from the North Sea, since it needed to retain its function of discharging river water into the North Sea (the Voordelta coastal area). However, the sluices were only used to discharge fresh water into the Voordelta, and no saltwater intrusion was allowed. In June 2011 the Dutch government decided after to allow limited saltwater intrusion into the Haringvliet in order to restore migration routes for migratory fish species and a salinity gradient. With the Volkerakdam and Grevelingendam, finished in 1969 and 1965, river discharge was not possible anymore through the Krammer-Volkerak and Grevelingen or Oosterschelde estuary, but only through the Haringvliet and Nieuwe Waterweg further north.

Severe pollution of the rivers Rhine and Meuse led to poor water quality and depauperation of the fish and invertebrate fauna of the Rhine. Breeding Great cormorants (*Phalacrocorax carbo*) disappeared.

Documented initial effects of the Delta works

Influx of sand from the North Sea into the Haringvliet stopped by the closure. Fluvial sediments, especially silt, have settled due to reduced current speeds since the dam was completed. In the 1970s pollution of the rivers was extremely high, and the settled silt contained micropollutants such as heavy metals and organic compounds (Bijlsma and Kuipers, 1989). Before closure the water level changed with the tides. All tidal movement was stopped when the dam was closed. This led to increased erosion of the wetlands bordering the lake, since wave attacks now took place at practically the same level during prolonged periods.

The tidal amplitude of 2 m changed into a semi-tide of about 20 cm which was partly dependent on the operation of the sluices in the Haringvlietdam. The vegetation in areas that became permanently dry changed dramatically. Before, the brackish part was characterized by extensive mud flats and large areas of brackish meadows and beds of bulrushes and reed. The freshwater tidal part was characterized by extensive willow-coppices, reed-beds, bulrushes and tidal flats, with a flora and fauna that was not particularly rich but nevertheless unique because of the rare freshwater tidal conditions they lived in. No documentation on changes in vegetation of the formerly brackish areas was found, but changes will be similar to those documented for Lake Grevelingen and Lake Veere. Vegetations dependent on tides and dependent on salt water have disappeared in favour of vegetations belonging to fresh water systems (Van Haperen, 1989; Troost, 2008).

The brackish-water zoobenthos disappeared rapidly and the lake was colonized by freshwater species originating from the rivers and surrounding polders. Freshwater fish species occurred everywhere in the lake after just a few weeks. Characteristic river species largely disappeared (Ferguson and Wolff, 1984).

Lake Haringvliet became more suitable for breeding birds such as Great crested grebes (*Podiceps cristatus*) and Coots (*Fulica atra*). Piscivore birds and diving ducks feeding on benthic animals have increased in number. Waders and gulls decreased in number but increased in winter. Other groups showed more comparable numbers by the end of the 1970s (Ferguson and Wolff, 1984 and references therein).

4 Analysis results

4.1 Oosterschelde

Oosterschelde benthic macrofauna

The available time series for benthic macrofauna starts 5 years after completion of the storm surge barrier. In the intertidal zone of the Oosterschelde estuary biodiversity and evenness, as well as species richness, showed an increase after 2002 (Figure 4). The trend was significantly positive for the period 2006 – 2010. Especially the years 2001 and 2002 showed a low biodiversity (SW index 0.6) which seems mainly due to a low evenness. In 2001 and 2002 the numerically most abundant mud snail *Hydrobia ulvae* reached average peak densities of 22,000 to 23,000 individuals per m^2 which explains the low evenness. Evenness was negatively correlated with density of *H. ulvae* (R^2 = 0.86). The higher biodiversity in 2009 and 2010 coincides with a relatively high species richness, which may be related to a different sampling design in the MWTL monitoring since 2009. In 2009 and 2010 the total surface area sampled was 2-3 times as large as in the period before which may have resulted in a higher species richness within the samples. In the subtidal all three biodiversity indices remained stable showing high biodiversity (3.5) due to high species richness.

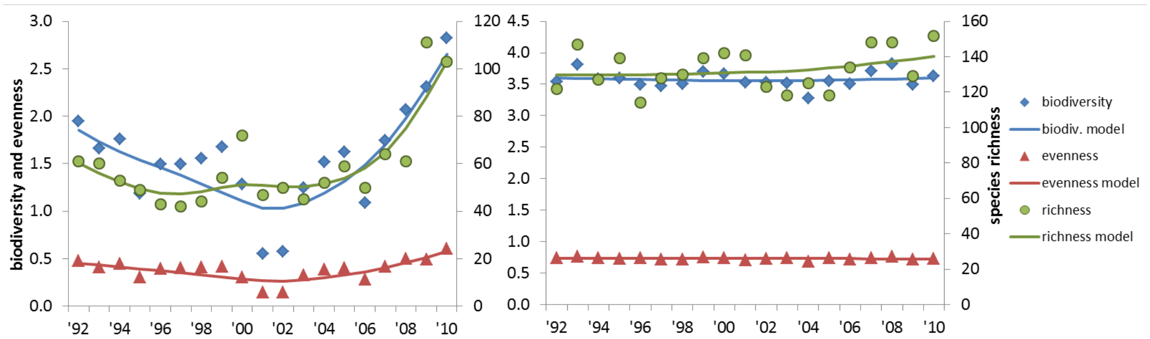


Figure 4. Biodiversity indices for macrobenthic fauna in the intertidal (left) and subtidal (right) of the Oosterschelde estuary. Samples were taken in autumn. Biodiversity (Shannon-Wiener index) and evenness (Pilou's index) are given on the primary y-axis, species richness (n species) on the secondary y-axis. Both the measured values (dots) and the TrendSpotter model (lines) are given. Confidence intervals are not given since they would crowd the graphs too much. Significance of observed trends is given in Appendix 2.

The abundance of filter feeders decreased significantly in the intertidal during the 1990s (Figure 5). This is mainly due to a decrease in the cockles stock (*Cerastoderma edule*). In the MWTL dataset cockles are the most abundant filter feeders in the intertidal. Other dominant filter feeders are the mussel *Mytilus edulis* and the slipper limpet *Crepidula fornicata*. Subsurface deposit feeders and grazers showed a large variation in total abundance from year to year, and the model reaches an optimum around 2002 followed by a significant decrease in the period 2005 – 2010. This was again caused by the mud snail *H. ulvae*, a grazer that is numerically the most abundant species within this particular trophic group. Another abundant species within this group is the subsurface deposit feeding polychaete *Capitella capitata*. In the subtidal no significant trends were observed except for subsurface deposit feeders that showed a continuous increase which was significant for the entire period. In the subtidal, as in the intertidal, the most abundant subsurface deposit feeders and grazers are *H. ulvae*, *C. capitata*, and oligochaetes (as a group). The increase in abundance of all species within this trophic group did not appear to be caused by changes in abundance of one particular species.

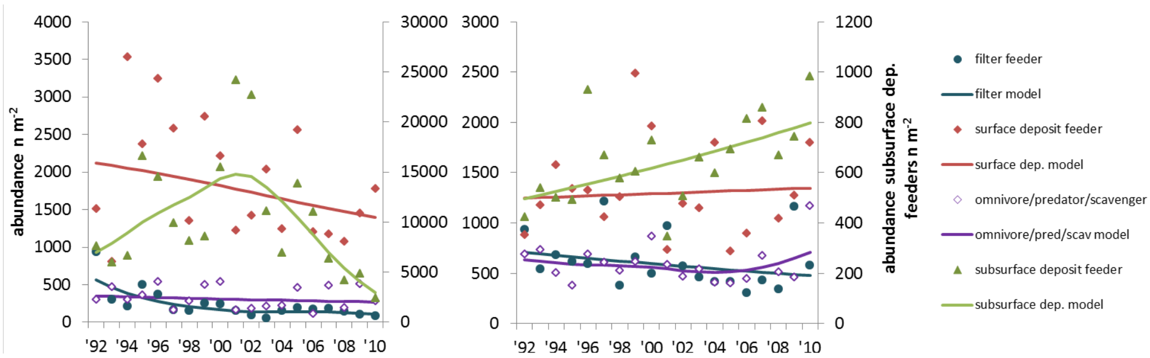


Figure 5. The total abundance of macrobenthic species within four trophic groups (filter feeders, surface deposit feeders, subsurface deposit feeders and omnivores/predators/scavengers) in the intertidal (left) and subtidal (right) parts of the Oosterschelde estuary.

Oosterschelde birds

The available data set of bird counts starts in the year 1987, right after completion of the storm surge barrier. Biodiversity indices of non-breeding bird numbers showed a significant increase which levelled off after 2002 (Figure 6).

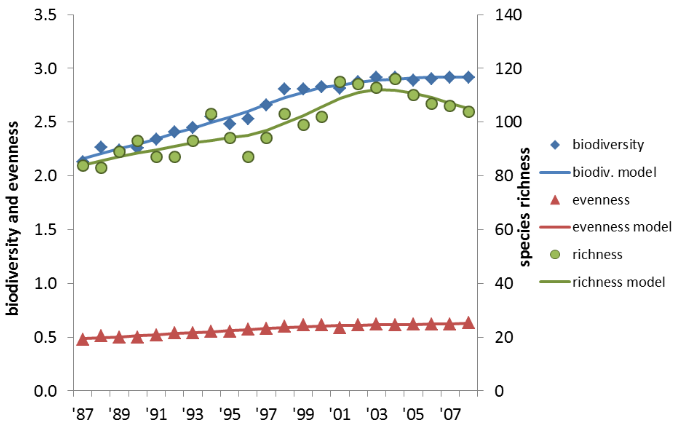


Figure 6. Indices for biodiversity and evenness (Shannon-Wiener and Pilou respectively; primary y-axis) and species richness (n species; secondary y-axis) for non-breeding birds in the Oosterschelde estuary. Measured values (dots) are season-averaged numbers. TrendSpotter models are shown with lines.

Non-breeding birds were divided into different trophic groups: benthivores, carnivores, herbivores, omnivores and piscivores. Benthivores (with dominant species the Oystercatcher *Haematopus ostralegus*, Knot *Calidris canutus*, and Dunlin *Calidris alpina*) and omnivores (with dominant species the Herring gull *Larus argentatus* and Black-headed gull *Larus ridibundus*) showed no clear trend (Figure 7). Omnivores showed a peak in 1993 which was caused by exceptionally high numbers of Herring gulls. The trend remained stable after 1997. Abundance of carnivores (the least abundant group with dominant species Kestrel *Falco tinnunculus* and Buzzard *Buteo buteo*), herbivores and piscivores showed an increase over time. Within the herbivore group the increase was mainly due to increasing populations of Wigeon, Barnacle goose *Branta leucopsis*, and Greylag goose *Anser anser*. Within the piscivore group almost all species showed an increase (Read-breasted Merganser *Mergus serrator*, Great crested grebe *Podiceps cristatus*, Great cormorant *Phalacrocorax carbo*, Little grebe *Tachybaptus ruficollis*, Black-necked grebe *Podiceps nigricollis*, and Little egret *Egretta garzetta*).

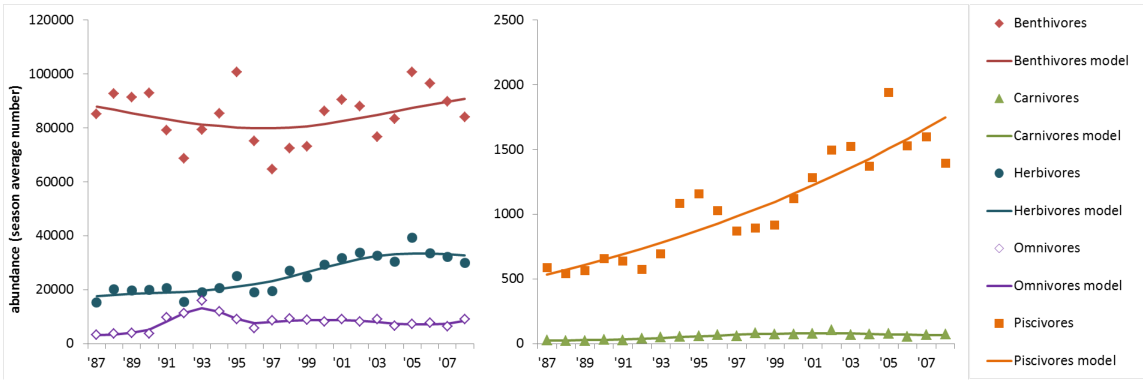


Figure 7. Total abundance (number of individuals) of birds within different trophic groups in the Oosterschelde estuary. Measured values are shown with dots. TrendSpotter models are shown with lines.

We digitized older count data from the period 1975 – 1983, and calculated the proportions of birds and bird species within the trophic groups of benthivores, herbivores, omnivores and piscivores. These proportions did seem not differ significantly from the period after 1987 (Figure 8). The total season-averaged number of birds counted in 1975-1983 was 149,668 (110,003 in the period 1987 – 1992) and the total number of species counted in 1975-1983 was 49 (77 in the period 1987-1992). In the period from 1987 to 2008, the total proportion of benthivores has decreased while the proportion of herbivores and piscivores increased. This is due to an increase in herbivores and piscivores while benthivores remained stable.

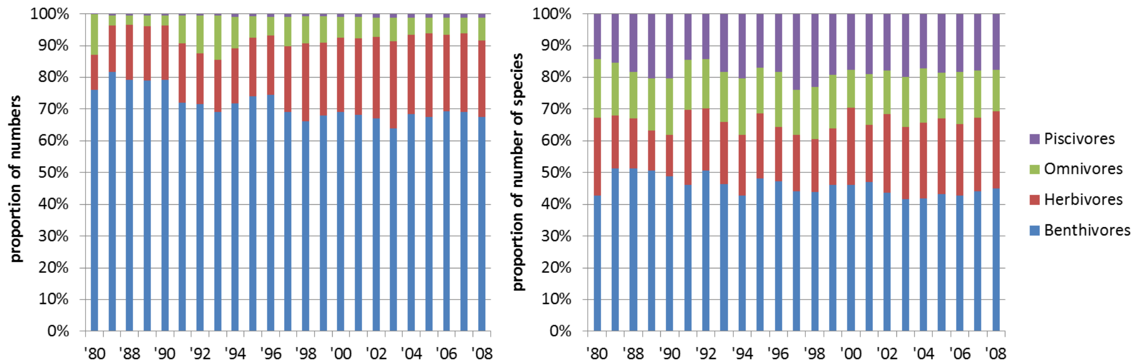


Figure 8. Proportion of season-averaged numbers (left) and proportion of the total number of species (right) of benthivore, herbivore, omnivore and piscivore birds in the Oosterschelde estuary in two periods of time: 1975- 1983 (Meininger et al., 1984; Meininger et al., 1985) (given for the year 1980) and 1987 – 2008. Carnivores were excluded because these were not counted in the first period.

The available dataset of breeding bird counts starts in 1979, 7 years before completion of the storm surge barrier (Figure 9). Breeding birds showed large fluctuations in biodiversity and evenness that coincide with the completion of the barrier and Oesterdam in 1986, Philipsdam in 1987 and completion of the Markiezaatkade in 1983. After 1990 the biodiversity indices all increased significantly, mainly due to an increase in species richness. Newly counted species were the Black-winged Stilt *Himantopus himantopus* (1989), the Mediterranean gull *Larus melanocephalus* (1994), the Yellow-legged gull *Larus michahellis* (2000) and the Greater black-backed gull *Larus marinus* (2002). The abundance of omnivore breeding birds increased significantly after 1993, mainly due to an increase in Herring gulls and Lesser black-backed gulls *Larus fuscus.* Piscivores showed an increase after 1996 due to an increase in abundance of the Common tern *Sterna hirundo*, and Sandwich tern *Thalasseus sandvicensis* (Strucker *et al.*, 2009). Benthivores showed in increase in the period 1998 – 2004 which can be mainly attributed to an increase in the Pied Avocet *Recurvirostra avosetta* (Figure 10).

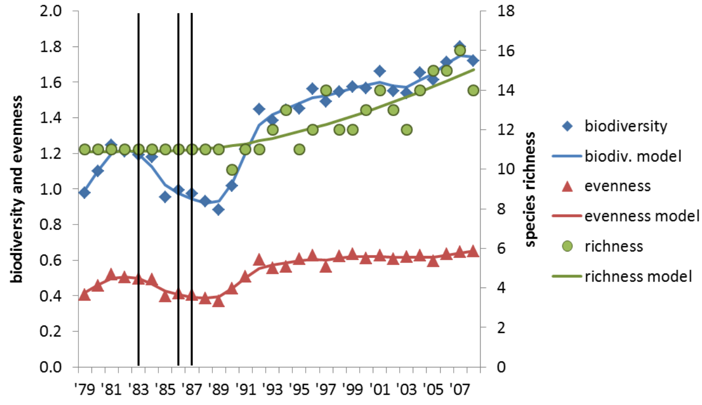


Figure 9. Indices for biodiversity and evenness (Shannon-Wiener and Pilou respectively; primary y-axis) and species richness (n species; secondary y-axis) for breeding birds in the Oosterschelde estuary. Measured values (dots) are season-averaged numbers. TrendSpotter models are shown with lines. The black bars indicate engineering works (respectively Markiezaatkade 1983; Oesterdam & Storm surge barrier 1986; Philipsdam 1987).

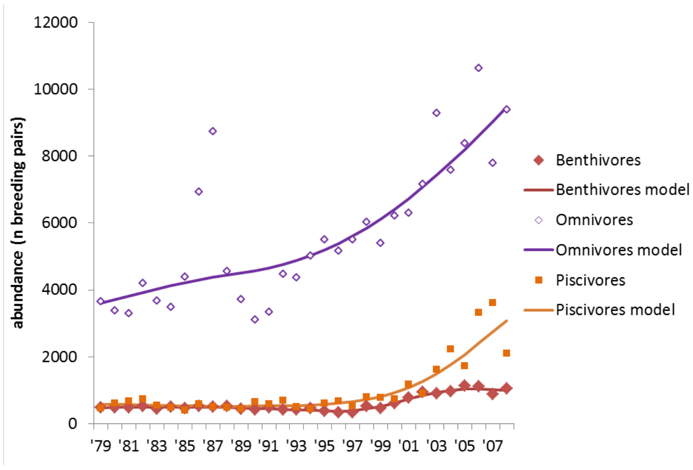


Figure 10. Total abundance (number of individuals) of breeding birds within different trophic groups in the Oosterschelde estuary. Measured values are shown with dots. TrendSpotter models are shown with lines.

Oosterschelde fish

Fish abundance showed fluctuations in species richness, with a significant increase from year to year in the period 1996 – 2000 (Figure 11). This did not result in significant changes in the trend in biodiversity which showed a large year-to-year variation. Evenness remained stable. Species richness was lower in the period in which engineering works were, and had just been, completed. Although species richness seems to have recovered this took a long time of about 10 years. Among the different trophic groups (benthivores, bentho-piscivores, piscivores and planktivores), not much change could be detected except for a significant increase from year to year in abundance of planktivores in the period 1997 – 1999 (Figure 12). Planktivores (mainly gobies *Pomatoschistus* sp. and Herring *Clupea harengus*) showed large fluctuations in abundance. All trophic groups showed a high year-to-year variation with a relatively low abundance in the years around, and just after, 1987.

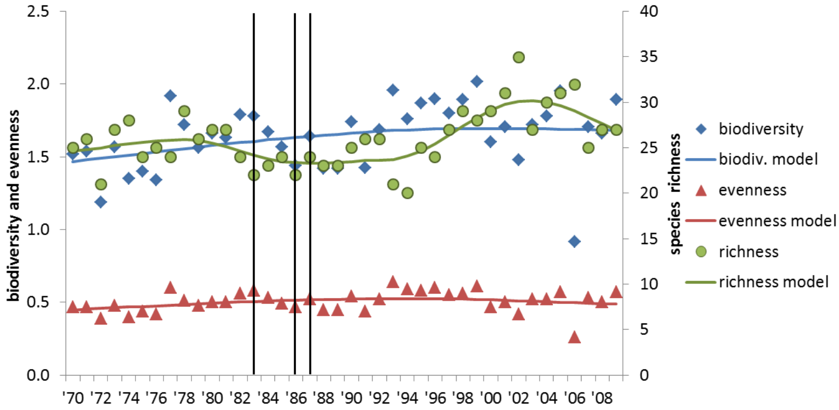


Figure 11. Biodiversity and evenness (Shannon Wiener and Pilou; primary y-axis) and species richness (n species; secondary y-axis) for fish in the Oosterschelde estuary. Measured values are given with dots, TrendSpotter models with lines. The black bars indicate engineering works (respectively Markiezaatkade 1983; Oesterdam & Storm surge barrier 1986; Philipsdam 1987).

