Deltares

Eems-Dollard model setup

Habitats

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Title
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Client	**Project**	**Pages**
Waterdienst	1200739-000	39

Keywords
Ems-Dollard, Habitat, ecology, effect-chain, modelling, land use, dredging, climate change, benthic fauna, fish, birds

Summary
The Waterdienst requested Deltares to develop an effect chain model in order to quantify the effect of human measures in the Ems-Dollard on the water quality and ecology of the system, in the period 2009-2011/2012. This report describes the setup of the final part of the chain; the habitat model.
The model setup is based on an inventory of anthropogenic changes to the system, both in the past and foreseen, as well as a system analysis of the organisms living in the Ems-Dollard and their interactions with their environment. This analysis, based on literature, expert knowledge and databases, showed that the bed level, suspended sediment, hydrodynamics, algae, fish and invertebrates are the key factors in this area. Directives and regulations are more inclined towards birds, mammals and ecotopes.
Out of the numerous types of ecological models, a habitat suitability model seems the most appropriate: it directly reflects limiting factors, making it a transparent model that matches the effect chain approach. Moreover, the model called 'Habitat' is designed to be used in conjunction to Delft3D and DelWAQ and provides a high spatial resolution. Habitat does not reveal population dynamics. Some temporal dynamics are covered by the use of four seasons rather than one moment in the year.
The total number of species in the Ems-Dollard is far too large to consider each species individually. Instead, two or three species per category are modeled specifically, while the other species are described based on their main behavioral characteristics. For all species or groups Habitat Suitability Indices (HSI) are developed, based on literature and the existing Habitat database. A HSI can relate to abiotic factors such as bed level or oxygen content, or the presence of other biota, e.g. vegetation. The actual HSI's and application of the Habitat model to various scenarios of development are described in the successive report of 2010.

Version	Date	Author	Initials	Review	Initials	Approval	Initials
final	2010-05-04	ir. J.T. Dijkstra		drs. F.J. Los		ir. T. Schilperoort	

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Contents

1 Introduction

The Ems-Dollard estuary occupies a unique position in comparison to other Dutch coastal inlets, both in geographical and institutional sense: a large part of it is German territory. Because of this situation, the management of this estuary is more complicated and therefore slightly lagging behind on that of the other, better known, estuaries. 'Better known' refers to how well the area with all its physical and biological processes is known by researchers and managers, but also to how well the Ems-Dollard is known by the general public as an area for nature conservation and recreation: few people realise that it is one of the only two Dutch estuaries that are still left.

This ignorance is unjust, as the Ems-Dollard is a valuable and diverse area that carries many functions: safety, transport, fisheries, nature, industry, recreation and drainage. These functions can act upon each other, sometimes beneficially and sometimes negatively, so they cannot be regarded separately. To what extend changes in the use or layout of the system affect the higher trophic levels is not really known yet. Fortunately, over the last couple of years the interest into this region has increased in both Germany and the Netherlands, partly due to European directives like Natura 2000 and the Water Framework Directive (WFD). A good example of increasing interest and European co-operation is the HARBASINS (Harmonised River Basins North Sea) project.

In order to support future management of the Ems-Dollard area, there is a need for a common long-term vision on the entire system. Such a vision requires understanding the current state of the system first, to see what the relations between the most important biotic and abiotic entities are. When these relations are clear, they can be aggregated into a model that can show the effect-chain between human or natural changes to the system, morphology, hydrodynamics, water quality and ecology.

The objectives of this project are to 1) identify and describe the biotic and abiotic factors that determine the structure and functioning of the Ems-Dollard estuarine system; 2) facilitate the prediction of impacts as a consequence of human or natural alterations like climate change, engineering works, drainage, fisheries, etc. The first objective will be assessed by means of consulting literature as well as experts on the area or similar systems. The second objective requires modelling of the chain of effects resulting from alterations. Since not all the processes in the estuary can be included, a focus towards the most relevant changes and the most relevant ecological parameters is necessary.