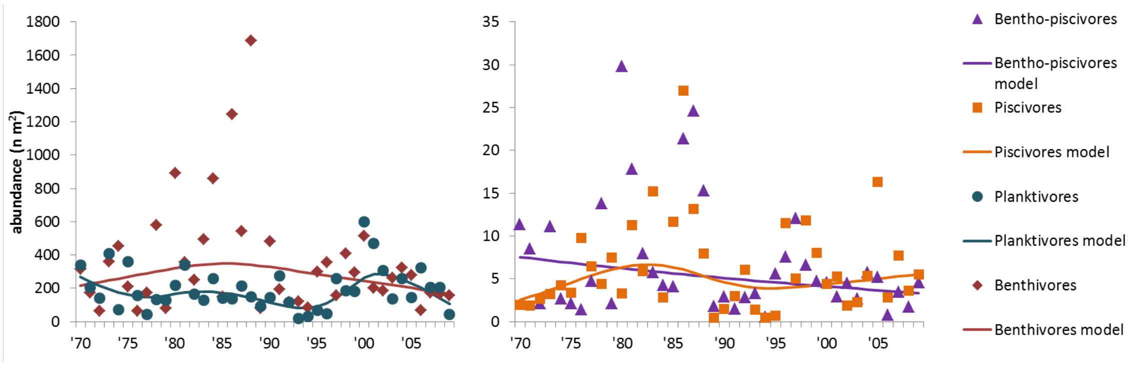


Figure 12. The total number of fish individuals ('abundance'; n m^2 collected by beam trawl) within different trophic groups in the Oosterschelde estuary. Measured values are given with dots, TrendSpotter models with lines.

4.2 Grevelingen

Grevelingen benthic macrofauna

Species richness and biodiversity among benthic macrofauna showed no changes over the study period of 1992 – 2010 although evenness showed a slight but significant continuous increase (Figure 13). Total abundance of macrobenthic fauna showed a continuous decline (Figure 14). This decline is mainly caused by continuous declines in the abundance of filter feeders and subsurface deposit feeders. The most abundant filter feeders are the bivalves *Corbula gibba* and *Kurtiella bidentata*, and the slipper limpet *Crepidula fornicata*. Of these, *C. fornicata* showed a decrease over time. The most abundant subsurface deposit feeders are oligochaetes as a group, and the polychaetes *Heteromastus filiformis* and *Capitella capitata*. Of these the oligochaetes showed a decrease over time. Surface deposit feeders (most dominant *Spio martinensis*, *Monocorophium insidiosum*) and omnivores/predators/scavengers showed no change. Only few data were found for the period before and around closure of the Grevelingendam (1965) and Brouwersdam (1971). The most reliable of these datasets was derived from the report by Weeber (1980), in which all data from sampling campaigns in 1962 and 1963 was listed. Calculated biodiversity and evenness indices and species richness are quite comparable to values found in the MWTL campaign. It should be noted, however, that a period of almost 30 year lies in between these data sets.

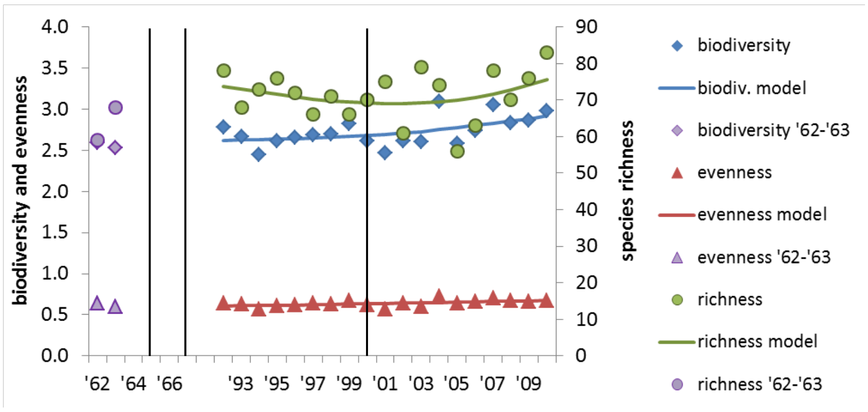


Figure 13. Biodiversity indices for macrobenthic fauna in Lake Grevelingen. Samples were taken in autumn. Biodiversity (Shannon-Wiener index) and evenness (Pilou's index) are given on the primary y-axis, species richness (n species) on the secondary y-axis. Both the measured values (dots) and the TrendSpotter model (lines) are given. Data from the period before the annual MWTL monitoring were included as purple dots. Black bars indicate the completion of engineering works (respectively Grevelingendam 1965, Brouwersdam and opening Brouwerssluice in 1970s, year-round opening of Brouwerssluice in 2000).

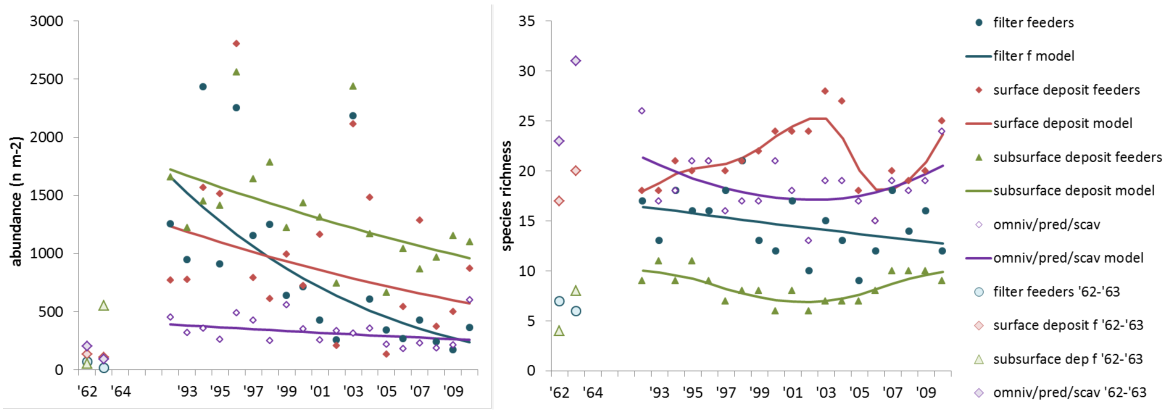


Figure 14. The total abundance (left) and species richness (right) of macrobenthic species within four trophic groups (filter feeders, surface deposit feeders, subsurface deposit feeders and omnivores/predators/scavengers) in Lake Grevelingen. Data for the year 1962 and 1963 is added (Weeber 1980) in lighter-coloured markers.

The filter feeders and subsurface deposit feeders (and grazers) contain more species in the period after 1992 than in 1962 and 1963. Species richness in the surface deposit feeder group is comparable to species richness in the first years of MWTL monitoring. Omnivores/predators/scavengers showed a higher species richness in 1962 and 1963 compared to the MWTL dataset. The abundance within the different trophic groups was much lower in the 1960s than in the period 1992-2010.

Grevelingen birds

Biodiversity and species richness of birds showed a continuous increase over the entire study period 1987 – 2008 (Figure 15). Evenness remained stable. All trophic groups showed an increase in total abundance (Figure 16). For carnivores the increase was restricted to 1992 – 1997 (largely attributed to Buzzard *Buteo buteo* and Peregrine Falcon *Falco peregrinus*) and for piscivores to 1988 – 1994 (mainly attributed to Great crested grebe *Podiceps cristatus* and Red-breasted Merganser *Mergus* *serrator*). Herbivores are the most abundant group (most abundant species Wigeon, Mallard, Barnacle Goose), and carnivores the least abundant with a maximum of 36 individuals in 2008. Among the most abundant benthivores are the Golden Plover *Pluvialis apricaria*, Lapwing *Vanellus vanellus*, and Dunlin *Calidris alpina*.

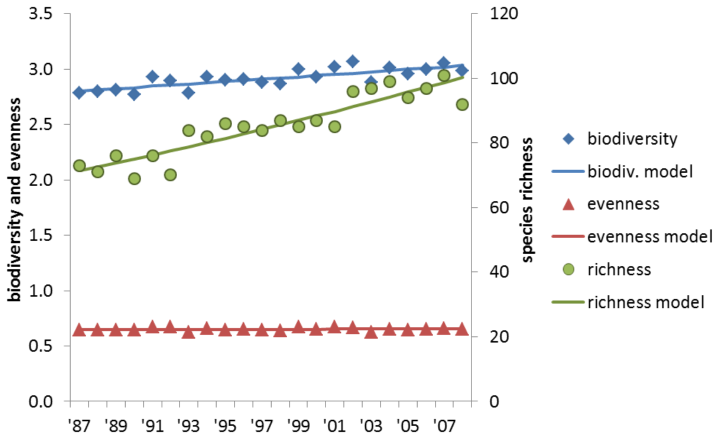


Figure 15. Indices for biodiversity and evenness (Shannon-Wiener and Pilou respectively; primary y-axis) and species richness (n species; secondary y-axis) for birds in Lake Grevelingen. Measured values (dots) are season-averaged numbers. TrendSpotter models are shown with lines.

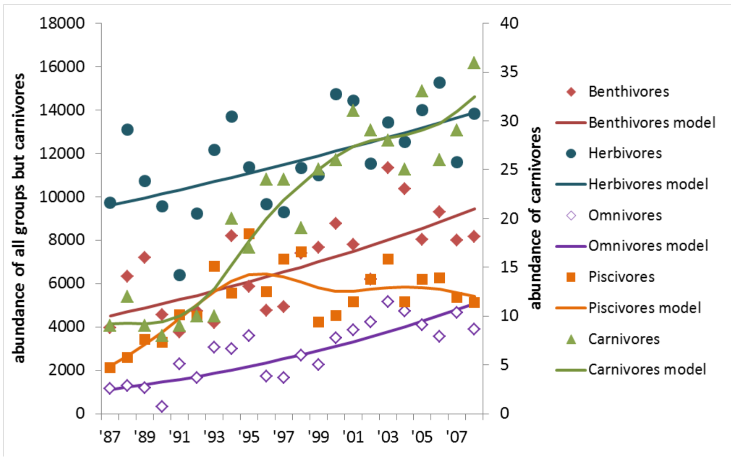


Figure 16. Total abundance (number of individuals) of birds within different trophic groups in Lake Grevelingen. Measured values are shown with dots. TrendSpotter models are shown with lines. Because numbers of carnivores are much lower, these are placed on the secondary y-axis.

Biodiversity of breeding birds showed a continuous increase after 1987 (Figure 17). Evenness also increased continuously after 1989. Species richness increased in the period 1980 – 1984 and remained stable at 13 species after that. Although we saw an increase in the abundance of piscivore birds in the period 1988 - 1994, the piscivore breeding birds showed a decrease during the same period (Figure 18). This is explained by the fact that the increase in non-breeding piscivores was mainly caused by an increase in Great crested grebe and Red-breasted Merganser whereas the piscivore breeding bird groups solely comprises terns. The decrease was observed in the measured values, but no significant trend changes were detected. We did find a significantly decreasing trend in the period 2004 – 2006, caused by the complete disappearance of the Sandwich Tern *Thalasseus sandvicensis* as a breeding bird after 2004. Omnivores/predators/scavenger showed a more dramatic decrease in the period 1989 – 1993, after a peak in abundance around 1986. Before 1992 the Black-headed gull *Larus ridibundus* was very abundant, but numbers decreased dramatically from around 8000 breeding pairs before 1992 to around 500 after 2002, explaining the decrease in omnivore breeding birds. Over time, the second-most abundant breeding bird the Herring Gull *Larus argentatus* increased about twofold in numbers (see also Strucker *et al.*, 2010b).

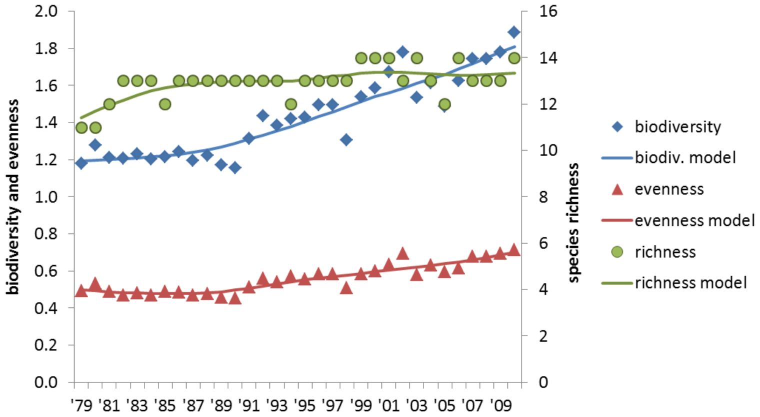


Figure 17. Indices for biodiversity and evenness (Shannon-Wiener and Pilou respectively; primary y-axis) and species richness (n species; secondary y-axis) for breeding birds in Lake Grevelingen. Measured values (dots) are season-averaged numbers. TrendSpotter models are shown with lines.

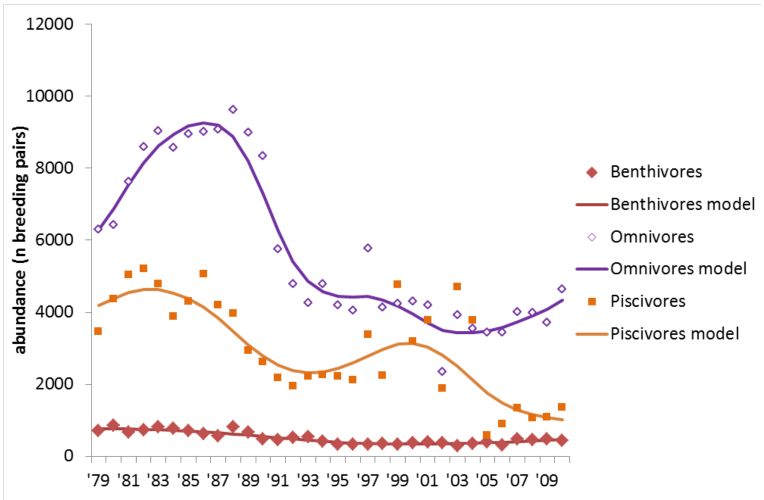


Figure 18. Total abundance (number of individuals) of breeding birds within different trophic groups in Lake Grevelingen. Measured values are shown with dots. TrendSpotter models are shown with lines.

Grevelingen fish

Biodiversity of fish showed large fluctuations during the study period of 1970 – 1986 (Figure 19). Biodiversity was relatively low in 1972 and 1973, (partially) due to a low evenness. This may be a direct effect of the construction of the Brouwersdam that was finished in 1971 and closed Lake Grevelingen off from the North Sea. Biodiversity increased afterwards (significantly so in the period 1974-'75), but the increase levelled off around 1979 and afterwards seemed to decrease again. No clear effect from the opening of the sluice in the Brouwersdam in 1978 can be detected.

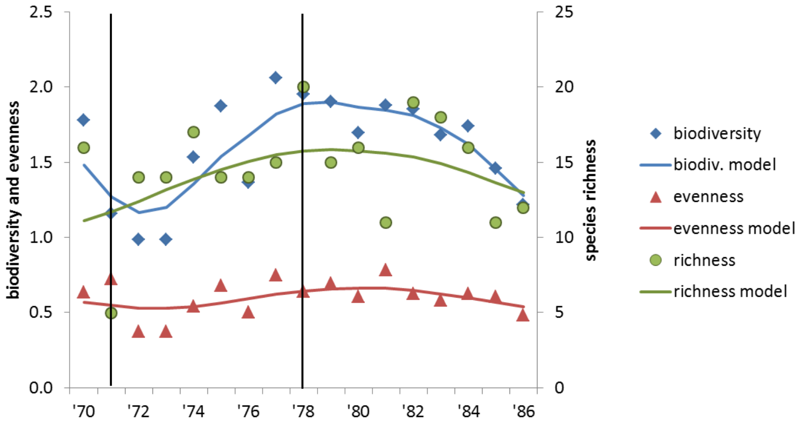


Figure 19. Biodiversity and evenness (Shannon Wiener and Pilou; primary y-axis) and species richness (n species; secondary y-axis) for fish in Lake Grevelingen. Measured values are given with dots, TrendSpotter models with lines. Black bars indicate the completion of engineering works (respectively Brouwerdam 1971, Brouwerssluice 1978).

The different trophic groups showed large differences in development (Figure 20). Significant changes in trend from year to year were hardly found because of the large year-to-year variation. Piscivores showed the smallest variation and showed a dramatic decrease in abundance in the period 1984 – 1986. No piscivore fish were found at all in 1985 and 1986. The six species in this group (*Dicentrarchus labrax*, *Gadus morhua*, *Hyperoplus lanceolatus*, *Merlangius merlangus*, *Scophthalmus rhombus*, and *Trachurus trachurus*) did not show a constant abundance. In each year another species was dominant. Planktivores on the other hand showed a relatively high abundance in 1986 and a significant increase in the period 1984 – 1986, mainly caused by an increase in gobies *Pomatoschistus* sp.. No trend was detected for benthivores (most abundant species Plaice *Pleuronectes platessa*) while the abundance of bentho-piscivores was relatively low in 1983 and 1984. This was caused by a dip in abundance of the dominant species *Myoxocephalus scorpius*, that was the only bentho-piscivore left in the samples in 1985 and 1986. All groups except for the piscivores showed a drop in abundance from 1970, when there was still an open connection with the North Sea, to 1971 when the Brouwersdam was completed and the Grevelingen closed off from the North Sea.

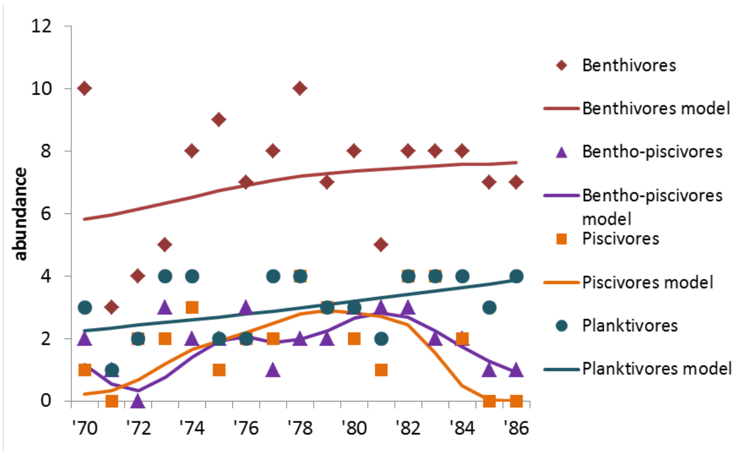


Figure 20. The total number of fish individuals ('abundance'; n m^2 collected by beam trawl) within different trophic groups in Lake Grevelingen. Measured values are given with dots, TrendSpotter models with lines.

4.3 Lake Veere

Lake Veere benthic macrofauna

Biodiversity of macrobenthic fauna showed a steady and significant increase in autumn in Lake Veere, from 2.0 in 1992 to 3.1 in 2010 (Figure 21). Evenness and species richness did not change significantly over time. For species richness significant trend changes could not be detected due to a large year to year variation. Measured values did increase after 2004 which indicates a positive effect of the Katse Heule sluice in the Zandkreekdam.

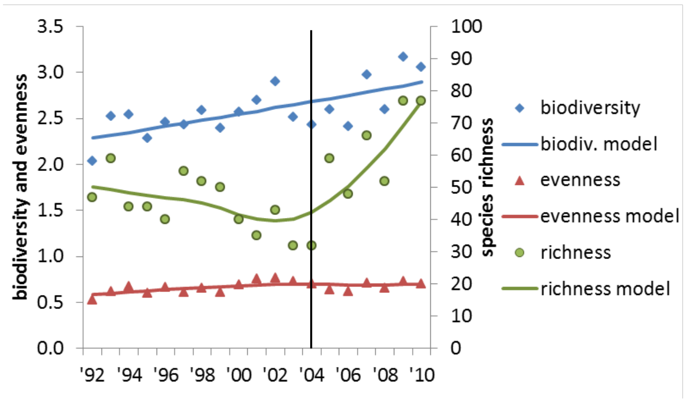


Figure 21. Biodiversity indices for macrobenthic fauna in Lake Veere. Samples were taken in autumn. Biodiversity (Shannon-Wiener index) and evenness (Pilou's index) are given on the primary y-axis, species richness (n species) on the secondary y-axis. Both the measured values (dots) and the TrendSpotter model (lines) are given. The black bar indicates the opening of the Katse Heule sluice.

A possible effect of the Katse Heule inlet was also seen in the abundance and species richness within different trophic groups (Figure 22). Species richness within the groups of filter feeders, surface deposit feeders, subsurface deposit feeders (and grazers) and omnivores/predators/scavengers all showed an increase after 2004. New species and species groups encountered in the samples after 2004 are Isopoda, the crab *Hemigrapsus takanoi*, and the amphipod *Microdeutopus* sp.. The total number of individuals within these groups, the abundance, remained the same (for the filter feeders) or decreased in the period 2004 – 2006. In the last two years of the data series, however, subsurface deposit feeders and omnivores/predators/scavengers showed an increase. Of the subsurface deposit feeders *Capitella capitata* and oligochaetes showed a higher abundance in 2010. Of the omnivores/predators/scavengers many species showed higher numbers in 2010. In the period before construction of the Katse Heule, deposit feeders (surface and subsurface) showed a long-term decrease in abundance and omnivores/predators/scavengers showed large fluctuations.

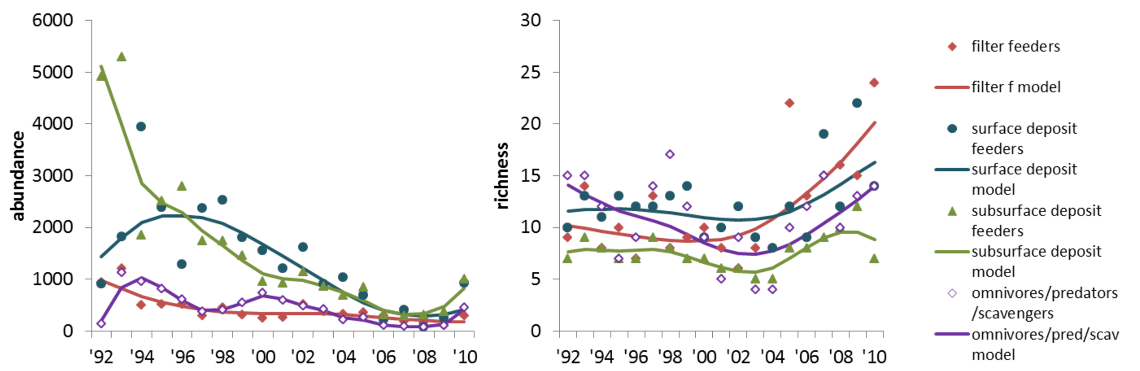


Figure 22. The total abundance (left) and species richness (right) of macrobenthic species within four trophic groups (filter feeders, surface deposit feeders, subsurface deposit feeders and omnivores/predators/ scavengers) in Lake Veere

Lake Veere birds

Biodiversity and evenness of birds showed a continuous increase over the entire study period of 1987 – 2008 (Figure 23). Species richness also increased, significantly so in the period 1990 – 1994. No effect of the Katse Heule was detected. The abundance of benthivores and carnivores increased continuously over time (Figure 24). The most abundant and increasing benthivores are the Lapwing *Vanellus vanellus* and Golden Plover *Pluvialis apricaria*. Although encountered in much lower numbers, the White Spoonbill *Platalea leucorodia* showed an increase after 1995 and a dramatic increase after 2003. The continuous increase in carnivores can be attributed to an increase in the most abundant species the Buzzard *Buteo buteo*. The Western Marsh Harrier *Circus aeruginosus*, the second-most abundant carnivore, increased in the period 1987 – 1995 and remained stable after that. Omnivores/predators/scavengers showed a decrease in abundance after 2000. The trend of omnivores is largely determined by the abundance of the Black Coot *Fulica atra*, by far the most abundant species in this group. The other species did not follow the same pattern as the Black Coot. Other relatively abundant species are the Herring Gull and Black-headed Gull that were absent before 1991, and the Tufted Duck *Aythya fuligula* that decreased after 2005. The abundance of herbivores was relatively high in 2000 – 2002 and decreased afterwards. This pattern is mainly caused by Wigeon and Mallard.

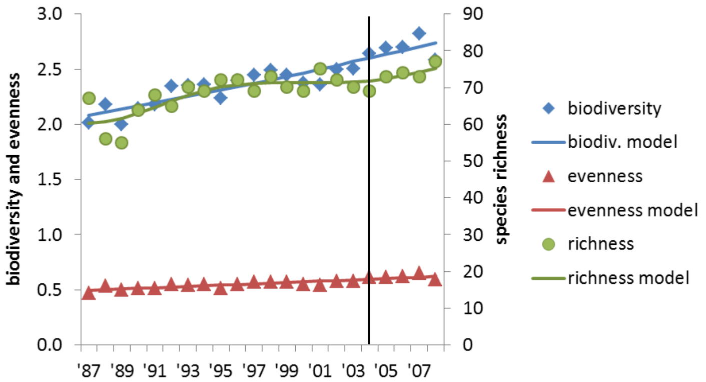


Figure 23. Indices for biodiversity and evenness (Shannon-Wiener and Pilou respectively; primary y-axis) and species richness (n species; secondary y-axis) for <u>birds</u> in Lake Veere. Measured values (dots) are season-averaged numbers. TrendSpotter models are shown with lines. The black bar indicates the opening of the Katse Heule sluice.

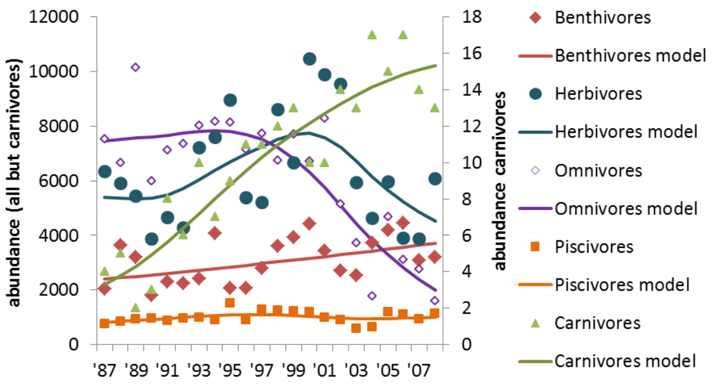


Figure 24. Total abundance (number of individuals) of <u>birds</u> within different trophic groups in Lake Veere. Measured values are shown with dots. TrendSpotter models are shown with lines. Because numbers of carnivores are much lower, these are placed on the secondary y-axis.

The abundance of breeding birds showed no significant trend changes in biodiversity, but seemed to have increased slightly which coincides with an increase in evenness in the period 1992 – 1996 (Figure 25). Species richness decreased in the period 1998 – 2001. This is due to the fact that after 1998 the Kentish Plover *Charadrius alexandrinus*, Ringed Plover *Charadrius hiaticula*, Mediterranean Gull *Larus melanocephalus*, and the Arctic Tern *Sterna paradisaea* were not encountered anymore in some years. Benthivore and piscivore breeding couples showed large fluctuations in abundance (Figure 26).

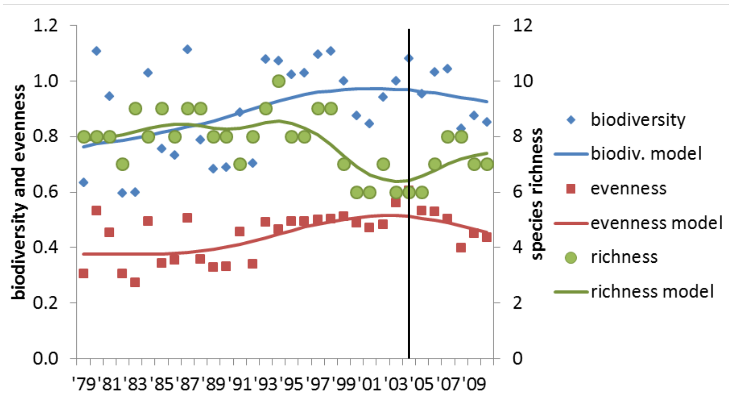


Figure 25. Indices for biodiversity and evenness (Shannon-Wiener and Pilou respectively; primary y-axis) and species richness (n species; secondary y-axis) for breeding birds in Lake Veere. Measured values (dots) are season-averaged numbers. TrendSpotter models are shown with lines. The black bar indicates the opening of the Katse Heule sluice.

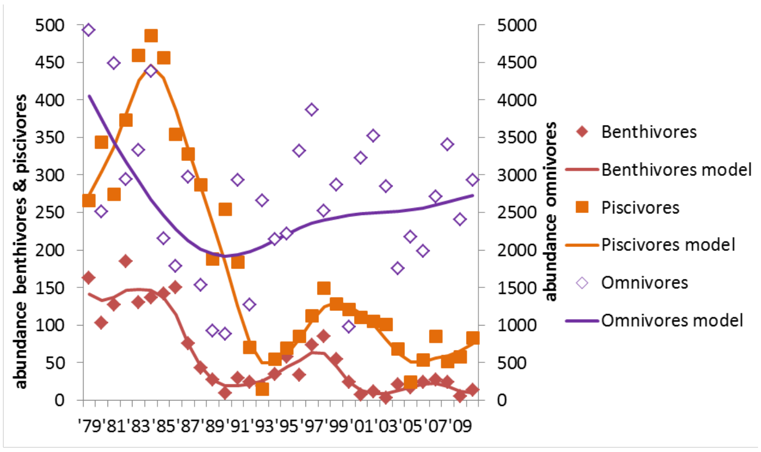


Figure 26. Total abundance (number of individuals) of breeding birds within different trophic groups in Lake Veere. Measured values are shown with dots. TrendSpotter models are shown with lines.

Benthivores showed two periods of decrease: 1987 – 1989 and 1999 – 2001. The Benthivore group consists of four species of which the Little ringed Plover *Charadrius dubius* was only encountered in two years. The other three species (Kentish Plover, Ringed Plover and Avocet *Recurvirostra avosetta*) showed a long-term decline. Although the Avocet, which is by far the most abundant benthivore breeding bird, also showed a long-term decline its numbers temporarily peaked in the period 1994 – 1999, causing the second period of decline in 1999 - 2000. Piscivores seemed to follow the same pattern as benthivores but lagged, with a significant decrease in 1990 – 1993. Indeed the most abundant species the Common Tern *Sterna hirundo* and the Arctic Tern *Sterna paradisaea* showed the same development in numbers over time as the Avocet, with a strong decline after 1985/1986, a revival in the second half of the 1990s and a decrease again after 1999. Variation from year to year was very high for the abundance of omnivore breeding couples. A significant decrease in the trend was detected for the period 1983 – 1986, which can be attributed to the Black-headed Gull *Larus ridibundus* that showed a long-term decline from thousands of breeding couples in the beginning of the time series to almost none at the end. The reason why we do not see a long-term decrease in omnivores is because of an increase in abundance of Herring Gulls *Larus argentatus* and Lesser Black-backed Gulls *Larus fuscus* after 1990.

Lake Veere fish

For Lake Veere no time series of fish were available.

4.4 Haringvliet

Haringvliet benthic macrofauna

Benthic macrofauna have only been sampled within MWTL for 4 years: 2002, 2005, 2007 and 2008 (Figure 27). This time series is too irregular and too short for TrendSpotter analysis. In the four available years, the biodiversity indices were relatively low in 2007. In this year extremely high numbers of the Quagga mussel *Dreissena polymorpha* were found. Other abundant species are the New Zealand mud snail *Potamopyrgus antipodarum*, the Zebra mussel *Dreissena polymorpha*, the European stream valvata *Valvata piscinalis* and the oligochaete *Nais pardalis*.

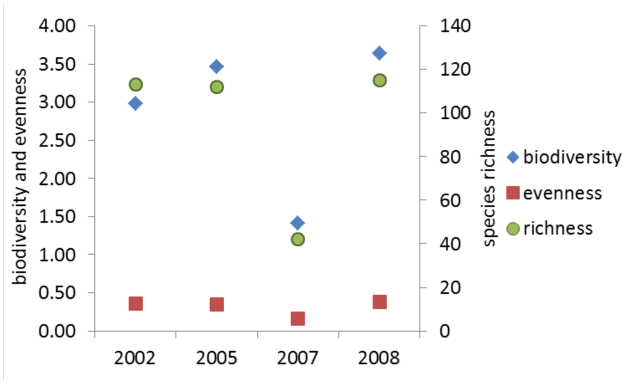


Figure 27. Biodiversity indices for macrobenthic fauna in the Haringvliet. Only measured values are given.

Haringvliet birds

Biodiversity of bird numbers decreased over time until 1999 (Figure 28). Evenness decreased slightly, and a significant decrease from year to year was detected in the period 1996 – 1999. Species richness showed a strong increase in the period 1994 – 1998, which was mainly reflected in an increase in the number of species within the benthivore and piscivore trophic groups (Figure). The most abundant benthivores are the Lapwing *Vanellus vanellus* and Golden Plover *Pluvialis apricaria*. The Dunlin *Calidris alpina* decreased over time, most strongly in the period before 1986. The White Spoonbill became very abundant after 1993. The abundance of herbivores increased strongly during two periods: 1976 – 1979 when the abundant species Wigeon, Mallard and Barnacle Goose increased, and 1992 – 1999 in which the abundant Barnacle Goose and Greylag Goose *Anser anser* increased. Piscivore abundance showed an on-going decrease due to a decrease in the most abundant Great Cormorant *Phalacrocorax carbo*. Also the piscivore Red-breasted Merganser *Mergus serrator* showed an on-going decrease. After 2001 the Little Egret *Egretta garzetta* and Great Egret *Egretta alba* showed a strong increase. Omnivores showed an increase in the period 1979 – 1992. During this period the abundant Tufted duck *Aythya fuligula* and Black-headed gull *Larus ridibundus* increased in numbers. Carnivores were left out of the analysis since a maximum of only 2 species (Peregrine Falcon *Falco peregrinus* and White-tailed Sea Eagle *Haliaeetus albicilla*) was present in season-averaged numbers of less than one individual.

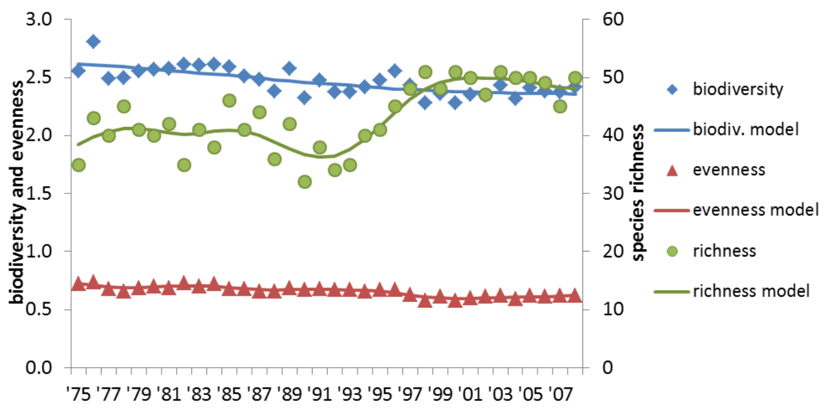


Figure 28. Indices for biodiversity and evenness (Shannon-Wiener and Pilou respectively; primary y-axis) and species richness (n species; secondary y-axis) for birds in Lake Haringvliet. Measured values (dots) are season-averaged numbers. TrendSpotter models are shown with lines.

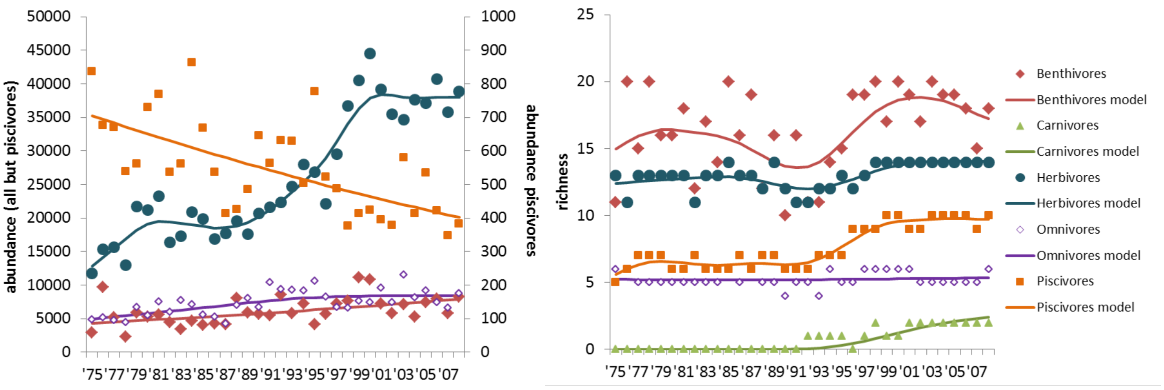


Figure 29. Total abundance (left; numbers) and species richness (right) of birds within different trophic groups in Lake Haringvliet. Measured values are shown with dots. TrendSpotter models are shown with lines. Because numbers of carnivores are much lower, these are placed on the secondary y-axis.

Breeding birds showed a steady species richness of 7 after an increase from 5 to 7 in the period 1979 – 1981 (Figure 30). Biodiversity and evenness showed relatively high values in 1982 – 1983, followed by a significant decrease to relatively low values in 1991 and 1992. After that, biodiversity and evenness increased again to values at the same level as in 1982 – 1983. The only carnivore in the dataset was the Western Marsh harrier *Circus aeruginosus*. Abundance of this species continuously and significantly decreased over the entire study period from 1979 to 2008 (Figure 31). Piscivores on the other hand showed a strong increase (significant in 1980 – 1989 and 1996 – 1999). Of the three piscivore species counted the Common tern *Sterna hirundo* and Little tern *Sterna albifrons* showed an increase before 1997 and a decrease after 2004. The third species, the Sandwich Tern *Thalasseus sandvicensis*, was only counted from 2004 onwards and showed a strong increase until 2007. If this species is left out, abundance of piscivores shows a decrease after 2004. Benthivores showed large fluctuations in abundance, with a significant decrease in 1990 and 2002, and a significant increase in 1994 – 1998. This pattern is mainly determined by the most abundant Avocet *Recurvirostra avosetta*, but the other two species the Ringed plover *Charadrius hiaticula* and Kentish plover *Charadrius alexandrinus* show the same pattern. Omnivores showed an increase in the period 1996 – 2004. The only species in this group is the Mediterranean gull *Larus melanocephalus*.

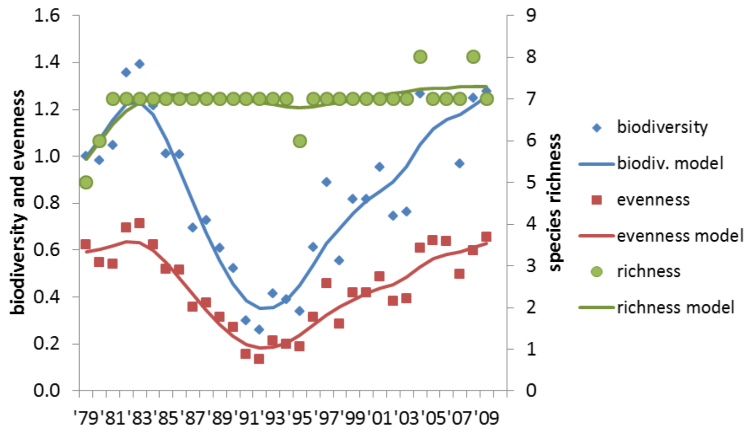


Figure 30. Indices for biodiversity and evenness (Shannon-Wiener and Pilou respectively; primary y-axis) and species richness (n species; secondary y-axis) for breeding birds in Lake Haringvliet. Measured values (dots) are season-averaged numbers. TrendSpotter models are shown with lines.