This report is part of a series of three on how this effect-chain model is made and applied: one on hydrodynamics and sediment transport in the area, one on water quality, and this one on ecology. With respect to its subject, each report describes the historic and current state of the system, the available information, how the relations between elements in the system are incorporated in the model and what scenarios of development are considered. Since this project runs over a number of years, the first series of reports will not be final but mainly an investigation into what we know, what is uncertain and what is important to improve in the coming years.

2 System description

This chapter aims to give an overview of what conditions can be encountered in the Ems-Dollard basin, which species occur or did occur in the past and why these have disappeared. Figure 2.1 shows the area in 2009, with the locations of the main activities discussed in the subsequent paragraphs.

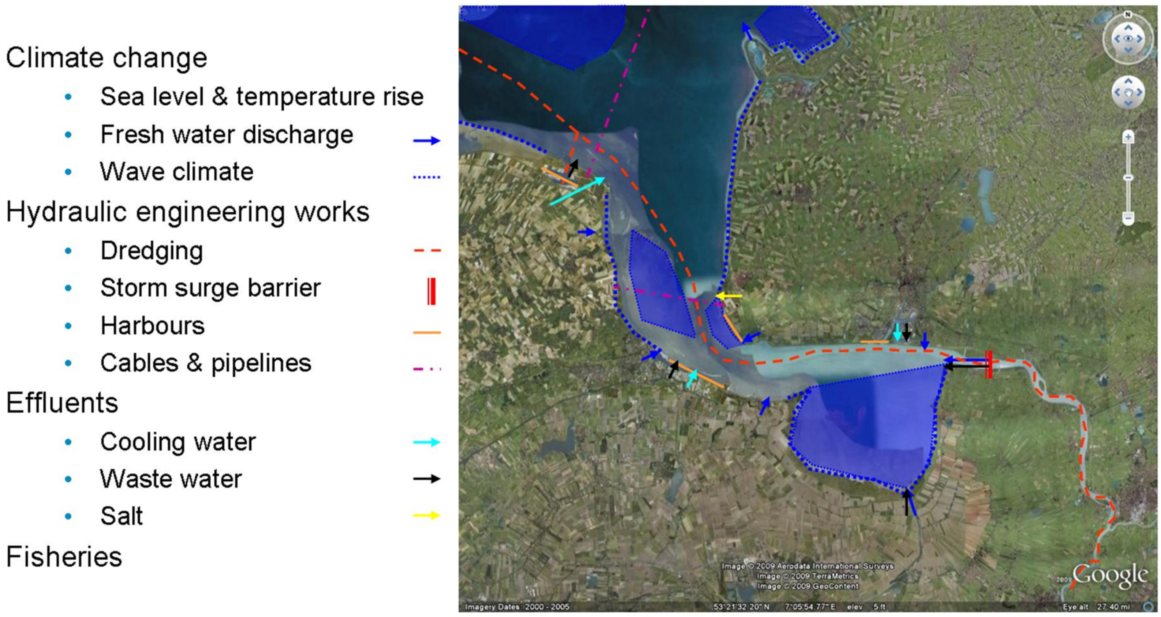

Figure 2.1 Location of main activities in the Ems-Dollard basin.

2.1 Area

The Ems-Dollard area is a mesotidal estuary that is rich in food and accommodates a large number of species. It serves as a resting, breeding and feeding place for numerous bird species, as well as a ‘nursery’ for fish that move to the North Sea when older. Next to nature, the area also houses a lot of human activity: three large harbours (Delfzijl, Eemshaven en Emden), a shipping route from sea to Herbrum on the Ems River, industry, deep drilling, recreation and fishery.