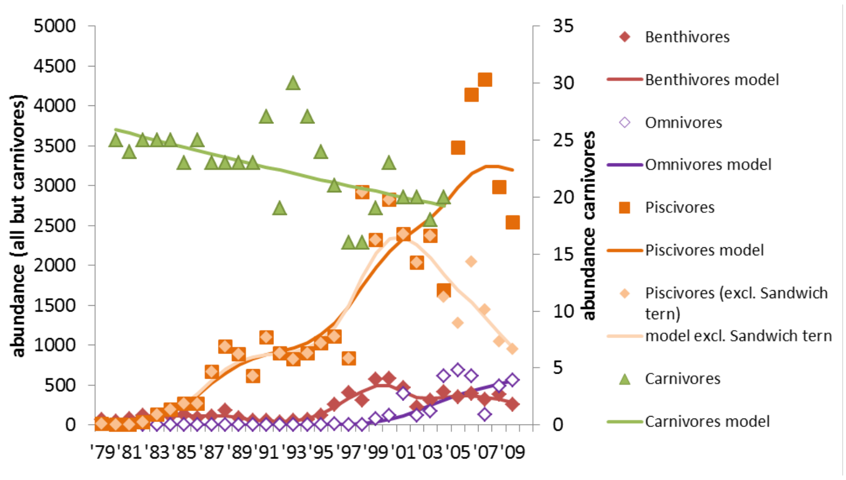


Figure 31. Total abundance (number of individuals) of breeding birds within different trophic groups in Lake Grevelingen. Measured values are shown with dots. TrendSpotter models are shown with lines.

Haringvliet fish

Time series of fish were not available for Lake Haringvliet.

4.5 Seagrass meadows, sea mammals and salt marshes

Seagrass

During the 1970s and 1980s more than 4000 hectares of seagrass (Common eelgrass *Zostera marina* and Dwarf eelgrass *Zostera noltii*) was found in the Oosterschelde estuary and Lake Grevelingen (Figure 32). It also occurred in a lower abundance in Lake Veere. Almost all seagrass has disappeared since then (CBS *et al.*, 2008). Causes for the decline in seagrass cover seem to be: a combination of high salinity and phosphorus limitation in a low-dynamic environment (Wijgergangs and Van Katwijk 1993; Kamermans *et al.*, 1999).

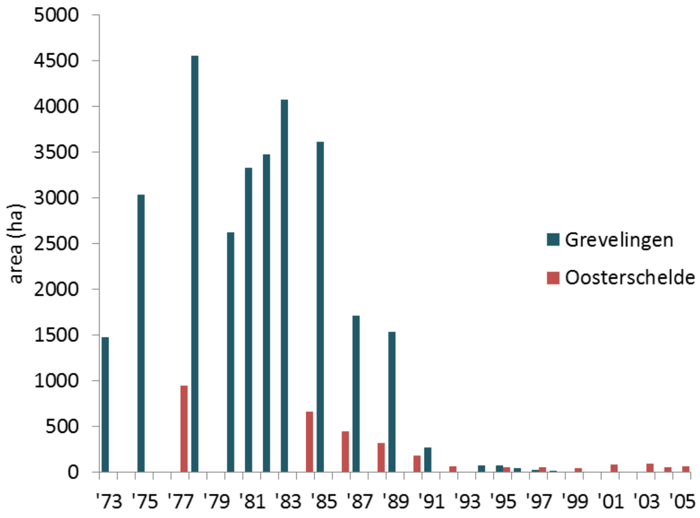
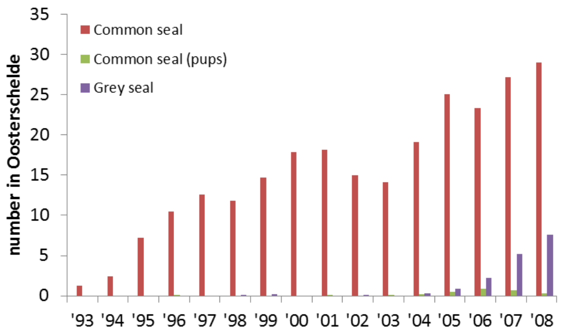


Figure 32. Development of seagrass meadows in the Oosterschelde and Grevelingen (in hectares; Zostera marina and Zostera noltii). Data from Rijkswaterstaat RIKZ through www.clo.nl

After construction of the Grevelingendam in 1964 common eelgrass (*Zostera marina*) developed in the eastern part of the Grevelingen. After construction of the Brouwersdam the area of eelgrass cover increased strongly to a maximum of over 4600 hectares in 1978. After that, the eelgrass beds decreased until none were left in 2000 (Wetsteyn, 2010). In the Oosterschelde area the seagrass beds showed a more gradual decline, but both species are still found here to date.

Sea mammals

Common seal (*Phoca vitulina*) increased strongly over the last decennium in the Oosterschelde estuary (Figure 33). Grey seal (*Halichoerus grypus*) are also increasing although in much lower numbers. Only low numbers of pups are found, and the Oosterschelde does not harbour a self-sustaining population. The numbers in the Oosterschelde are dependent on numbers in the Delta area, which again are dependent on the population in the Wadden Sea and migration to the Delta area (Strucker *et al.,* 2007; CBS *et al.*, 2012).



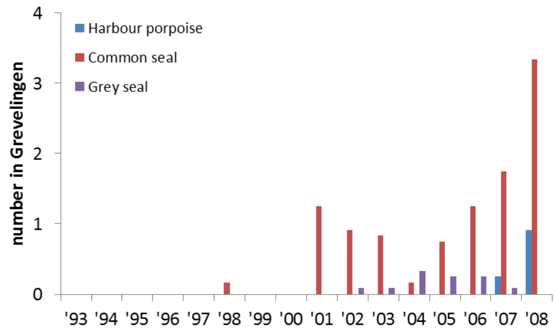


Figure 33. Season-averaged numbers of sea mammals in the Oosterschelde estuary (left) and Lake Grevelingen (right).

In Lake Grevelingen only low numbers of both species of seal are found, and also some Harbour porpoises (*Phocoena phocoena*). Migration possibilities were blocked with the closure of the Brouwersdam, but with the opening of the Brouwerssluice it is possible for these animals to migrate, although it is not known how many make use of this possibility. In the Oosterschelde estuary no data series of Harbour porpoises were available. There are indications that a group of Harbour porpoises lives in the Oosterschelde estuary year round. Sightings of young animals with their mothers indicate that the animals are reproducing in the estuary. In the summer of 2011 a number of 61 individuals was counted (Rugvin 2011).

Salt marshes

The area of salt marshes in the Southwestern Delta in the period 1856 – 1996 was described and analysed by Van der Pluijm and De Jong (1998). A summary of their conclusions is given here.

Although the tidal amplitude in the Oosterschelde estuary was reduced by about 10%, a large portion of the salt marshes remained. Inundations of the salt marshes occur less frequently, and in the first years after closure of the storm surge barrier erosion of the salt marshes increased. In 1998 the area of the salt marshes was still gradually decreasing.

With the closure of the Brouwersdam in 1971 the Grevelingen turned into a stagnant saltwater lake with a fixed water level. This marked the end of all saltmarshes in this area. The same happened in Lake Veere when it was dammed off from the Oosterschelde and North Sea. Also in Lake Haringvliet, the abrupt change into a freshwater lake meant the sudden end of salt marshes. The plant communities gradually changed. In Lake Grevelingen and Lake Haringvliet the change to a fixed water level resulted in dramatic erosion of the former salt marshes because waves now attacked the same level for prolonged periods of time.

4.6 Comparisons between water bodies

Benthic macrofauna

In comparison to the other water bodies and in general, biodiversity in the sublittoral zone of the Oosterschelde estuary is exceptionally high with an average value around 3.5 (Figure 34). Biodiversity in the littoral zone of the Oosterschelde estuary is lower than in the other systems because the littoral zone is an extreme environment where less species are able to survive. Also in Lake Haringvliet high biodiversity values were found. Biodiversity in the lakes Veere and Grevelingen is comparable. Species richness in these systems is not. In Lake Grevelingen over almost the complete time series a higher species richness was found. This may be caused by the larger surface area of Lake Grevelingen, by the longer period after major changes took place in Lake Veere, or the different water levels between summer and winter in Lake Veere for a long period of time.

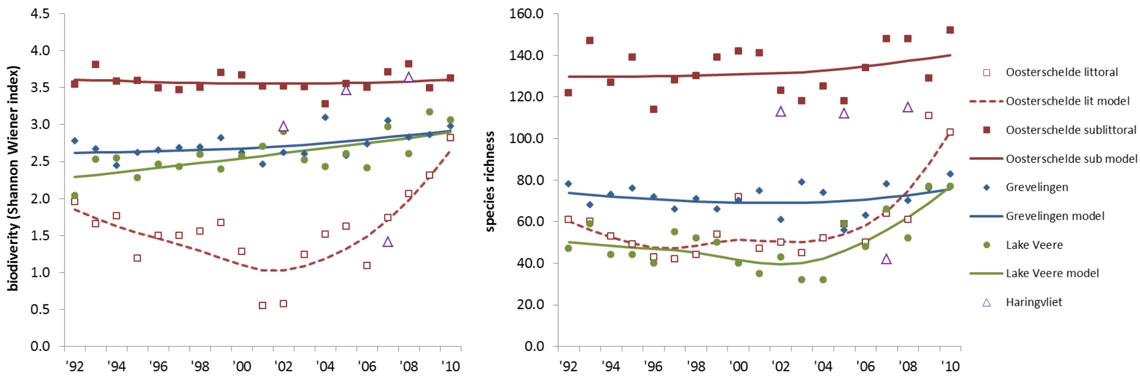


Figure 34. Biodiversity (left) and species richness (right) of benthic macrofauna in the four different water bodies. For the Oosterschelde estuary is distinction is made between the littoral and sublittoral zone. For Lake Haringvliet data was only available for four years.

The large differences observed between the littoral and sublittoral zone of the Oosterschelde estuary ask for a closer look. We therefore also calculated the biodiversity indices for the entire Oosterschelde estuary, the littoral and sublittoral zone combined (weighted according to the total area sampled in the littoral and sublittoral zones) (Figure 35). Not surprisingly, species richness is highest in the total area. As we had already seen, species richness and biodiversity are much higher in the sublittoral than in the littoral area. Although we would have expected to see the highest biodiversity in the total area, with the littoral and sublittoral zone combined into a higher habitat heterogeneity, we in fact see that biodiversity in the total area is mainly determined by the sublittoral zone. When combining the sublittoral with the littoral area the total biodiversity decreases, due to the lower species richness and much lower evenness in the littoral zone. There is also the fact to consider that the total area sampled was 3 times higher in the sublittoral than the littoral zone, reflecting the ration between both tidal zones in the entire estuary.

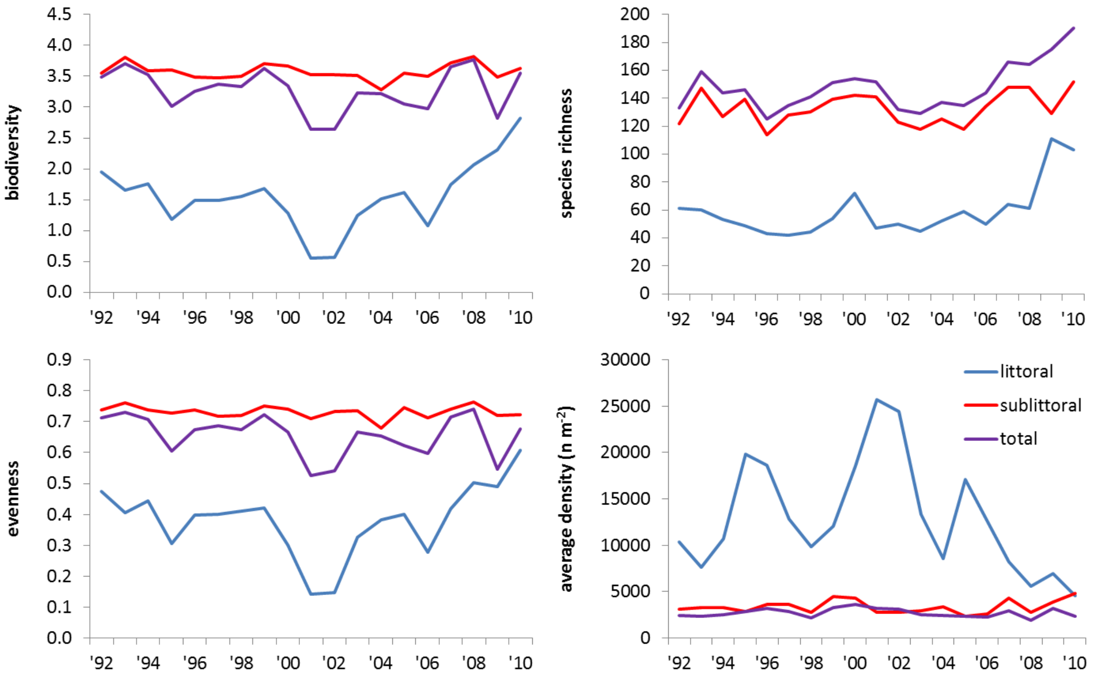


Figure 35. Biodiversity indices (Shannon-Wiener index for biodiversity, species richness and Pilou's index for evenness) and total abundance (average density) of benthic macrofauna in the Oosterschelde estuary, given for the littoral zone (blue), the sublittoral zone (red) and both zones combined (purple; species abundance weighted according to total area sampled in both zones). Calculated values from measured values are given, no TrendSpotter trends.

Birds

Biodiversity among birds is quite high in all water bodies (Figure 36). The highest biodiversity was found in Lake Grevelingen over the whole time period analysed, with a high Shannon Wiener index of around 3.0. Biodiversity among birds showed a relatively large change in the Oosterschelde estuary with an increase by almost 1.0 from beginning to end. In contrast to biodiversity, species richness showed large differences between the water bodies, with the lowest species richness in Lake Haringvliet, followed by Lake Veere.

Apart from a dip in the late 1980s the Shannon Wiener index gave similar results for breeding birds in the Oosterschelde estuary and Lake Grevelingen (Figure 37). The Shannon Wiener index is low for all water bodies, presumably because only a selected number of species is counted and the species richness is therefore low. What is striking is the decrease in Lake Haringvliet during the 1980s, while biodiversity increased or remained the same in the other water bodies. Regarding species richness, again Lake Veere and Lake Haringvliet showed the lowest values.

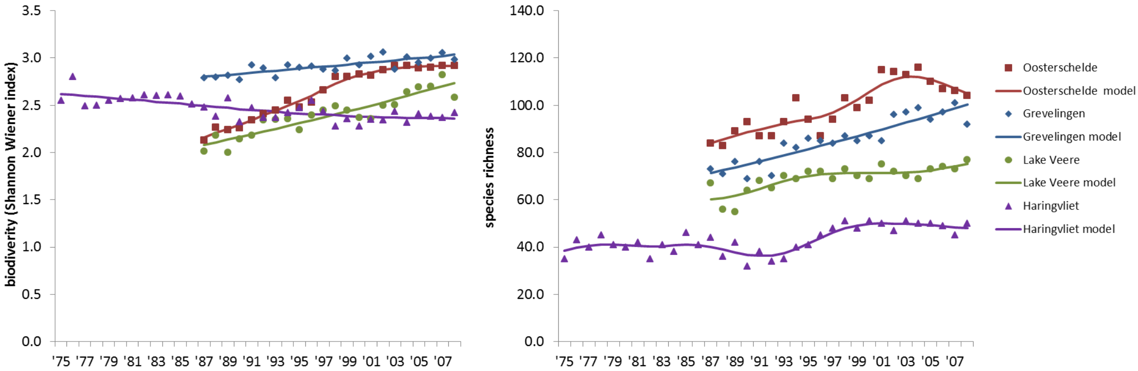


Figure 36. Biodiversity (left) and species richness (right) of <u>non-breeding birds</u> in the four different water bodies.

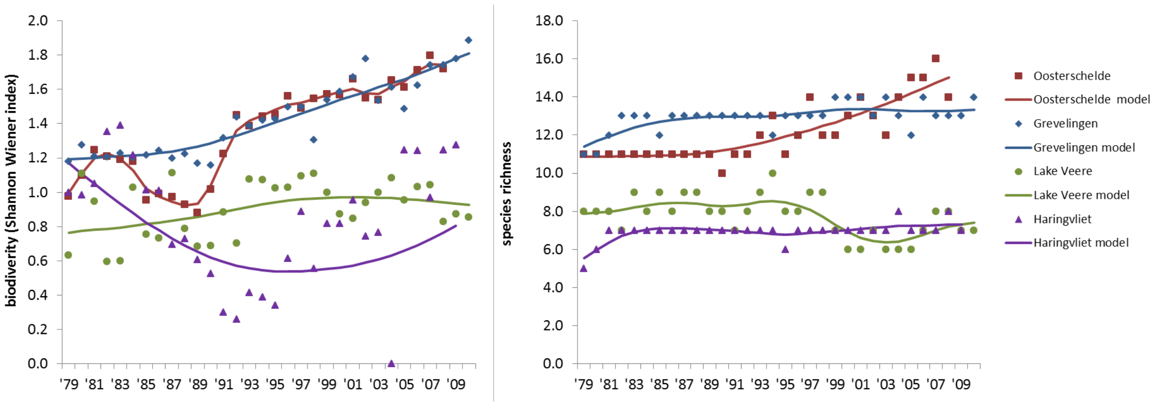


Figure 37. Biodiversity (left) and species richness (right) of <u>breeding birds</u> in the four different water bodies.

Fish

For fish, only long-term data series were available for the Oosterschelde estuary and Lake Grevelingen, not for the lakes Veere and Haringvliet. Biodiversity was low in both systems (around 1.5) and strongly fluctuating in Lake Grevelingen. Species richness is much higher in the Oosterschelde estuary than in Lake Grevelingen during the period 1970 – 1986. This may be due to a higher degree of heterogeneity in habitats and more opportunities for migratory species (Figure 38).

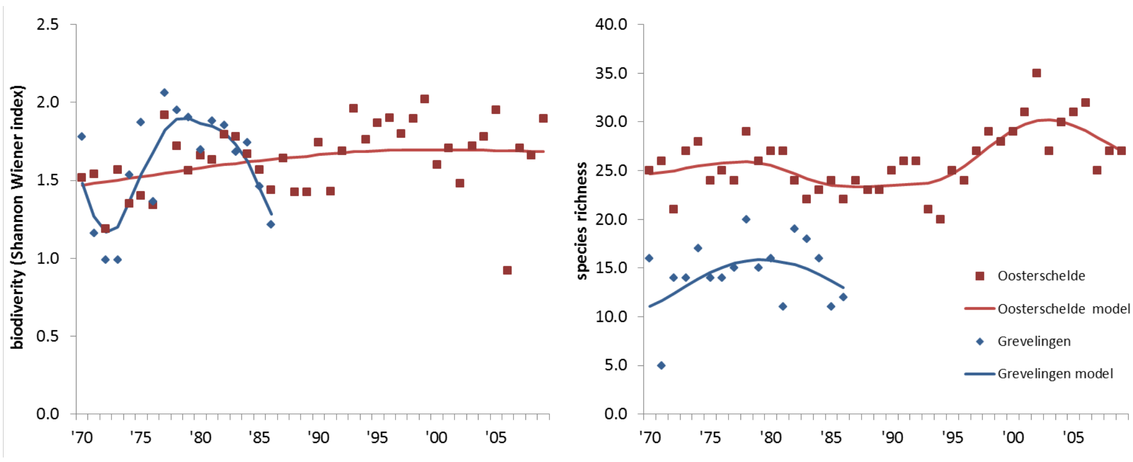


Figure 38. Biodiversity (left) and species richness (right) of <u>fish</u> in the two different water bodies.

5 Discussion and conclusions

5.1 Oosterschelde

Changes in hydromorphology, flora and fauna as a consequence of completion of the storm surge barrier in the mouth of the Oosterschelde estuary have been well documented (Nienhuis and Smaal, 1994), although these studies suffered from the fact that the 'before' situation lies in the construction period, and there were a series of severe winters in the years before completion and a series of mild winters in the years after completion, influencing the analysis of ecological changes (Mees, 1994).

In the Oosterschelde estuary most long-term data series start just after completion of the storm surge barrier. By then, all Delta works in the Oosterschelde and adjoining water bodies were completed. The study by Meire *et al.,* (1994) revealed no clear changes in benthic macrofauna between the period before and after closure of the storm surge barrier. Also in the period after 1987, from 1992 onward, we did not find changes in diversity and species richness that could be attributed to the Delta works. We did see a decrease in filter-feeders abundance in the 1990s which was due to a strong decrease in cockle *C. edule* stock in the Eastern part of the estuary (Troost and Ysebaert, 2011). Total filter feeder biomass actually increased due to expansion of the Pacific oyster *Crassostrea gigas* (Troost *et al.*, 2009), but this does not show in the dataset because intertidal oyster beds are not sampled in the MWTL monitoring programme. Also, the Oosterschelde contains a large stock of cultured filter-feeders, and there are indications that the carrying capacity for filter-feeding organisms in the Oosterschelde may already have been reached.

For benthivore waders and Shelduck ofcourse a large part of their intertidal foraging grounds were lost when parts of the Oosterschelde estuary were dammed off (e.g. by the Oesterdam in 1987). This was extensively studied and described by (Schekkerman *et al.*, 1994). Especially winter numbers of many species of waders decreased. Species richness did not seem to be affected. Also the proportions of the different trophic groups did not seem different in the period before and shortly after completion of the barrier. Although benthivores as a group did not change over time since 1987, one particular species, the Oystercatcher *H. ostralegus* does show a long-term decline which is a combination of factors acting on a larger spatial scale, and a decreased food availability (Troost and Ysebaert, 2011). Most piscivore species increased over time, most likely due to an increased water transparency and reduced hydrodynamics. Strucker *et al.* (2008a) show that the Great Crested Grebe and Red-breasted Merganser show similar trends and presume a relationship with changes in the fish community.

Breeding birds appeared to be affected by the completion of the storm surge barrier, since they showed a temporary decrease in biodiversity. In the period 1985 - 1990 the proportion of Black-headed gulls (*L. ridibundus*) was higher than 70% and the abundance of this species was relatively high. The Little tern (*S. albifrons*) occurred in relatively low numbers. In later years, although the Kentish plover (*Ch. alexandrius*) declined by about 50% in 1987, the total abundance of breeding birds showed an increase in abundance and in species richness. This may be due to the Oosterschelde becoming a less harsh environment and to active management aimed at improving breeding opportunities for shorebirds and wetland birds, and development of wetlands such as 'Plan Tureluur' which was executed in 1999. It was designed to compensate for the loss of intertidal flats as a consequence of sand starvation. The overall aim of this plan is to develop 850 hectares of saltwater inland nature along the borders of the Oosterschelde estuary, mainly on Schouwen-Duivenland at the northern shore of the estuary. Between 1999 and 2009, 510 hectares of nature divided over numerous larger and smaller areas was developed. These areas are of high importance as foraging and breeding grounds for birds. It is likely that the growth of breeding bird couples was supported by this increase in habitat. Especially the Avocet *Recurvirostra avosetta* showed high increase in abundance (Strucker *et al.*, 2008c). It has to be underlined here that 'Plan Tureluur' concerns inland, saltwater nature areas lacking tidal influence and should therefore not to be confused with saltmarshes that are part of the estuarine ecosystem.

Although we tried to relate changes in abundance and biodiversity of birds to the coastal engineering project, it should be kept in mind that in many cases factors acting on a larger spatial scale (e.g. predation in arctic breeding areas, hunting, etc.) are more determining for population changes than factors acting on a local scale. At least when individual species are considered. We do expect that changes in trophic groups, including multiple species, are strongly influenced by hydromorphological, chemical or biotic changes on a local scale.

Not much changes in the fish communities were detected. Hostens and Hamerlynck (1994) could only demonstrate a loss in anadromous species (diadromous species that live in the sea and migrate to inland freshwater for spawning). We did not detect clear trends in biodiversity indices apart from a dip in species richness in the period around completion of the storm surge barrier in 1986. Obviously, the Delta works completely blocked migration possibilities for anadromous (e.g Twaite and Allis shad *Alosa fallax* and *A. alosa*, and Atlantic Salmon *Salmo salar*) and katadromous (living in freshwater and migrating to the sea for spawning, e.g. the European eel *Anguilla anguilla* and Flounder *Platichthys flesus*) fish species.

The abundance of sea mammals in the Oosterschelde estuary is directly dependent on the abundance in the Dutch Wadden Sea, since the delta area has no self-sustaining population itself. Because the Oosterschelde retained an open connection with the North Sea migration of seals and harbour porpoises is still possible.

The disappearance of Common eelgrass *Zostera marina* and strong reduction in Dwarf eelgrass *Zostera noltii* is likely to be caused by the Delta works, since the area it covers has increased in the Wadden Sea (CBS *et al.*, 2008) but spectacularly decreased in the Southwestern Delta. Many years of research have, however, not yet led to a conclusion on the exact causes although the increased salinity in the Oosterschelde estuary seems to be one of the causes (Wijgergangs and Van Katwijk, 1993; Kamermans *et al.*, 1999; Wetsteyn 2010).

5.2 Grevelingen

In Lake Grevelingen, as was seen in the Oosterschelde estuary for the cockle *C. edule*, the abundance of filter feeders showed a decline. As in the Oosterschelde estuary, also in the MWTL dataset of Lake Grevelingen filter feeders on the culture plots (oysters *O. edulis* and *C. gigas*) are not included. Nevertheless the decrease in filter feeders in Lake Grevelingen does seem to reflect changes as result of the Delta project. A shift is observed from filter feeders to deposit feeders, and the relative amount of worms is increasing (Wetsteyn, 2010). Relative to data from the period 1962-1963 overall species richness seemed to have increased. This may be because the environment in the estuary has become less extreme and harsh, with a total absence of tides and a salinity gradient. The increased richness cannot be attributed to the area sampled, since the area of one sample and the total area sampled was much larger in 1962-1963 (0.1 m^2 per sample and 5.2 – 8.9 m^2 sampled in total) than in 1992 – 2010 (0.015 m^2 per sample and 1.0 m^2 sampled in total). The observation is counter-intuitive since a water body with full estuarine gradients would be expected to have a higher diversity in habitats and therefore a higher species richness and biodiversity. We will come back to this in paragraph 5.5. Finally, It should be kept in mind that 30 years lie between both sampling periods and the methods used were quite different (compare Weeber, 1980; Escaravage *et al.*, 2003a).

Overall species richness of non-breeding birds increased over time in the study period 1987 - 2008. This cannot really be attributed to the Delta works in Lake Grevelingen anymore, since the Lake was already dammed off in 1971. The increase observed is more likely caused by active nature management aimed at increasing local populations of (breeding) shorebirds. Through an enhancement of breeding opportunities also numbers of 'non-breeding' birds increased. Benthivore wader species remained, although in much lower numbers. Lake Grevelingen the most important water body for piscivore birds in the Southwestern delta area. Piscivores showed a steady decrease since 1987 but this levelled off when the Brouwerssluice became permanently open. Causes of the decrease in mainly Great cormorants (*P. carbo*) and Great crested grebes (*P. cristatus*) are still not understood (Wetsteyn, 2010). The Great crested grebe followed the national trend until 1999/2000 when winter numbers suddenly dropped, which points to a relationship with the year-round opening of the Brouwerssluice. Unfortunately the fish monitoring by beam trawl stopped after 1986. Since 2006 fish is monitored again, but only once every three years. For the period in-between it is not possible to determine whether there were significant changes in the food source for piscivore birds of open water. However, Bouma *et al.*, (2008, in Wetsteyn, 2010) deducted from changes in abundance of several piscivore birds that a shift in in the fish community is a likely scenario.

Damming the estuary off made the area less extreme, and therefore less hostile to breeding birds. On the other hand, rapid overgrowth of bare grounds due to desalination made the area less suitable again for many breeding birds. Since 2005 management of the water level is adapted to breeding birds of bare grounds, with a lowered water level of -0,26 NAP in the period April – July (instead of -0,20) and a raised water level by 4 cm on several occasions during September – February (Wetsteyn, 2010). The decrease in omnivore breeding birds was caused by the decrease in Black-headed gull *L. ridibundus* which is a pattern observed on a larger spatial scale (Strucker *et al.,* 2010b; CBS and SOVON 2012). Just when the Brouwerssluice was opened, the piscivore terns decreased.

In 1971, the year in which the Brouwersdam was completed, species richness among fish was extremely low. This seemed a temporary effect, however, since species richness rapidly increased again after 1972. Ofcourse closing the lake off from the North Sea and rivers stopped all migrations possibilities for migratory fish species. Although exchange with the North Sea became possible again in 1978 with the opening of the Brouwerssluice, no clear effects could be detected in the biodiversity indices. Piscivore fish showed a decrease until 1986 when the monitoring stopped.

As also happened in the Oosterschelde estuary, the area covered with seagrass decreased, presumably because of the Delta works. In Lake Grevelingen Common eelgrass *Zostera marina* disappeared completely. During the 1980s and 1990s only one common seal was recorded to permanently live in the lake. Since the year-round opening of the Brouwerssluice the population has increased to a permanent group of 15 seals that are known to sometimes cross the sluice. In the past few years some pups were even recorded. Only one harbour porpoise seems to be living in Lake Grevelingen since 2007 (Wetsteyn, 2010).

5.3 Lake Veere

The present Lake Veere was already formed in 1961, with the completion of the Veersegatdam. None of the datasets go as far back as to allow for comparison of the situation before and after closure. Presumably similar effects occurred as in Lake Grevelingen, since the intertidal completely disappeared. An important distinction, however, is the fact that Lake Veere has always been a more marine system with no direct input from rivers. Another distinction is the fact that flora and fauna in Lake Veere suffered from an artificially low winter water level of -0.7 m relative to NAP while the summer water level was maintained at around NAP.

With the datasets available it was more feasible to assess changes due to opening of the Katse Heule sluice. Richness and abundance of benthic macrofauna decreased in the years before 2004 but slowly recovered in the years afterwards, illustrating the direct dependence of benthic macrofauna on water quality and salinity (Wijnhoven *et al.*, 2010). Birds are more mobile species that are less directly dependent on water quality in a particular system. No clear changes in bird biodiversity indices could be detected. Patterns observed were mainly attributable to specific species that show strong trends on a larger spatial scale. Breeding birds showed two periods of decline (piscivores and herbivores). Especially piscivores decreased strongly, but seemed to recover slightly after 2004. The two periods of decline remain intriguing and unsolved.

5.4 Haringvliet

In contrast with the lakes Grevelingen and Veere, Lake Haringvliet completely changed from a brackish into a freshwater system. No saltwater influence remained at all because the system was flushed continuously with fresh water from the Rhine and Meuse rivers.

Wijnhoven *et al.* (2011) analysed in detail changes in biomass and biodiversity of benthic macrofauna in the Rhine-Meuse estuary. They concluded that the direct effects of the hydromorhphological and abiotic changes in Lake Haringvliet as a consequence of the completion of the Haringvlietdam in 1971 were difficult to identify because of heavy pollution in the period before completion. Because of severe pollution of the rivers, the benthic community in the Haringvliet estuary was already impoverished. From the 1970s on the impoverished communities were replaced by new species assemblages that belonged to low dynamic freshwater communities. Wijnhoven *et al.* (2011) concluded that the former estuarine situation was more diverse than the lake system. The highly dynamic and changing conditions in the past led to a variety of niches, in space (both horizontally and vertically) and time.

Since closure of the Haringvlietdam in 1971, the abundance of piscivore birds decreased (since 1975; mainly the Great Cormorant *Ph. carbo*) and herbivore birds increased, which seems to be a direct effect of the transformation of a brackish tidal system to a freshwater stagnant lake. Piscivore breeding birds showed an opposite pattern, since terns increased dramatically over time, likely related to the development of conservation areas. Unfortunately, no fish data were available.

5.5 Conclusions

Effects of the Delta works on biodiversity among marine and aquatic communities are highly diverse and depend on many different factors and histories specific for the different water bodies. Some common effects could nevertheless be identified. Main effects are due to a loss in connectivity between basins and with the rivers systems and North Sea, and due to a loss in estuarine gradients. However, a reduced water quality and pollution hamper the comparison between an open and a fragmented Southwestern Delta.

Connectivity

The results of this study point out that open connections between different water bodies and with the rivers and North Sea are very important and largely determined effects of the Delta works on the fish communities. Especially migratory fish were affected by the Delta works. On the other hand only limited effects were found on birds, which may be explained by their high level of mobility. From a bird's point of view the different water bodies remained as connected as they had ever been, because birds simply fly from one system to another, largely unhampered by man-made barriers although important barriers preventing bird migration may be their site-faithfulness (e.g. in the

Oystercatcher *H. ostralegus*). Benthic fauna on the other hand is largely restricted to certain locations and highly dependent on water quality, as could be observed in Lake Veere where a significant improvement in water quality led to an increase in benthic species richness.

Estuarine gradients

It would seem that most effects of the Delta works are related to changes from estuaries with gradients in exposure time and salinity into stagnant water bodies with more stable environments. Species specific for extreme habitats such as found in the intertidal and the brackish part of the estuarine salinity gradient, and only occurring there, have been lost in areas such as Lake Grevelingen, Lake Veere and Lake Haringvliet. It is easily expected that the loss of estuarine dynamics led to a loss in biodiversity within the separate water bodies, because of a loss in habitat heterogeneity. On the other hand, the environment became less extreme, likely offering habitat to more (new) species. This is still speculation and needs further study, but see Whitfield *et al.* (2012).

The analysis of biodiversity (Shannon Wiener index) and species richness in the littoral and sublittoral zone in the Oosterschelde gives an idea of what might have happened in the lakes Grevelingen, Veere and Haringvliet. The sublittoral of the Oosterschelde estuary shows a high biodiversity index and high species richness. Adding data for the littoral zone increased total species richness, albeit only moderately. Apparently, only few of the species inhabiting the intertidal live there exclusively and the majority lives in the sublittoral zone as well. The biodiversity index decreased slightly if the littoral zone was also included, due to a low species richness in the littoral zone which is explained by the fact that the littoral zone is a very harsh environment with large extremes in environmental values. Only few species can live here. Also, numbers were distributed very unevenly (Pilou), showing that some species occur in much higher numbers compared to many. The mudsnail *H. ulvae* which sometimes occurs in tens of thousands per m^2 will have had a large influence on the low evenness and biodiversity. Based on the observations for the Oosterschelde estuary it is hypothesized that also in the lakes Grevelingen, Veere and Haringvliet not much changed in species richness and the biodiversity index of macrobenthic fauna. This seems to be confirmed by our analysis for Lake Grevelingen.

The same principle is expected to apply for estuarine salinity gradients. The brackish zone is also an extreme environment that is known for its extremely low species richness (Whitfield *et al.*, 2012). Nevertheless some species occur only here, because this is the only environment where they are able to outcompete others with less broad tolerances for environmental extremes. Excluding the brackish zone from a system will therefore likely result in a slight loss in species richness and perhaps a slight gain or no change at all in biodiversity index. Although considered in this way the extreme environments of the littoral zone and the brackish zone do not seem to add much 'value' in terms of biodiversity (species richness and diversity), these species are rare because their habitat is relatively unique. In that sense, their importance for global biodiversity can still be considered high.

One aspect not covered by the biodiversity indices is variation in time. Variation in time is expected to be higher in a more dynamic system and may be argued to contribute to biodiversity, or at least to a high species richness considered at a longer time-scale. On the other hand, it may also lead to a lower evenness and therefore a lower Shannon Wiener index.

Poor water quality and pollution

The comparison between an open delta and a fragmented delta are hampered by the many abiotic changes and problems occurring as a result of hydromorphological changes due to the Delta works, as well as changes in management. Although no direct effects of sand starvation in the Oosterschelde estuary on benthic or bird communities are detected yet (Troost & Ysebaert, 2011), in Lake Grevelingen and Lake Veere poor water quality and oxygen deficiency in deeper water layer affected benthic fauna and possibly also fish and bird communities. In Lake Veere this is confirmed by the observed changes after opening of the Katse Heule. Connectivity may thus also indirectly affect marine faunal communities, through improvement of water quality. In Lake Haringvliet patterns observed may well be influenced by the pollution peak of the 1970s and the sedimentation of polluted silts after closure of the Haringvlietdam in 1971.

Open vs. fragmented
One could argue that the biodiversity of the Southwestern Delta as a whole increased due to the fragmentation into smaller areas that all developed into a different direction (tidal saltwater, stagnant saltwater, brackish and fresh). However, would it be allowed to regard the Southwestern Delta as one area? For benthic fauna and fish this is not really the case since for these species migration and exchange possibilities are extremely limited, and in the delta area as a whole the relative contribution of species solely inhabiting the extreme environments in the tidal zone and brackish zone has decreased strongly. Furthermore, many water bodies changed from estuarine areas into areas that are less unique (stagnant freshwater lakes) and/or contain less unique species or communities on a global scale. It should be noted, however, that the present study did not include terrestrial fauna and flora, which is documented to have increased in richness in Lake Grevelingen (Van Haperen, 1989). Furthermore, isolation of areas may well lead to unique communities and rare species, if only given a long period of time of perhaps more than a few hundred years to evolve.

Concluding
The main problems of the Delta works are: almost no migration possibilities for fish, a loss in estuarine dynamics causing overgrowth of pioneer vegetations and breeding habitats on bare grounds as well as bad water quality, a loss in species strictly associated with the intertidal and brackish zones in estuarine salinity gradients. If connections are to be restored (even to some extent) between saltwater and freshwater systems, allowing for migration and salinity gradients as well as some tidal movement, this is likely to lead to a higher species richness. Only a slight effect on the biodiversity index is expected. Additionally, restoration of connections and estuarine gradients and dynamics is likely to occur on a scale that is much more reduced in comparison with the situation before the Delta works. Effects on species richness and biodiversity may therefore be modest.

We did, however, not include Lake Krammer-Volkerak in our study. Before the Delta works this lake was a brackish tidal systems connecting the Oosterschelde estuary to the Rhine and Meuse. Many changes occurred in this now freshwater lake. Whether changes led to changes in communities or to an impoverished version of the former estuarine communities remains to be studied.

5.6 Recommendations for further research

In this study we compared four different water bodies with a different history regarding the Delta works and with different abiotic and biotic characteristics. The results of this study contribute to insights in long-term consequences of the Delta works and allow for careful predictions on the effects of restoration of estuarine gradients and connectivity between water bodies. We did, however, not include the Krammer-Volkerak and Zoommeer. Before the Delta works these lakes were brackish tidal systems. The Krammer-Volkerak connected the Oosterschelde estuary to the Rhine and Meuse, and Grevelingen estuary. The Zoommeer was part of the Oosterschelde estuary. Changes in these systems may have been the most radical in terms of the abiotic environment (from brackish tidal to stagnant fresh) and biodiversity. Preliminary results of a biodiversity study by Tangelder *et al.* (2012) where overall biodiversity of the Southwestern delta was considered, show a strong degradation of fish richness in both lakes which is supposedly related to water quality degradation. Changes in community structure and trophic groups of fish and birds as well as benthic community responses in Lake Krammer-Volkerak and Zoommeer still remain to be studied.

On a more overall scale the diverging characteristics in the basins of the Southwest Delta contributed to a higher richness of the delta as a whole (Tangelder, 2012). At the same time Tangelder *et al.* (2012) discuss whether the Southwestern Delta can be regarded and treated as one system when considering biodiversity, taking into account the lack of connectivity. Results of the present study indicate that restoration of estuarine gradients may not have a large effect on overall biodiversity, but may lead to a higher species richness locally (by adding species exclusively found in the tidal and brackish zone and by increasing habitat heterogeneity). Two important questions remain. Firstly, did communities indeed evolve differently in the different water bodies and will they become more similar when connections are restored? A community analysis using the already collected data is recommended to answer this question. The second remaining question is that of uniqueness. Although we assessed changed in biodiversity using three indices for biodiversity (species richness, diversity and evenness), these three indices do not give a complete picture of biodiversity. The occurrence of species and communities that are rare, or associated to rare habitats, is also of great importance for biodiversity and for nature appreciation. We therefore recommend to not only perform the above mentioned community analysis, but to also analyse which species are exclusively found in habitats that have been lost as a consequence of the Delta works (short-term and long-term effects) and that may return when connections and gradients are restored.