On the seaward side, near the islands Borkum and Rottum, the water is salt, whereas further inland the water is brackish due to discharges from the River Ems and from the Westerwoldsche Aa. Between the islands the channels are deep (>30 m), with adjacent tidal flats. The tide is semi-diurnal with a range just over 2 m here (De Jonge 1983); the tidal prism is around 10^9 m^3. In the middle reaches the main channel (Oostfriese gaatje) is around 12 m deep, with a smaller channel (Bocht van Watum) to the west of a single flat, the Hond-Paap. Further upstream, where the tidal range is just over 3 m, two very different areas are found: The Dollard, which is a large shallow and brackish area with a network of gullies and tidal flats (about 80% becomes dry during low tide), bordered by ‘kwelders’ (salt marshes; 9 km^2). The other is the River Ems, which is dredged regularly, has a narrow profile bordered by dikes and groynes, and supplies fresh water (average discharge about 120 m^3/s, range 30 - 300 m^3/s (de Jonge 2000)) to the system. Because of this fresh water, a turbidity maximum occurs.

This estuarine turbidity maximum (ETM) stretches over several kilometres upstream of Emden. The exact position and strength of the ETM depend on the tide and river discharge. Concentrations of suspended matter can reach values of 400 mg/l over longer times, and incidentally even higher, which indicates fluid mud rather than ‘normal’ water. These high concentrations of suspended matter also bring in a lot of organic material that requires oxygen to be decomposed. Together with the reduced mixing as a result of the density stratification, the water in this area can become completely anoxic.

2.1.1 Hydrodynamics

Compared to the tidal prism at Borkum, the prism at the mouth of the Dollard is small with just 150-200 10^6 m^3. The tidal distance is about 12 km here, versus 17 km close to sea. Average flow velocities are 0.3-0.4 m/s, with maxima of 1 m/s in the Dollard and 2 m/s in the outer area. Residual circulation patterns depend on local topography and in more extreme conditions also on wind. The retention time in the outer reaches is around one week, and around seven weeks in the Dollard, largely depending on fresh water discharges (BOEDE-groep 1983). During summertime, with lower discharges, the salt wedge protrudes further into the Ems River. The report on sediment transport discusses tidal asymmetry and ETM formation. Ship waves might influence bed stability close to shipping lanes, but there are no measurements on wave heights available.

2.1.2 Sediment

The suspended sediment concentration in the mouth is about 25 mg/l, increasing to over 100 mg/l at the seaward end of the Geiseleitdam and more than 400 mg/l at the turbidity maximum. Mulder and Mijwaard (1997) estimated a net import of sediment from the North Sea. Their study also showed the siltation of the Bocht van Watum and deepening of the Oostfriese Gaatje. Earlier, the BOEDE-report (BOEDE-groep 1983) summarised the research of several other: the siltation in the Dollard is about 8 mm/yr. A rate of 7 mm/yr for the whole estuary would require 5 million tons of sediment, whereas the river only supplies 0.1 million tons; this also indicates a net import that corresponds to geological observations.

Apart from grain size and cohesiveness that are important parameters for transport processes (see the sediment-report for maps of spatial distribution of sediment properties), other properties like permeability, sulphide content, organic content and sand/silt composition can be relevant for ecological processes. However, the effects of these parameters cannot always be expressed in quantitative relations, and morphological models do not account for these properties. Besides, measurements on these properties are only available for a very limited number of locations. For example, adsorption and resorption of phosphate, and therefore its spatial distribution, depend on the salt content but also on other processes like decomposition. In the top layer of the sediment, biota, permeability, oxygen- and nutrient content mutually affect each other via not well-understood processes.

2.1.3 Water quality

The term ‘water quality’ actually encompasses several substances (contaminants, salt, nutrients, oxygen) and the temperature of the water. Contaminants like TBT, PCB, PAK, metals enter the system via shipping (anti-fouling), industrial wastewater, runoff from agricultural land or come to the surface again during dredging. The salinity distribution has a natural gradient from 30 psu at sea to 24 psu in the Dollard area, and lower further upstream. Discharges of fresh (drainage) water or possible flushing of salt caverns can change this locally. Nutrients are another component, possibly harmful because of the formation of algal blooms. Oxygen levels are generally fairly good (>6 mg/l) throughout the area due to mixing by waves and tidal currents, but dramatically low (~2mg/l) due to the turbidity maximum between Leer and Papenburg. Similarly, high water temperature only causes problems near discharges of cooling water, and in summer contributes to even lower oxygen levels in the Ems. Low temperatures and ice may lead to a sharp decrease of especially macrofauna.

2.1.4 Legislation

The WFD compels to define water bodies to facilitate testing against the WFD-guidelines. A water body is a (part of) a river, lake or coast and defined based on physical limits, the type of water and its status. For the Ems-Dollard estuary this is done in the report of Schans 2005), resulting in the classification in Figure 2.2. With exception of the harbour areas, large parts of the Ems-Dollard are Specially Protected Areas under Natura 2000.

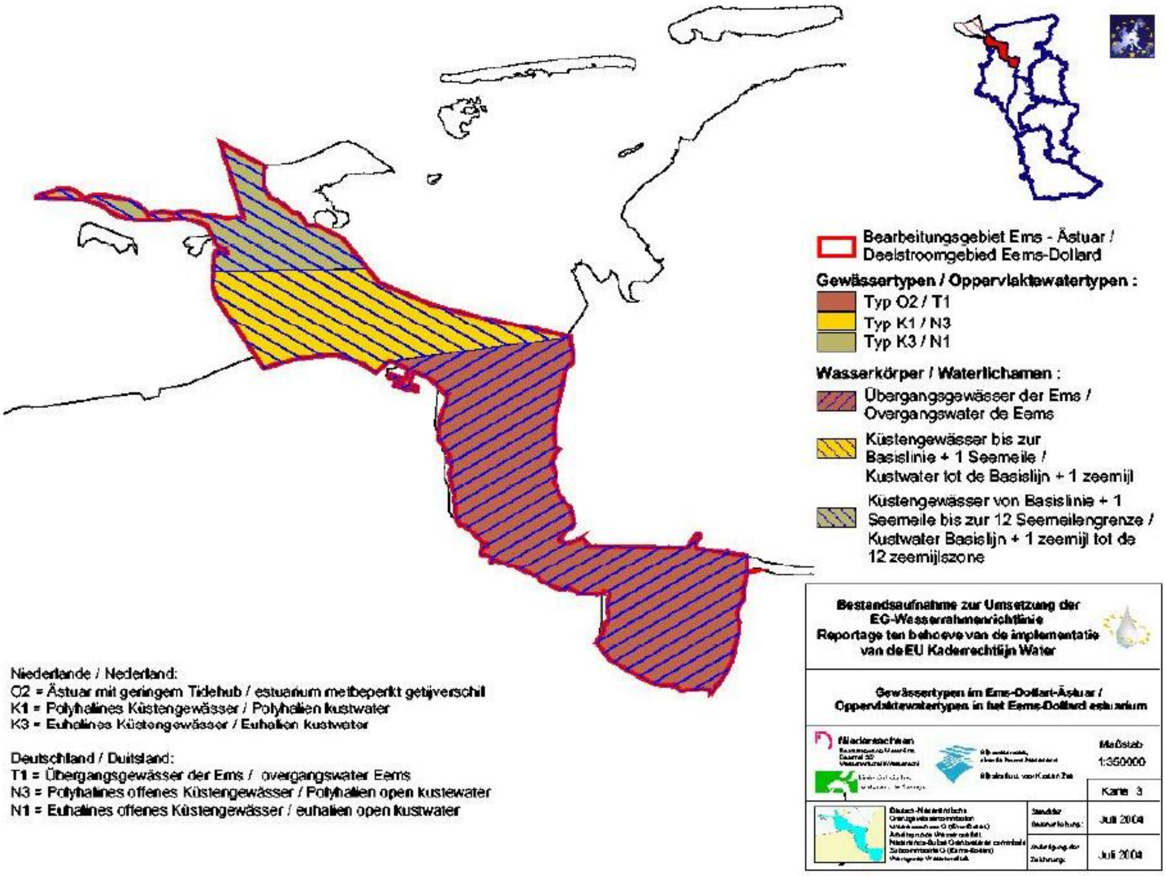

Figure 2.2 Water body classification according to WFD guidelines, Schans (2005).