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Appendix 1 List of species and their feeding guilds

Benthic macrofauna

Species name	Synonym (accepted name, WoRMS)	Trophic group
Abludomelita obtusata	*Abludomelita obtusata*	II
Abra	*Abra*	II
Abra alba	*Abra alba*	II
Abra nitida	*Abra nitida*	II
Abra prismatica	*Abra prismatica*	II
Abra tenuis	*Abra tenuis*	II
Acanthocardia	*Acanthocardia*	I
Acanthocardia echinata	*Acanthocardia echinata*	I
Acanthocardia paucicostata	*Acanthocardia paucicostata*	I
Acanthocardia tuberculata	*Acanthocardia tuberculata*	I
Acentria ephemerella		not used (Haringvliet)
Achelia echinata	*Achelia echinata*	IV
ACTINIARIA	*Actiniaria*	IV
Adyte pellucida	*Subadyte pellucida*	IV
Agraylea multipunctata		not used (Haringvliet)
Agraylea sexmaculata		not used (Haringvliet)
Alboglossiphonia		not used (Haringvliet)
Alboglossiphonia heteroclita		not used (Haringvliet)
Alkmaria romijni	*Alkmaria romijni*	II
Ampelisca	*Ampelisca*	I
Ampelisca brevicornis	*Ampelisca brevicornis*	I
Ampelisca gibba	*Ampelisca gibba*	I
Ampharete	*Ampharete*	II
Ampharete acutifrons	*Ampharete acutifrons*	II
Ampharete finmarchica	*Ampharete finmarchica*	II
Ampharetidae	*Ampharetidae*	II
Amphilochus neapolitanus	*Amphilochus neapolitanus*	III
Amphipholis squamata	*Amphipholis squamata*	I
Amphitrite	*Amphitrite*	II
Amphiuridae	*Amphiuridae*	I
Anacaena limbata		not used (Haringvliet)
Anaitides mucosa	*Phyllodoce mucosa*	IV
Ancylus fluviatilis		not used (Haringvliet)
Anoplodactylus petiolatus	*Anoplodactylus petiolatus*	IV
Aonides oxycephala	*Aonides oxycephala*	II
Aora typica	*Aora typica*	na
Aoridae	*Aoridae*	II
Aphelochaeta	*Aphelochaeta*	II
Aphelochaeta marioni	*Aphelochaeta marioni*	II
Apherusa	*Apherusa*	II
Apherusa bispinosa	*Apherusa bispinosa*	II
Aphrodita aculeata	*Aphrodita aculeata*	IV
Arenicola	*Arenicola*	III
Arenicola defodiens	*Arenicola defodiens*	III
Arenicola marina	*Arenicola marina*	III
Aricidea	*Aricidea*	II
Aricidea minuta	*Aricidea minuta*	II
Arrenurus crassicaudatus		not used (Haringvliet)
ASCIDIACEA	*Ascidiacea*	I
Ascidiella aspersa	*Ascidiella aspersa*	I
Asellus aquaticus		not used (Haringvliet)
Asterias	*Asterias*	IV
Asterias rubens	*Asterias amurensis*	IV
ASTEROIDEA	*Asteroidea*	IV
Athanas nitescens	*Athanas nitescens*	IV
Atyaephyra desmaresti		not used (Haringvliet)
Atylus	*Atylus*	IV
Atylus falcatus	*Nototropis falcatus*	IV
Atylus guttatus	*Atylus guttatus*	IV
Atylus swammerdami	*Atylus swammerdami*	IV
Autolytus	*Myrianida*	IV
Autolytus brachycephalus	*Myrianida brachycephala*	na
Autolytus edwardsi	*Myrianida edwardsi*	na
Autolytus langerhansi	*Myrianida langerhansi*	na
Autolytus prolifer	*Myrianida prolifera*	na
Balanus crenatus	*Balanus crenatus*	I
Balanus improvisus	*Balanus improvisus*	I
Barnea candida	*Barnea candida*	III
Bathyporeia	*Bathyporeia*	II
Bathyporeia elegans	*Bathyporeia elegans*	II
Bathyporeia guilliamsoniana	*Bathyporeia guilliamsoniana*	II
Bathyporeia pelagica	*Bathyporeia pelagica*	II
Bathyporeia pilosa	*Bathyporeia sarsi*	II
Bathyporeia sarsi	*Bathyporeia sarsi*	II

I	suspension or filter feeder
II	interface feeder, surface deposit feeder, facultative suspension feeder
III	subsurface deposit feeder, grazer
IV	predator, omnivore, scavenger
na	not available

Species name	Synonym (accepted name, WoRMS)	Trophic group
Bembidion	*Bembidion*	empty
Bithynia		not used (Haringvliet)
Bithynia leachi		not used (Haringvliet)
Bithynia tentaculata		not used (Haringvliet)
Bivalvia		not used (Haringvliet)
Boccardiella ligerica	*Boccardiella ligerica*	II
Bodotria pulchella	*Bodotria pulchella*	II
Bodotria scorpioides	*Bodotria scorpioides*	II
Bodotriidae	*Bodotriidae*	II
Botryllus	*Botryllus*	I
Botryllus schlosseri	*Botryllus schlosseri*	I
BRACHYURA	*Brachyura*	na
Branchiura sowerbyi		not used (Haringvliet)
Bryozoa		not used (Haringvliet)
Caenis horaria		not used (Haringvliet)
Caenis luctuosa		not used (Haringvliet)
Callianassa tyrrhena	*Pestarella tyrrhena*	III
Cancer pagurus	*Cancer pagurus*	IV
Capitella capitata	*Capitella capitata*	III
Capitellidae	*Capitellidae*	III
Caprellidae	*Caprellidae*	na
Carcinus maenas	*Carcinus maenas*	IV
Cardiidae	*Cardiidae*	I
CARIDEA	*Caridea*	na
Caulleriella alata	*Caulleriella alata*	II
Cerastoderma	*Cerastoderma*	I
Cerastoderma edule	*Cerastoderma edule*	I
Cerastoderma glaucum	*Cerastoderma glaucum*	I
Cerastoderma lamarcki	*Cerastoderma glaucum*	I
Ceratopogonidae		not used (Haringvliet)
Cerianthus lloydii	*Cerianthus lloydii*	IV
Chaetocladius piger agg.		not used (Haringvliet)
Chaetogaster		not used (Haringvliet)
Chaetogaster diaphanus		not used (Haringvliet)
CHAETOGNATHA	*Chaetognatha*	IV
Chaetozone gibber	*Chaetozone gibber*	II
Chaetozone setosa	*Chaetozone setosa*	II
Cheirocratus sundevallii	*Cheirocratus sundevalli*	III
Chelicorophium curvispinum		not used (Haringvliet)
Chelicorophium robustum		not used (Haringvliet)
Chironomidae		not used (Haringvliet)
Chironomini		not used (Haringvliet)
Chironomus		not used (Haringvliet)
Chironomus luridus agg.		not used (Haringvliet)
Chironomus nudiventris		not used (Haringvliet)
Chironomus obtusidens		not used (Haringvliet)
Chironomus plumosus		not used (Haringvliet)
Chironomus plumosus agg.		not used (Haringvliet)
Chironomus salinarius	*Chironomus salinarius*	empty
Ciona intestinalis	*Ciona intestinalis*	I
Cirratulidae	*Cirratulidae*	II
Cirratulus cirratus	*Cirratulus cirratus*	II
Cladotanytarsus		not used (Haringvliet)
Cladotanytarsus atridorsum		not used (Haringvliet)
Cladotanytarsus mancus gr.		not used (Haringvliet)
Cladotanytarsus pallidus		not used (Haringvliet)
Cliona celata	*Cliona celata*	I
Cnidaria		not used (Haringvliet)
Corbicula		not used (Haringvliet)
Corbicula fluminalis		not used (Haringvliet)
Corbicula fluminea		not used (Haringvliet)
Corbula gibba	*Corbula gibba*	I
Cordylophora caspia		not used (Haringvliet)
Corophiidae	*Corophiidae*	II
Corophium	*Corophium*	II
Corophium acherusicum	*Monocorophium ascherusicum*	II
Corophium arenarium	*Corophium arenarium*	II
Corophium bonnellii	*Crassicorophium bonellii*	II
Corophium insidiosum	*Monocorophium insidiosum*	II
Corophium multisetosum	*Corophium multisetosum*	II
Corophium sextonae	*Monocorophium sextonae*	II
Corophium volutator	*Corophium volutator*	II
Cossura	*Cossura*	III
Cossura longocirrata	*Cossura longocirrata*	III
Cossura pygodactylata	*Cossura pygodactylata*	III
Crangon	*Crangon*	IV
Crangon crangon	*Crangon crangon*	IV
Crangonidae	*Crangonidae*	IV
Crassicorophium bonellii	*Crassicorophium bonellii*	empty
Crassostrea	*Crassostrea*	I
Crepidula fornicata	*Crepidula fornicata*	I
Cricotopus		not used (Haringvliet)
Cricotopus bicinctus		not used (Haringvliet)
Cricotopus cylindraceus/festivellus gr.		not used (Haringvliet)

Species name	Synonym (accepted name, WoRMS)	Trophic group
Cricotopus intersectus agg.		not used (Haringvliet)
Cricotopus sylvestris		not used (Haringvliet)
Cricotopus sylvestris gr.		not used (Haringvliet)
CRUSTACEA	*Crustacea*	empty
Cryptochironomus		not used (Haringvliet)
Cryptochironomus defectus		not used (Haringvliet)
Cryptochironomus obreptans/supplicans		not used (Haringvliet)
Cryptochironomus redekei		not used (Haringvliet)
CUMACEA	*Cumacea*	U
Cumopsis goodsiri	*Cumopsis goodsir*	II
Cyathura carinata	*Cyathura carinata*	empty
Cyrnus trimaculatus		not used (Haringvliet)
DECAPODA	*Decapoda*	na
Dendrocoelum lacteum		not used (Haringvliet)
Dendrocoelum romanodanubiale		not used (Haringvliet)
Dexamine thea	*Dexamine thea*	III
Diastylis	*Diastylis*	II
Diastylis bradyi	*Diastylis bradyi*	II
Diastylis lucifera	*Diastylis lucifera*	II
Diastylis rathkei	*Diastylis rathkei*	II
Diastylis rugosa	*Diastylis rugosa*	II
Diastylis tumida	*Diastylis tumida*	II
Dicrotendipes nervosus		not used (Haringvliet)
Didemnidae	*Didemnidae*	I
Didemnum candidum	*Didemnum candidum*	I
Dikerogammarus		not used (Haringvliet)
Dikerogammarus villosus		not used (Haringvliet)
Dodecaceria concharum	*Dodecaceria concharum*	II
Dorvilleidae	*Dorvilleidae*	IV
Dreissena		not used (Haringvliet)
Dreissena bugensis		not used (Haringvliet)
Dreissena polymorpha		not used (Haringvliet)
Echinocardium cordatum	*Echinocardium cordatum*	III
Echinogammarus		not used (Haringvliet)
ECHINOIDEA	*Echinoidea*	II
Ecnomus tenellus		not used (Haringvliet)
Einfeldia carbonaria		not used (Haringvliet)
Elysia viridis	*Elysia viridis*	empty
Enchytraeus		not used (Haringvliet)
Endochironomus albipennis		not used (Haringvliet)
Ensis	*Ensis*	I
Ensis arcuatus	*Ensis magnus*	I
Ensis directus	*Ensis directus*	I
Ensis ensis	*Ensis ensis*	I
Ephemeroptera		not used (Haringvliet)
Ephydatia fluviatilis		not used (Haringvliet)
Epitonium clathratulum	*Epitonium clathratulum*	IV
Epitonium clathrus	*Epitonium clathrus*	IV
Ericthonius	*Ericthonius*	I
Ericthonius difformis	*Ericthonius brasiliensis*	I
Erpobdella		not used (Haringvliet)
Erpobdella octoculata		not used (Haringvliet)
Erpobdella testacea		not used (Haringvliet)
Erpobdella vilnensis		not used (Haringvliet)
Eteone	*Eteone*	IV
Eteone flava	*Eteone flava*	IV
Eteone longa	*Eteone longa*	IV
Eulalia viridis	*Eulalia viridis*	IV
Eumida	*Eumida*	IV
Eumida bahusiensis	*Eumida bahusiensis*	IV
Eumida sanguinea	*Eumida sanguinea*	IV
Eunereis longissima	*Eunereis longissima*	IV
Eunicidae	*Eunicidae*	IV
Eurydice	*Eurydice*	IV
Eurydice pulchra	*Eurydice pulchra*	IV
Eurydice spinigera	*Eurydice spinigera*	IV
Euspira pulchella	*Euspira pulchella*	IV
Euzonus flabelligerus	*Euzonus flabelligerus*	III
Exogone	*Exogone*	II
Exogone (Exogone) naidina	*Exogone (Exogone) naidina*	II
Exogone hebes	*Exogone (Parexogone) hebes*	II
Exogone naidina	*Exogone (Exogone) naidina*	II
Exogoninae	*Exogoninae*	na
Fabricia stellaris stellaris	*Fabricia stellaris stellaris*	na
Ferrissia fragilis		not used (Haringvliet)
Ficopomatus enigmaticus	*Ficopomatus enigmaticus*	na
Flabelligera affinis	*Flabelligera affinis*	II
Forelia variegator		not used (Haringvliet)
Gammaridae	*Gammaridae*	IV
GAMMARIDEA	*Gammaridea*	na
Gammarus	*Gammarus*	IV
Gammarus duebeni	*Gammarus duebeni*	IV
Gammarus locusta	*Gammarus locusta*	IV
Gammarus salinus	*Gammarus salinus*	IV

Species name	Synonym (accepted name, WoRMS)	Trophic group
Gammarus tigrinus		not used (Haringvliet)
Gammarus zaddachi	*Gammarus zaddachi*	IV
GASTROPODA	*Gastropoda*	IV
Gastrosaccus	*Gastrosaccus*	IV
Gastrosaccus sanctus	*Gastrosaccus sanctus*	IV
Gastrosaccus spinifer	*Gastrosaccus spinifer*	IV
Gattyana cirrosa	*Gattyana cirrhosa*	IV
Gibbula	*Gibbula*	III
Glossiphonia		not used (Haringvliet)
Glossiphonia complanata		not used (Haringvliet)
Glossiphonia nebulosa		not used (Haringvliet)
Glycera	*Glycera*	IV
Glycera alba	*Glycera alba*	IV
Glycera oxycephala	*Glycera oxycephala*	IV
Glycera tridactyla	*Glycera convoluta*	IV
Glyptotendipes		not used (Haringvliet)
Glyptotendipes pallens		not used (Haringvliet)
Glyptotendipes paripes		not used (Haringvliet)
Gyraulus		not used (Haringvliet)
Gyraulus albus		not used (Haringvliet)
Gyraulus laevis		not used (Haringvliet)
Halacaridae		not used (Haringvliet)
Haliplus		not used (Haringvliet)
Harmothoe	*Harmothoe*	IV
Harmothoe imbricata	*Harmothoe imbricata*	IV
Harmothoe impar	*Harmothoe impar*	IV
Harnischia		not used (Haringvliet)
Harnischia fuscimana		not used (Haringvliet)
Harpinia	*Harpinia*	III
Haustorius arenarius	*Parahaustorius holmesi*	II
Helobdella stagnalis		not used (Haringvliet)
Hemigrapsus	*Hemigrapsus*	IV
Hemigrapsus penicillatus	*Hemigrapsus penicillatus*	IV
Hemigrapsus takanoi	*Hemigrapsus takanoi*	IV
Hemimysis anomala		not used (Haringvliet)
Hesionidae	*Hesionidae*	IV
Heteromastus filiformis	*Heteromastus filiformis*	III
Hinia	*Nassarius*	I
Hippolyte	*Hippolyte*	IV
Hippolyte longirostris	*Hippolyte longirostris*	IV
Hippolyte varians	*Hippolyte varians*	IV
Hirudinea		not used (Haringvliet)
Hyale prevosti	*Apohyale prevostii*	empty
Hydra		not used (Haringvliet)
Hydrobia	*Hydrobia*	III
Hydrobia ulvae	*Hydrobia ulvae*	III
Hydrobia ventrosa	*Ventrosia ventrosa*	III
HYDROZOA	*Hydrozoa*	IV
Hygrobates		not used (Haringvliet)
Hygrobates longipalpis		not used (Haringvliet)
Hygrobates nigromaculatus		not used (Haringvliet)
Hypania invalida		not used (Haringvliet)
Idotea	*Idotea*	IV
Idotea chelipes	*Idotea chelipes*	IV
Idotea linearis	*Idotea linearis*	IV
Idotea neglecta	*Idotea neglecta*	IV
Ilyodrilus templetoni		not used (Haringvliet)
INSECTA	*Insecta*	empty
ISOPODA	*Isopoda*	na
Jaera	*Jaera*	III
Jaera albifrons	*Jaera (Jaera) albifrons*	III
Jaera istri		not used (Haringvliet)
Janira maculosa	*Janira maculosa*	III
Janiridae	*Janiridae*	III
Jassa	*Jassa*	I
Jassa falcata	*Jassa marmorata*	I
Kefersteinia cirrata	*Kefersteinia cirrata*	na
Kurtiella bidentata	*Kurtiella bidentata*	empty
Laevicardium crassum	*Laevicardium crassum*	I
Lanice conchilega	*Lanice conchilega*	II
Lebertia		not used (Haringvliet)
Lebertia inaequalis		not used (Haringvliet)
Lebertia insignis		not used (Haringvliet)
Lekanesphaera hookeri	*Lekanesphaera hookeri*	empty
Lekanesphaera rugicauda	*Lekanesphaera rugicauda*	empty
Lepidochitona	*Lepidochitona*	III
Lepidochitona cinerea	*Cyanoplax caverna*	III
Lepidonotus squamatus	*Lepidonotus squamatus*	IV
Leucothoe incisa	*Leucothoe incisa*	U
Limnesia maculata		not used (Haringvliet)
Limnesia marmorata		not used (Haringvliet)
Limnodrilus claparedianus		not used (Haringvliet)
Limnodrilus hoffmeisteri		not used (Haringvliet)
Limnodrilus profundicola		not used (Haringvliet)