2.2 Changes to the system

The report by Talke and de Swart (2006) gives a good overview of models and literature as well as changes to the system; part of it is summarized here.

2.2.1 Land use and climate change

The Ems-Dollard estuary as we see it on a map today differs quite a lot from the system in the 14th and 15th century, when the Dollard basin was formed by storm surges. Since then, first land reclamation and later also diking and dredging have changed not only the area of the system, but also the water quality, tidal characteristics and sediment transport patterns. Since the second half of the 20th century, the boundaries of the estuary have remained practically the same as land reclamation stopped. However, dredging and the construction of river training works have drastically changed especially the River Ems in this period: the hydraulic roughness decreased, as a result of which the tidal amplitude and the intrusion of salt water increased.

After the active land reclamation with ‘kwelderwerken’ stopped in 1954, the area of kwelders in the Dutch part of the Dollard retreated from 800 ha to 710 in 1994 (Dijkema et al. 2005, Esselink et al. 2000a), at a frequently measured transect at a rate of 2 m/yr (Esselink 1998).

In 1984 the maintenance of the drainage channels was also halted, combined with more extensive grazing by cows, resulting in a more diverse vegetation composition including pioneer species. The vegetation in the German salt marshes has become grassier as a result of grazing by geese over the years 1977-1993 (Esselink et al. 2000b).
With industrialisation and population increase, the dumping of organic effluents caused severe stress to especially the Dollard basin. The anoxic conditions there in the 1970's led to the BOEDE (Biologic Research ED-estuary, BOEDE 1983) project. Already during this project, the findings led to a sharp reduction of the amount of waste, with a subsequent improvement in oxygen content and species diversity accredited to this reduction.
Apart from direct human changes, the estuary will also be affected by climate change. Sea level rise will probably increase from 18 cm over the past century to 9-88 cm over the next one (IPCC 2001). The expected rise of seawater temperature is 2 degrees (range 1-6, IPCC 2001). This change in temperature can have large effects as warmth governs the growth of both pelagic and benthic algae, and ice cover protects the mudflats in winter. Higher storm surges as a result of stronger winds are not relevant to this project, but higher waves that cause more erosion and turbidity are, especially if the frequency of storms increases. Global warming also seems to lead to more rainfall in Germany and the Netherlands (12% in 100 years or 40% for 10-day averages; Verbeek 2003), hence to increasing river discharges that affect the extension of the turbidity maximum.

2.2.2 Dredging and other engineering works

Yearly dredging in the Emder Fahrwasser and the harbours of Delfzijl and Eemshaven amounts to 7.2 Mm^3/yr (Table 2.1). Dumping leads to increased turbidity on the short term and introduces mud in an otherwise sandy area. Waves agitate the deposits, dispersing most of it away from the dumping locations (Boon et al. 2002).

Table 2.1 Dredging and dumping volumes

Dredging location	Dumping location	Material	Volume (Mm^3 /yr)	Mass (Mm^3 /yr)	West (m –RD)	North (m –RD)
Delfzijl harbour	Groote Gat		1.1	400	271419	593390
Delfzijl harbour	Bocht van Watum		1.1	400	257370	596260
Eemshaven	Oude Westereems		1	450	246515	611473
Emder Fahrwasser	Klappstelle 6		4	1200	257100	608500
Shipping channel	North Sea	Sand	2.5	?	?	?

The harbour of Emden itself is not dredged in a traditional way: the silt is aerated (so bacteria produce slime that preserves an open structure) and kept in suspension as a very fluid mud so it remains navigable. This has resulted in an increase of the silt layer from a few dm to two meters. Dredging upstream of Emden is estimated at 0.5-1 Mm^3/yr. This material is dumped on land, which is very costly.
Despite significant local increases in turbidity, most dredging works do not have a crucial effect on eelgrass fields (Ochieng and Erftemeijer submitted): the population on the Hond-Paap is intertidal as the estuary is too turbid for a subtidal population anyway, and tidal exposure accounts for 99% of the light. According to de Jonge (pers. comm. in Talke and de Swart 2006), biota in the estuary are very sensitive to the amount and timing of dumping.
Other engineering works are port expansions at Emden (1970's and 2004, Clasmeier et al. 2004), the construction of the Eemshaven (early 1970's) with a 1750 MW power plant, and

installation of the NordNed high-voltage cable (2008). Power plants may affect the estuary in three ways: by deeper and busier navigation channels, by the intake of cooling water that mechanically damages fish and by thermal pollution. Currently, new power plants (Nuon, multi-fuel, 1200MW, 2011; RWE, coal 1600-2200MW, 2013; Advanced Power, gas, 1200MW, 2015) and an LNG terminal are planned or under construction in the Eemshaven. These will use much more cooling water, and because the LNG-carriers have a draught of 14 m, the shipping channel will be enlarged to 15.5 m by 300/400 m (Arcadis 2006), resulting in about 3.5 Mm^3 dredging material.
The construction of large wind farms will not take place in the Ems-Dollard itself, but further offshore. Small-scale wind farms and individual mills have been and will be built along the margins of the estuary, but their effect is considered negligible. German harbour expansion plans comprehend expansion near Rysumer Nacken, where four births should facilitate a coal power plant, a container terminal and a wind turbine construction yard, amongst others. Further, a 1.5 Mm^3 underground gas storage will be built near Jemgum (www.speicher-jemgum.de) in salt layers. The brine formed in this process will be transported via a pipeline to Rysum, where 15.000 tonnes per flood will be discharged (at unknown concentration).
The construction of the Geiseleitdamm around 1960, the Emssperrwerk in 2001 and placement (1975) and repositioning (2002) of a gas pipeline were other major operations in the area. The Geiseleitdamm reduced the width of the river to deepen the Emder Fahrwasser and fixed the Groote gat as the drain of the Dollard basin. Nowadays, the dam allows the exchange of (fresh) water due to and increase in water levels and the lack of maintenance. As a protection against storm surges and to facilitate the navigation of large ships from the Meyer Werft in Papenburg, a barrier (the Emssperrwerk) was built near Gandersum in 2001. It is closed about twice a year. The legal maximum closure is 104 hrs in total, and may only occur in winter (16 September – 14 March). To ensure a rapid filling of the basing during low river discharges, a pump capacity of 100 m^3 is installed (NLWKN-website). Measurements during trial closures showed that the oxygen concentration remained stable, whether the initial concentration was <1 mg/l (Weener) or 6 mg/l (Gandersum); the concentration gradient over the fluid mud / free water remained strong. Several hours after closure, the salt concentration at Terborg and Leerort increases, and remains strongly disturbed several days after opening. Oxygen levels generally do not decrease after closure and are lower the farther upstream. At Weener and Papenburg they increase after about one day when the salt wedge arrives here. After opening however, they decrease sharply, to lower levels than before.
The gas pipeline running from Rysum to Delfzijl suffered from erosion at the south-east side of the Paap. For years, the pipeline was protected with provisional measures (sandbags, rocks, fences) that only caused more scour, until it was deepened in 2002, together with the removal of those temporary protections. Effects of those efforts on ecology were studied by Erftemeijer and Wijsman (2004), and found to be small compared to the seasonal and natural dynamics of the area.