Species name	Synonym (accepted name, WoRMS)	Trophic group
Limnodrilus udekemianus		not used (Haringvliet)
Limnomysis benedeni		not used (Haringvliet)
Limnophyes		not used (Haringvliet)
Liocarcinus	*Liocarcinus*	IV
Liocarcinus arcuatus	*Liocarcinus navigator*	IV
Liocarcinus depurator	*Liocarcinus depurator*	empty
Liocarcinus holsatus	*Liocarcinus holsatus*	IV
Liocarcinus navigator	*Liocarcinus navigator*	IV
Lipiniella araenicola		not used (Haringvliet)
Littorina	*Littorina*	III
Littorina littorea	*Littorina littorea*	III
Lumbricidae		not used (Haringvliet)
Lumbrineris	*Lumbrineris*	IV
Lymnaeidae		not used (Haringvliet)
Lysianassidae	*Lysianassidae*	na
Macoma balthica	*Macoma balthica*	II
Macropodia	*Macropodia*	IV
Macropodia parva	*Macropodia parva*	IV
Magelona	*Magelona*	II
Magelona johnstoni	*Magelona johnstoni*	II
Magelona papillicornis	*Magelona mirabilis*	II
Malacoceros	*Malacoceros*	II
Malacoceros fuliginosus	*Malacoceros fuliginosus*	II
Malacoceros tetracerus	*Malacoceros tetracerus*	II
Malmgreniella lunulata	*Malmgreniella lunulata*	IV
Manayunkia aestuarina	*Manayunkia aestuarina*	na
Marenzelleria	*Marenzelleria*	II
Marphysa	*Marphysa*	IV
Marphysa sanguinea	*Marphysa sanguinea*	IV
Megaluropus agilis	*Megaluropus agilis*	I
Melita	*Melita*	II
Melita palmata	*Melita palmata*	II
Melitidae	*Melitidae*	na
Microchironomus tener		not used (Haringvliet)
Microdeutopus	*Microdeutopus*	na
Microdeutopus anomalus	*Microdeutopus anomalus*	na
Microdeutopus damnoniensis	*Microdeutopus chelifer*	na
Microdeutopus gryllotalpa	*Microdeutopus gryllotalpa*	na
Micronecta		not used (Haringvliet)
Micronecta minutissima		not used (Haringvliet)
Micronecta scholtzi		not used (Haringvliet)
Microphthalmus	*Microphthalmus*	III
Microphthalmus aberrans	*Microphthalmus aberrans*	III
Microphthalmus listensis	*Microphthalmus listensis*	III
Microphthalmus sczelkowii	*Microphthalmus sczelkowii*	III
Microphthalmus similis	*Microphthalmus similis*	III
Microprotopus	*Microprotopus*	IV
Microprotopus maculatus	*Microprotopus maculatus*	IV
Mideopsis orbicularis		not used (Haringvliet)
Molgula	*Molgula*	I
Molgula manhattensis	*Molgula manhattensis*	I
MOLLUSCA	*Mollusca*	empty
Montacuta ferruginosa	*Tellimya ferruginosa*	I
Mya	*Mya*	I
Mya arenaria	*Mya arenaria*	I
Myrianida langerhansi	*Myrianida langerhansi*	na
Myrianida prolifera	*Myrianida prolifera*	na
Myriochele	*Myriochele*	II
Mysella bidentata	*Kurtiella bidentata*	I
Mysida		not used (Haringvliet)
MYSIDACEA	*Mysida*	IV
Mysidae	*Mysidae*	na
Mysta picta	*Mysta picta*	na
Mytilicola intestinalis	*Mytilicola intestinalis*	IV
Mytilidae	*Mytilidae*	I
Mytilopsis leucophaeata		not used (Haringvliet)
Mytilus edulis	*Mytilus edulis*	I
Naididae		not used (Haringvliet)
Nais		not used (Haringvliet)
Nais barbata		not used (Haringvliet)
Nais bretscheri		not used (Haringvliet)
Nais pardalis		not used (Haringvliet)
Nassarius nitidus	*Nassarius nitidus*	IV
Nassarius reticulatus	*Nassarius reticulatus*	IV
NATANTIA	*Natalscia warreni*	IV
NEMERTEA	*Nemertea*	empty
Neoamphitrite	*Neoamphitrite*	II
Neoamphitrite affinis	*Neoamphitrite affinis*	II
Neoamphitrite figulus	*Neoamphitrite figulus*	II
Neomysis integer	*Neomysis integer*	II
Nephtys	*Nephtys*	IV
Nephtys assimilis	*Nephtys assimilis*	IV
Nephtys caeca	*Nephtys caeca*	IV
Nephtys cirrosa	*Nephtys cirrosa*	IV

Species name	Synonym (accepted name, WoRMS)	Trophic group
Nephtys hombergii	*Nephtys hombergii*	IV
Nephtys longosetosa	*Nephtys longosetosa*	IV
Nereis	*Nereis*	IV
Nereis diversicolor	*Hediste diversicolor*	IV
Nereis longissima	*Eunereis longissima*	IV
Nereis succinea	*Alitta succinea*	IV
Nereis virens	*Alitta virens*	IV
Notomastus (Notomastus) latericeus	*Notomastus (Notomastus) hedlandica*	III
NUDIBRANCHIA	*Nudibranchia*	IV
Nymphon	*Nymphon*	IV
Nymphon brevirostre	*Nymphon brevirostre*	IV
Nymphon rubrum	*Nymphon brevirostre*	IV
Nymphonidae	*Nymphonidae*	IV
Oecetis		not used (Haringvliet)
Oecetis ochracea		not used (Haringvliet)
OLIGOCHAETA	*Oligochaeta*	III
Ophelia	*Ophelia*	III
Ophelia rathkei	*Ophelia rathkei*	III
Ophiodromus	*Ophiodromus*	IV
Ophiodromus flexuosus	*Ophiodromus flexuosus*	IV
Ophiothrix	*Ophiothrix*	I
Ophiothrix fragilis	*Ophiothrix fragilis*	I
Ophiura	*Ophiura*	IV
Ophiura albida	*Ophiura albida*	IV
Ophiura ophiura	*Ophiura ophiura*	IV
Ophiura sarsi	*Ophiura sarsii*	IV
OPHIUROIDEA	*Ophiuroidea*	IV
Ophryotrocha gracilis	*Ophryotrocha gracilis*	IV
Orchestia remyi	*Macarorchestia remyi*	I
Orthocladiinae		not used (Haringvliet)
Orthocladius		not used (Haringvliet)
Ostrea edulis	*Ostrea chilensis*	I
Ostreidae	*Ostreidae*	I
Oulimnius		not used (Haringvliet)
Oulimnius tuberculatus		not used (Haringvliet)
Owenia fusiformis	*Owenia fusiformis*	II
OWENIIDA	*Oweniida*	empty
Pagurus bernhardus	*Pagurus bernhardus*	IV
Palaemon		not used (Haringvliet)
Palaemon adspersus	*Palaemon adspersus*	IV
Palaemon longirostris	*Palaemon longirostris*	IV
Parachironomus		not used (Haringvliet)
Parachironomus arcuatus gr.		not used (Haringvliet)
Parachironomus biannulatus		not used (Haringvliet)
Paradoneis fulgens	*Paradoneis fulgens*	III
Paraonidae	*Paraonidae*	na
Paraphaenocladius impensus agg.		not used (Haringvliet)
Parapleustes bicuspis	*Parapleustes bicuspis*	III
Paratanytarsus dissimilis		not used (Haringvliet)
Pectinaria	*Pectinaria*	III
Pectinaria koreni	*Lagis koreni*	I
PELECYPODA	*Bivalvia*	na
Petricola	*Petricola*	I
Petricola pholadiformis	*Petricolaria pholadiformis*	I
Phaxas pellucidus	*Phaxas pellucidus*	I
Pherusa flabellata	*Pherusa flabellata*	II
Pherusa plumosa	*Pherusa plumosa*	II
Pholoe	*Pholoe*	IV
Pholoe minuta	*Pholoe minuta*	IV
PHORONIDA	*Phoronida*	I
Phoronidae	*Phoronida*	I
Phoronidae + koker	*Phoronida*	I
Photis reinhardi	*Photis pollex*	II
Phoxichilidium femoratum	*Phoxichilidium femoratum*	IV
Phyllodoce	*Phyllodoce*	IV
Phyllodoce lineata	*Phyllodoce lineata*	IV
Phyllodoce rosea	*Phyllodoce rosea*	IV
Phyllodocidae	*Phyllodocidae*	IV
Phyllodocinae	*Phyllodocinae*	IV
Physa acuta		not used (Haringvliet)
Physa fontinalis		not used (Haringvliet)
Physella acuta		not used (Haringvliet)
Physidae		not used (Haringvliet)
Pinnotheres pisum	*Pinnotheres pisum*	IV
Pirata piraticus		not used (Haringvliet)
Piscicola		not used (Haringvliet)
Piscicola geometra		not used (Haringvliet)
Piscicolidae		not used (Haringvliet)
Pisidia longicornis	*Pisidia longicornis*	IV
Pisidium		not used (Haringvliet)
Pisidium amnicum		not used (Haringvliet)
Pisidium casertanum		not used (Haringvliet)
Pisidium casertanum f. plicatum		not used (Haringvliet)
Pisidium casertanum f. ponderosum		not used (Haringvliet)

Species name	Synonym (accepted name, WoRMS)	Trophic group
Pisidium henslowanum		not used (Haringvliet)
Pisidium milium		not used (Haringvliet)
Pisidium moitessierianum		not used (Haringvliet)
Pisidium nitidum		not used (Haringvliet)
Pisidium subtruncatum		not used (Haringvliet)
Pisidium supinum		not used (Haringvliet)
Planorbarius		not used (Haringvliet)
PLATHYHELMINTHES	*Oncis mortoni*	empty
Platynereis dumerilii	*Platynereis dumerilii*	IV
Plecoptera		not used (Haringvliet)
Pleustidae	*Pleustidae*	III
Poecilochaetus serpens	*Poecilochaetus serpens*	II
Polycelis nigra/tenuis		not used (Haringvliet)
POLYCHAETA	*Polychaeta*	na
Polycirrus	*Polycirrus*	II
Polycirrus medusa	*Polycirrus medusa*	II
Polydora	*Polydora*	II
Polydora caeca	*Dipolydora coeca*	II
Polydora ciliata	*Polydora ciliata*	II
Polydora cornuta	*Polydora cornuta*	II
Polydora quadrilobata	*Dipolydora quadrilobata*	II
Polynoidae	*Polynoidae*	IV
Polypedilum		not used (Haringvliet)
Polypedilum bicrenatum		not used (Haringvliet)
Polypedilum bicrenatum gr.		not used (Haringvliet)
Polypedilum nubeculosum		not used (Haringvliet)
Polypedilum tritum		not used (Haringvliet)
Pontocrates altamarinus	*Pontocrates altamarinus*	II
Pontocrates longimanus	*Perioculodes longimanus*	II
Porcellana platycheles	*Porcellana platycheles*	IV
PORIFERA	*Porifera*	I
Portunidae	*Portunidae*	IV
Potamopyrgus antipodarum		not used (Haringvliet)
Potamothrix moldaviensis		not used (Haringvliet)
Potthastia longimanus		not used (Haringvliet)
Praunus	*Praunus*	I
Praunus flexuosus	*Praunus flexuosus*	I
Proceraea cornuta	*Proceraea cornuta*	na
Processa parva	*Processa parva*	IV
Procladius		not used (Haringvliet)
Prostoma		not used (Haringvliet)
Psammechinus	*Psammechinus*	IV
Psammechinus miliaris	*Psammechinus miliaris*	IV
Psammoryctides barbatus		not used (Haringvliet)
Psectrocladius		not used (Haringvliet)
Psectrocladius oxyura		not used (Haringvliet)
Psectrocladius sordidellus/limbatellus gr.		not used (Haringvliet)
Pseudocuma	*Pseudocuma*	II
Pseudocuma longicornis	*Pseudocuma (Pseudocuma) longicorne*	II
Pseudopolydora	*Pseudopolydora*	II
Pseudopolydora pulchra	*Pseudopolydora pulchra*	II
Pseudopotamilla reniformis	*Pseudopotamilla reniformis*	II
Psychodidae		not used (Haringvliet)
PYCNOGONIDA	*Pycnogonida*	VI
Pygospio elegans	*Pygospio elegans*	II
Quistadrilus multisetosus		not used (Haringvliet)
Radix		not used (Haringvliet)
Radix auricularia		not used (Haringvliet)
Radix balthica		not used (Haringvliet)
Radix baltica		not used (Haringvliet)
Radix peregra/ovata		not used (Haringvliet)
Retusa obtusa	*Retusa obtusa*	IV
Rhithropanopeus harrisii		not used (Haringvliet)
Rhithropanopeus harrissii	*Rhithropanopeus harrisii*	empty
Ruditapes	*Ruditapes*	IV
Ruditapes decussatus	*Ruditapes decussatus*	IV
Ruditapes philippinarum	*Ruditapes philippinarum*	IV
Sabella crassicornis	*Bispira crassicornis*	na
Sabellidae	*Sabellidae*	I
Sagartiogeton undatus	*Sagartiogeton undatus*	IV
Salvatoria alvaradoi	*Salvatoria alvaradoi*	empty
Salvatoria limbata	*Salvatoria limbata*	empty
Scalibregma inflatum	*Scalibregma inflatum*	III
Schistomysis kervillei	*Schistomysis kervillei*	II
Scolelepis	*Scolelepis*	II
Scolelepis bonnieri	*Scolelepis bonnieri*	II
Scolelepis foliosa	*Scolelepis (Scolelepis) foliosa*	II
Scolelepis squamata	*Scolelepis (Scolelepis) squamata*	II
Scoloplos armiger	*Scoloplos (Scoloplos) armiger*	III
Scrobicularia plana	*Scrobicularia plana*	II
Scypha	*Sycon*	empty
Serpulidae	*Serpulidae*	I
Sigalion mathildae	*Sigalion mathildae*	IV
Sigara		not used (Haringvliet)

Species name	**Synonym (accepted name, WoRMS)**	**Trophic group**
Sigara falleni		not used (Haringvliet)
Sigara falleni gr.		not used (Haringvliet)
Sigara iactans		not used (Haringvliet)
Sigara lateralis		not used (Haringvliet)
Sigara striata		not used (Haringvliet)
Siphonoecetes striatus	*Siphonoecetes (Siphonoecetes) smithianus*	II
Siriella clausii	*Siriella clausi*	na
Sisyra		not used (Haringvliet)
Sphaeroma	*Sphaeroma*	empty
Spio	*Delavalia*	II
Spio filicornis	*Spio filicornis*	II
Spio goniocephala	*Spio goniocephala*	II
Spio martinensis	*Spio martinensis*	II
SPIONIDA	*Spionida*	na
Spionidae	*Spionidae*	II
Spiophanes bombyx	*Spiophanes bombyx*	II
Spirorbidae	*Dexiospira*	empty
Spirorbis	*Spirorbis*	empty
Spirorbis tridentatus	*Spirorbis (Spirorbis) tridentatus*	empty
Spisula	*Spisula*	I
Spisula subtruncata	*Spisula subtruncata*	I
Stagnicola palustris complex		not used (Haringvliet)
Stempellina		not used (Haringvliet)
Stempellina almi		not used (Haringvliet)
Stempellina bausei		not used (Haringvliet)
Stenochironomus		not used (Haringvliet)
Stenothoe	*Stenothoe*	I
Stenothoe marina	*Stenothoe marina*	I
Sthenelais boa	*Sthenelais boa*	IV
Stictochironomus		not used (Haringvliet)
Stictochironomus sticticus		not used (Haringvliet)
Streblospio	*Streblospio*	II
Streblospio benedicti	*Streblospio benedicti*	II
Streblospio shrubsolii	*Streblospio shrubsolii*	II
Streptosyllis websteri	*Streptosyllis websteri*	II
Styela clava	*Styela clava*	I
Stylaria lacustris		not used (Haringvliet)
Syllidae	*Syllidae*	IV
Syllidia armata	*Syllidia armata*	na
Syllis gracilis	*Syllis gracilis*	na
TANAIDACEA	*Tanaidacea*	II
Tanytarsini		not used (Haringvliet)
Tanytarsus		not used (Haringvliet)
Tanytarsus eminulus gr.		not used (Haringvliet)
Tanytarsus excavatus		not used (Haringvliet)
Tanytarsus lestagei		not used (Haringvliet)
Tellimya ferruginosa	*Tellimya ferruginosa*	I
Tellina	*Tellina*	II
Tellina fabula	*Tellina fabula*	II
Tellina tenuis	*Tellina tenuis*	II
TELLINACEA	*Tellinoidea*	II
Tellinidae	*Tellinidae*	II
TEREBELLIDA	*Terebellida*	II
Terebellidae	*Seraphsidae*	II
Thia scutellata	*Thia scutellata*	IV
Thoralus cranchii	*Eualus cranchii*	IV
Tinodes waeneri		not used (Haringvliet)
Trichoptera		not used (Haringvliet)
Tryphosella sarsi	*Tryphosella sarsi*	na
Tubificidae		not used (Haringvliet)
TUNICATA	*Tunicata*	I
Unio pictorum		not used (Haringvliet)
Unio tumidus		not used (Haringvliet)
Unionicola aculeata		not used (Haringvliet)
Urothoe	*Urothoe*	II
Urothoe brevicornis	*Urothoe brevicornis*	II
Urothoe poseidonis	*Urothoe poseidonis*	II
Valvata		not used (Haringvliet)
Valvata piscinalis		not used (Haringvliet)
Veneridae	*Veneridae*	I
Venerupis	*Venerupis*	I
Venerupis senegalensis	*Venerupis senegalensis*	I
Xenochironomus xenolabis		not used (Haringvliet)

Birds

English name	Dutch name	Latin name	Trophic group
American Wigeon	Amerikaanse Smient	*Anas americana*	herbivoren
Arctic Skua	Kleine Jager	*Stercorarius parasiticus*	piscivoren
Australian Shelduck	Australische Bergeend	*Tadorna tadornoides*	benthivoren
Australian Shoveller	Australische Slobeend	*Anas rhynchotis*	omnivoren
Bahama Pintail	Bahamapijlstaart	*Anas bahamensis*	omnivoren
Bar-headed Goose	Indische Gans	*Anser indicus*	herbivoren
Barnacle Goose	Brandgans	*Branta leucopsis*	herbivoren
Bar-tailed Godwit	Rosse Grutto	*Limosa lapponica*	benthivoren
Black Coot	Meerkoet	*Fulica atra*	omnivoren
Black Guillemot	Zwarte Zeekoet	*Cepphus grylle*	piscivoren
Black Kite	Zwarte Wouw	*Milvus migrans*	carnivoren
Black Redstart	Zwarte Rotgans	*Phoenicurus ochruros*	herbivoren
Black Scoter	Zwarte Zee-eend	*Melanitta nigra*	benthivoren
Black Stork	Zwarte Ooievaar	*Ciconia nigra*	carnivoren
Black Swan	Zwarte Zwaan	*Cygnus atratus*	herbivoren
Black-headed Gull	Kokmeeuw	*Larus ridibundus*	omnivoren
Black-necked Grebe	Geoorde Fuut	*Podiceps nigricollis*	piscivoren
Black-tailed Godwit	Grutto	*Limosa limosa*	benthivoren
Black-throated Diver	Parelduiker	*Gavia arctica*	piscivoren
Black-winged Stilt	Steltkluut	*Himantopus himantopus*	benthivoren
Böhm's Flycatcher	Bokje	*Muscicapa boehmi*	benthivoren
Booted Eagle	Dwergarend	*Hieraaetus pennatus*	carnivoren
Brent Goose	Rotgans	*Branta bernicla*	herbivoren
Broad-billed Sandpiper	Breedbekstrandloper	*Limicola falcinellus*	benthivoren
Buff-breasted Sandpiper	Blonde Ruiter	*Tryngites subruficollis*	benthivoren
Canada Goose	Canadese Gans	*Branta canadensis*	herbivoren
Cattle Egret	Koereiger	*Bubulcus ibis*	carnivoren
Chilean Flamingo	Chileense Flamingo	*Phoenicopterus chilensis*	benthivoren
Cinnamon Teal	Kaneeltaling	*Anas cyanoptera*	omnivoren
Common Crane	Kraanvogel	*Grus grus*	carnivoren
Common Goldeneye	Brilduiker	*Bucephala clangula*	benthivoren
Common Greenshank	Groenpootruiter	*Tringa nebularia*	benthivoren
Common Guillemot	Zeekoet	*Uria aalge*	piscivoren
Common Kestrel	Torenvalk	*Falco tinnunculus*	carnivoren
Common Pochard	Tafeleend	*Aythya ferina*	herbivoren
Common Redshank	Tureluur	*Tringa totanus*	benthivoren
Common Sandpiper	Oeverloper	*Actitis hypoleucos*	benthivoren
Common Shelduck	Bergeend	*Tadorna tadorna*	benthivoren
Common Snipe	Watersnip	*Gallinago gallinago*	benthivoren
Curlew Sandpiper	Krombekstrandloper	*Calidris ferruginea*	benthivoren
Dotterel	Morinelplevier	*Eudromias morinellus*	benthivoren
Dunlin	Bonte Strandloper	*Calidris alpina*	benthivoren
Egyptian Goose	Nijlgans	*Alopochen aegyptiacus*	herbivoren
Eider	Eidereend	*Somateria mollissima*	benthivoren
Emperor Goose	Keizergans	*Anser canagicus*	herbivoren
Eurasian Bittern	Roerdomp	*Botaurus stellaris*	carnivoor
Eurasian Buzzard	Buizerd	*Buteo buteo*	carnivoren
Eurasian Woodcock	Houtsnip	*Scolopax rusticola*	benthivoren
European Golden Plover	Goudplevier	*Pluvialis apricaria*	benthivoren
European Wigeon	Smient	*Anas penelope*	herbivoren
Ferruginous Duck	Witoogeend	*Aythya nyroca*	omnivoren
Gadwall	Krakeend	*Anas strepera*	herbivoren
Garganey	Zomertaling	*Anas querquedula*	omnivoren
Goosander	Grote Zaagbek	*Mergus merganser*	piscivoren
Great Cormorant	Aalscholver	*Phalacrocorax carbo*	piscivoren
Great Crested Grebe	Fuut	*Podiceps cristatus*	piscivoren
Great Egret	Grote Zilverreiger	*Egretta alba*	piscivoren
Great Northern Diver	IJsduiker	*Gavia immer*	piscivoren
Great Sand Plover	Woestijnplevier	*Charadrius leschenaultii*	benthivoren
Great Skua	Grote Jager	*Catharacta skua*	carnivoor
Great Snipe	Poelsnip	*Gallinago media*	benthivoren
Greater Flamingo	Flamingo	*Phoenicopterus ruber*	benthivoren
Greater Scaup	Toppereend	*Aythya marila*	benthivoren
Green Sandpiper	Witgatje	*Tringa ochropus*	benthivoren
Green-winged Teal	Wintertaling	*Anas crecca*	benthivoren
Grey Heron	Blauwe Reiger	*Ardea cinerea*	piscivoren
Grey Phalarope	Rosse Franjepoot	*Phalaropus fulicarius*	benthivoren
Grey Plover	Zilverplevier	*Pluvialis squatarola*	benthivoren
Greylag Goose	Grauwe Gans	*Anser anser*	herbivoren
Gyr Falcon	Giervalk	*Falco rusticolus*	carnivoren
Hen Harrier	Blauwe Kiekendief	*Circus cyaneus*	carnivoren
Herring Gull	Zilvermeeuw	*Larus argentatus*	omnivoren
Horned Lark	Strandleeuwerik	*Eremophila alpestris*	omnivoren
Kentish Plover	Strandplevier	*Charadrius alexandrinus*	benthivoren
Lanner Falcon	Lannervalk	*Falco biarmicus*	carnivoren
Lapland Bunting	IJsgors	*Calcarius lapponicus*	omnivoren
Leach's Storm Petrel	Vaal Stormvogeltje	*Oceanodroma leucorhoa*	piscivoren
Lesser Flamingo	Kleine Flamingo	*Phoeniconaias minor*	benthivoren
Lesser White-fronted Goose	Dwerggans	*Anser erythropus*	herbivoren
Lesser Yellowlegs	Kleine Geelpootruiter	*Tringa flavipes*	benthivoren
Little Auk	Kleine Alk	*Alle alle*	piscivoren
Little Egret	Kleine Zilverreiger	*Egretta garzetta*	piscivoren
Little Grebe	Dodaars	*Tachybaptus ruficollis*	piscivoren

English name	Dutch name	Latin name	Trophic group
Little Ringed Plover	Kleine Plevier	*Charadrius dubius*	benthivoren
Little Stint	Kleine Strandloper	*Calidris minuta*	benthivoren
Long-billed Dowitcher	Grote Grijze Snip	*Limnodromus scolopaceus*	benthivoren
Long-tailed Duck	IJseend	*Clangula hyemalis*	benthivoren
Long-tailed Skua	Kleinste Jager	*Stercorarius longicaudus*	piscivoren
Mallard	Wilde Eend	*Anas platyrhynchos*	herbivoren
Mandarin Duck	Mandarijneend	*Aix galericulata*	omnivoren
Maned Goose	Manengans	*Chenonetta jubata*	herbivoren
Marsh Sandpiper	Poelruiter	*Tringa stagnatilis*	benthivoren
Merlin	Smelleken	*Falco columbarius*	carnivoren
Montague's Harrier	Grauwe Kiekendief	*Circus pygargus*	carnivoren
Moorhen	Waterhoen	*Gallinula chloropus*	herbivoren
Mute Swan	Knobbelzwaan	*Cygnus olor*	herbivoren
Nankeen Night Heron	Kwak	*Nycticorax nycticorax*	piscivoren
Northern Fulmar	Noordse Stormvogel	*Fulmarus glacialis*	piscivoren
Northern Gannet	Jan Van Gent	*Morus bassanus*	piscivoren
Northern Goshawk	Havik	*Accipiter gentilis*	carnivoren
Northern Hobby	Boomvalk	*Falco subbuteo*	carnivoren
Northern Lapwing	Kievit	*Vanellus vanellus*	benthivoren
Northern Pintail	Pijlstaart	*Anas acuta*	herbivoren
Northern Shoveller	Slobeend	*Anas clypeata*	omnivoren
Northern Sparrow Hawk	Sperwer	*Accipiter nisus*	carnivoren
Osprey	Visarend	*Pandion haliaetus*	piscivoren
Pacific Golden Plover	Aziatische Goudplevier	*Pluvialis fulva*	benthivoren
Palaearctic Oystercatcher	Scholekster	*Haematopus ostralegus*	benthivoren
Pectoral Sandpiper	Gestreepte Strandloper	*Calidris melanotos*	benthivoren
Peregrine Falcon	Slechtvalk	*Falco peregrinus*	carnivoren
Pied Avocet	Kluut	*Recurvirostra avosetta*	benthivoren
Pigeon Guillemot	Duikeend	*Cepphus columba*	benthivoren
Pink-footed Goose	Kleine Rietgans	*Anser brachyrhynchus*	herbivoren
Pomarine Skua	Middelste Jager	*Stercorarius pomarinus*	carnivoor
Pratincole	Vorkstaartplevier	*Glareola pratincola*	carnivoor
Purple Heron	Purperreiger	*Ardea purpurea*	piscivoren
Purple Sandpiper	Paarse Strandloper	*Calidris maritima*	benthivoren
Razorbill	Alk	*Alca torda*	piscivoren
Red Kite	Rode Wouw	*Milvus milvus*	carnivoor
Red Knot	Kanoetstrandloper	*Calidris canutus*	benthivoren
Red-breasted Goose	Roodhalsgans	*Branta ruficollis*	herbivoren
Red-breasted Merganser	Middelste Zaagbek	*Mergus serrator*	piscivoren
Red-crested Pochard	Krooneend	*Netta rufina*	herbivoren
Red-necked Grebe	Roodhalsfuut	*Podiceps grisegena*	piscivoren
Red-necked Phalarope	Grauwe Franjepoot	*Phalaropus lobatus*	benthivoren
Red-throated Diver	Roodkeelduiker	*Gavia stellata*	piscivoren
Ringed Plover	Bontbekplevier	*Charadrius hiaticula*	benthivoren
River Kingfisher	IJsvogel	*Alcedo atthis*	piscivoren
Roraiman Flycatcher	Ross Gans	*Myiophobus roraimae*	herbivoren
Rough-legged Buzzard	Ruigpootbuizerd	*Buteo lagopus*	carnivoren
Ruddy Shelduck	Casarca	*Tadorna ferruginea*	herbivoren
Ruddy Spinetail	Rosse Stekelstaart	*Synallaxis rutilans*	omnivoren
Ruddy Turnstone	Steenloper	*Arenaria interpres*	benthivoren
Ruff	Kemphaan	*Philomachus pugnax*	benthivoren
Saffron-breasted Redstart	Caribische Flamingo	*Myioborus cardonai*	benthivoren
Saker Falcon	Sakervalk	*Falco cherrug*	carnivoren
Sanderling	Drieteenstrandloper	*Calidris alba*	benthivoren
Semipalmated Sandpiper	Grijze Strandloper	*Calidris pusilla*	benthivoren
Shag	Kuifaalscholver	*Phalacrocorax aristotelis*	piscivoren
Short-eared Owl	Velduil	*Asio flammeus*	carnivoren
Short-toed Eagle	Slangenarend	*Circaetus gallicus*	carnivoren
Slavonian Grebe	Kuifduiker	*Podiceps auritus*	benthivoren
Smev	Nonnetje	*Mergus albellus*	piscivoren
Snow Bunting	Sneeuwgors	*Plectrophenax nivalis*	omnivoren
Snow Goose	Sneeuwgans	*Anser caerulescens*	herbivoren
Spotted Crake	Porseleinhoen	*Porzana porzana*	omnivoren
Spotted Redshank	Zwarte Ruiter	*Tringa erythropus*	benthivoren
Temminck's Stint	Temmincks Strandloper	*Calidris temminckii*	benthivoren
Tufted Duck	Kuifeend	*Aythya fuligula*	omnivoren
Tundra Bean Goose	Toendrarietgans	*Anser serrirostris*	herbivoren
Tundra Swan	Kleine Zwaan	*Cygnus columbianus*	herbivoren
Twite	Frater	*Acanthis flavirostris*	omnivoren
Variegated Antpitta	Bonte Kraai	*Grallaria varia*	omnivoren
Velvet Scoter	Grote Zee-eend	*Melanitta fusca*	benthivoren
Water Rail	Waterral	*Rallus aquaticus*	omnivoren
Western Curlew	Wulp	*Numenius arquata*	benthivoren
Western Honey Buzzrd	Wespendief	*Pernis apivorus*	carnivoren
Western Marsh Harrier	Bruine Kiekendief	*Circus aeruginosus*	carnivoren
Western Red-footed Falcon	Roodpootvalk	*Falco vespertinus*	carnivoren
Whimbrel	Regenwulp	*Numenius phaeopus*	benthivoren
White Spoonbill	Lepelaar	*Platalea leucorodia*	benthivoren
White Stork	Ooievaar	*Ciconia ciconia*	carnivoren
White-bellied Diver	Geelsnavelduiker	*Gavia adamsii*	piscivoren
White-bellied Redstart	Witbuikrotgans	*Hodgsonius phaenicuroides*	herbivoren
White-fronted Goose	Kolgans	*Anser albifrons*	herbivoren
White-tailed Sea Eagle	Zeearend	*Haliaeetus albicilla*	carnivoren
Whooper Swan	Wilde Zwaan	*Cygnus cygnus*	herbivoren

English name	Dutch name	Latin name	Trophic group
Wilson's Phalarope	Grote Franjepoot	*Phalaropus tricolor*	benthivoren
Wood Sandpiper	Bosruiter	*Tringa glareola*	benthivoren
Zwarte Zeekoet	Black Guillemot	*Cepphus grylle*	piscivoren
Zwarte Zwaan	Black Swan	*Cygnus atratus*	herbivoren

Fish

Latin name	Dutch name	trophic groups	vertical habitat
Agonus cataphractus	Harnasmannetje	benthivore	demersal
Alosa fallax	Fint	planktivore	pelagic
Ammodytes sp.	unknown	planktivore	pelagic
Anguilla anguilla	Aal	bentho-piscivore	demersal
Aphia minuta	unknown	bentho-piscivore	demersal
Arnoglossus laterna	unknown	bentho-piscivore	demersal
Atherina	unknown	bento-piscivore	
Barnea candida	unknown		
Buglossidium luteum	Dwergtong	benthivore	demersal
Callionymus lyra	Pitvis	benthivore	demersal
Callionymus maculatus	unknown	benthivore	demersal
Callionymus reticulatus	unknown	benthivore	demersal
Ciliata mustela	Vijdradige meun	benthivore	demersal
Clupea harengus	Haring	planktivore	pelagic
Dasyatis pastinaca	unknown	bentho-piscivore	
Dicentrarchus labrax	Zeebaars	piscivore	pelagic
Echiichthys vipera	Kleine pieterman	bentho-piscivore	demersal
Enchelyopus cimbrius	Vierdradige meun	benthivore	demersal
Engraulis encrasicolus	Ansjovis	planktivore	pelagic
Entelurus aequoraeus	unknown	planktivore	pelagic
Eutrigla gurnardus	Grauwe poon	benthivore	demersal
Gadus morhua	Kabeljauw	piscivore	demersal
Gaidropsarus vulgaris	unknown	benthivore	demersal
Galeorhinus galeus	unknown	piscivore	pelagic
Gasterosteus aculeatus	unknown	benthivore	demersal
Gobius niger	unknown	benthivore	
Hyperoplus lanceolatus	Smelt	piscivore	pelagic
Limanda limanda	Schar	benthivore	demersal
Liparis liparis	Slakdolf	benthivore	demersal
Merlangius merlangus	Wijting	piscivore	demersal
Microstomus kitt	unknown	benthivore	demersal
Mugilidae	Harderachtige	detritivore	
Mullus surmuletus	unknown	benthivore	demersal
Myoxocephalus scorpius	Zeedonderpad	bentho-piscivore	demersal
Osmerus eperlanus	Spiering	bentho-piscivore	pelagic
Pholis gunnellus	Botervis	benthivore	demersal
Platichthys flesus	Bot	benthivore	demersal
Pleuronectes platessa	Schol	benthivore	demersal
Pollachius virens	unknown	piscivore	demersal
Pomatoschistus sp.	Grondel	planktivore	demersal
Psetta maxima	Tarbot	piscivore	demersal
Raja clavata	Rog	bentho-piscivore	demersal
Raniceps raninus	unknown	benthivore	demersal
Sardina pilchardus	unknown	planktivore	pelagic
Scophthalmus rhombus	Griet	piscivore	demersal
Solea solea	Tong	benthivore	
Sprattus sprattus	Sprot	planktivore	pelagic
Squalus acanthias	unknown	piscivore	pelagic
Symphodus melops	unknown		
Syngnathus sp.	Zeenaalden	planktivore	demersal
Taurulus bubalis	unknown	benthivore	demersal
Trachurus trachurus	Horsmakreel	piscivore	pelagic
Trigla lucerna	Rode poon	benthivore	demersal
Trisopterus luscus	Steenbolk	benthivore	demersal
Trisopterus minutus	Dwergbollk	benthivore	demersal
Zeus faber	unknown	piscivore	pelagic
Zoarces viviparus	Puitaal	benthivore	demersal

Appendix 2 Significance tables (TrendSpotter)

Oosterschelde

		'70	'71	'72	'73	'74	'75	'76	'77	'78	'79	'80	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10
Birds	**biodiversity**																		x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0	0	0	0	0	0		
	evenness																		x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0	0	0	0	0	0		
	richness																		x	0	0	0	0	0	0	0	0	0	0	0	+	+	+	0	0	0	0	0	0	0		
	abundance																		x																							
abundance	**benthivore**																		x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	carnivore																		x	0	0	+	+	+	+	+	+	+	+	+	0	0	0	0	0	0	0	0	0	0		
	herbivore																		x	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	0	0	0	0	0	0		
	omnivore																		x	0	0	+	+	+	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0		
	piscivore																		x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
proportion trophic groups	**benthivore**																		x	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0		
	herbivore																		x	0	0	0	0	0	0	0	+	+	+	+	+	0	0	0	0	0	0	0	0	0		
	omnivore																		x	0	0	0	+	+	0	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0		
	piscivore																		x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0	0	0		
Breeding birds	**biodiversity**										x	+	+	0	0	-	-	0	0	0	0	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	evenness										x	+	+	0	0	-	-	0	0	0	0	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	richness										x	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
	abundance										x	0	0	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	0	0	0		
abundance	**benthivore**										x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	0	0	0	0		
	omnivore										x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
	piscivore										x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	+	+	+	+	+		
Macrobenthos littoral	**biodiversity**																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	0
(autumn)	**evenness**																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	0	0
	richness																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+
	abundance																							x	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-	0
abundance	**filter feeder**																							x	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0
	surface deposit feeder																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	subsurface deposit feeder																							x	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-	-
	predator/omnivore/scavenger																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macrobenthos sublittoral	**biodiversity**																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(autumn)	**evenness**																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	richness																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	abundance																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
abundance	**filter feeder**																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	surface deposit feeder																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	subsurface deposit feeder																							x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	predator/omnivore/scavenger																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish	**biodiversity**	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	evenness	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	richness	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	0	0	0	0	0	0	0	0	0	0
	abundance	x																																								
abundance	**benthivore**	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	bentho-piscivore	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	piscivore	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	planktivore	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	0	0	0	0	0	0	0	0	0	0	0

Grevelingen

		'70	'71	'72	'73	'74	'75	'76	'77	'78	'79	'80	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10
Birds	**biodiversity**																		x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
	evenness																		x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	richness																		x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
	abundance																		x																							
abundance	**benthivore**																		x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
	carnivore																		x	0	0	0	0	+	+	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0		
	herbivore																		x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
	omnivore																		x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
	piscivore																		x	+	+	+	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Breeding birds	**biodiversity**										x	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	evenness										x	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	+	+	+	+	+	+	0	+	+	+	+	+	0	0
	richness										x	+	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	abundance										x	0	0	0	0	0	0	0	0	0	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
abundance	**benthivore**										x	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	omnivore										x	0	+	+	0	0	0	0	0	0	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	piscivore										x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	0	0	0	0
Macrobenthos sublittoral	**biodiversity**																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(autumn)	**evenness**																							x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	richness																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	abundance																							x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
abundance	**filter feeder**																							x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	surface deposit feeder																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	subsurface deposit feeder																							x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	predator/omnivore/scavenger																							x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fish	**biodiversity**	x	0	0	0	+	+	0	0	0	0	0	0	0	0	0	0	0																								
	evenness	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																								
	richness	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																								
	abundance	x																																								
abundance	**benthivore**	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																								
	bentho-piscivore	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																								
	piscivore	x	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-																								
	planktivore	x	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+																								

Lake Veere

		'70	'71	'72	'73	'74	'75	'76	'77	'78	'79	'80	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10
Birds	**biodiversity**																		x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
	evenness																		x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
	richness																		x	0	0	+	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	abundance																		x																							
abundance	**benthivore**																		x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
	carnivore																		x	+	+	+	+	+	+	+	+	+	+	+	+	+	0	0	0	0	0	0	0	0		
	herbivore																		x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0		
	omnivore																		x	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-		
	piscivore																		x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Breeding birds	**biodiversity**										x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	evenness										x	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0		
	richness										x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-	0	0	0	0	0	0	0		
	abundance										x	0	0	0	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
abundance	**benthivore**										x	0	0	0	0	0	0	0	-	-	-	0	0	0	0	0	0	0	0	0	-	-	-	0	0	0	0	0	0	0		
	omnivore										x	0	0	0	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	piscivore										x	0	0	0	0	0	0	0	0	0	0	-	-	-	-	0	0	+	0	0	0	0	0	0	0	0	0	0	0	0		
Macrobenthos sublittoral	**biodiversity**																							x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
(autumn)	**evenness**																							x	0	0	0	0	+	+	0	0	0	0	0	0	0	0	0	0	0	0
	richness																							x	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	0
	abundance																							x	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	0	+	+
abundance	**filter feeder**																							x	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0
	surface deposit feeder																							x	0	0	0	0	0	0	0	0	0	0	0	-	-	-	0	0	0	0
	subsurface deposit feeder																							x	-	-	0	0	0	0	0	0	0	0	0	0	0	-	0	0	+	+
	predator/omnivore/scavenger																							x	+	0	0	-	-	0	+	0	0	0	0	-	0	-	0	0	+	+

Haringvliet

		'70	'71	'72	'73	'74	'75	'76	'77	'78	'79	'80	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10
Birds	**biodiversity**						x	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0		
	evenness						x	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-	0	0	0	0	0	0	0	0	0		
	richness						x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	0	0	0	0	0	0	0	0	0	0		
	abundance						x																																			
abundance	**benthivore**						x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
	carnivore						x	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0	0	0	0	0	0		
	herbivore						x	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	+	0	0	0	0	0	0	0	0	0		
	omnivore						x	0	0	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	piscivore						x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
Breeding birds	**biodiversity**										x	0	0	0	0	0	0	-	-	-	-	-	-	0	0	0	+	+	+	0	0	0	0	0	0	0	0	0	0	0		
	evenness										x	0	0	0	0	0	0	-	-	-	-	-	-	0	0	0	+	+	+	0	0	0	0	0	0	0	0	0	0	0		
	richness										x	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	abundance										x	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0	0	0	0		
abundance	**benthivore**										x	0	0	0	0	0	0	0	0	0	0	-	0	0	0	+	+	+	+	+	0	0	0	-	0	0	0	0	0	0		
	carnivore										x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	omnivore										x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	+	+	+	+	0	0	0	0		
	piscivore										x	+	+	+	+	+	+	+	+	+	+	0	0	0	0	0	0	+	+	+	+	0	0	0	0	0	0	0	0	0		

Verschenen documenten in de reeks Werkdocumenten van de Wettelijke Onderzoekstaken Natuur & Milieu vanaf 2009

Werkdocumenten zijn verkrijgbaar bij het secretariaat van Unit Wettelijke Onderzoekstaken Natuur & Milieu, te Wageningen. T 0317 – 48 54 71; E info.wnm@wur.nl
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