2.2.3 Cooling water intake and outfall

Currently, the Eemscentrale (operated by Electrabel) near the Eemshaven is the major user of cooling water. According to Hartholt and Jager 2004) the yearly average discharge is 55 m^3/s, at which 18 million fish where impinged in 1996/1997. Herring, sprat, gobies and stickleback showed the largest numbers. There are seasonal differences: Herring, sprat, eel and gunnel show peaks in spring and fall, stickleback and sparling in spring, and pipefish, chub, bull rout, hooknose, goby, dab, whiting and sea-snail in fall. The time of day (amount of light for visual navigation) and the tidal phase also affect the number and composition of sucked up fish. Some species (herring, sprat) are more vulnerable to mechanical damage than others (eel, gunnel). The actual effect of cooling systems on populations is more difficult to estimate: most sucked-in fish are young ones.

Adult fish produce a lot of offspring, but only two of them have to survive and spawn to keep the population constant. Smaller organisms like phytoplankton, copepods, fish larvae, fish eggs, jellyfish and crustaceans are also sucked in; their mortality is unknown. An estimate of sucked in shrimps is 67 tons in 1996/1997, or 42 million, which is about 4% of the commercially fished amount in the eastern Wadden Sea.
Regarding thermal effects, in fresh water organisms showed no mortality at 30°C, but practically everything died at 40°C. Cladocera and diatoms suffer the most, and fish larvae suffer more (30-70% mortality) than fish eggs (7-20% mortality; only tested for three species). Generally, estuarine fish species are more capable of dealing with higher temperatures than purely marine species, as the shallow waters of estuaries warm up quickly to 24-25°C. Besides, most fish are capable of evading the warm water at the surface when they recognize it, though this can be difficult if an entire channel is covered with warm water. Due to the size of the estuary, the cooling water can never cause a significant warm-up of the whole area, but locally more warmth-loving (invasive) species can occur. Plants, algae and benthic fauna are only affected when the warm water reaches the bed, but cannot evade. Again, most estuarine species are used to higher temperatures (up to 30°C) during low tide. 25°C is considered as a serious risk level ('ernstig risiconiveau', ER). Electrabel conducted its own measurements in August 2004, which are reported in Bijstra and de Jong (2006): maximum temperatures reached 30°C at an air temperature of 25.8°C, with only one unit active and a discharge of 34 m^3/s. Due to the construction of the drainage point, which induces mixing, no stratification was found.
Concentrations of free oxidants (chlorine) in the cooling system are much higher than acute toxic levels (0.2 to 1 mg/l vs. 0.02 mg/l), but application occurs intermittently and usually only from April until October.
Other intakes of cooling water are from industry in the Eemshaven, Delfshaven and Emden, with the gas power plant in Emden harbour (452 MW) as the biggest contributor. Three other power plants are planned or under construction near the Eemshaven, and a new coal power plant is planned west of Emden.

2.2.4 Fishing

Nowadays, fishery in the estuary is less extensive than at the beginning of the 20th century. On the River Ems, German fishermen use standing nets for fish on eel, flounder and to a lesser extent sparling. In the Dollard, the number of fyke-fishing permits decreased sharply in the 1990's as a result of an abolishment policy. Shrimp-fishing may only be done by locals (both Dutch and German); the number of Dutch permits varies little over the years, between 13 and 19 (Jager 1998). The main shrimp-fishing area is located on the east side of the Hond-Paap. The amount of by-catch (mainly young flatfish) is relatively high, and the mortality of the discards is estimated at 90%.

2.2.5 Recreation and shipping

With 10.000 movements of sea-going vessels and 6000 movements of inland navigation vessels per year, the Ems-Dollard is a busy shipping lane. Figures on shipping accidents, pollution caused by ships (either trough accidental spills, ballast water or anti-fouling substances) are not known.
Sailing is the main recreational activity in the area, with impacts probably similar to those of professional shipping, though at smaller numbers.

2.3 Species

Flora

2.3.1 Vascular plants

Within the Ems-Dollard basin there are two groups of plants: the seagrasses *Zostera marina* and *Zostera noltii* that occur on the intertidal flats, and a number of species that occur on the salt marshes at the margins of the basin (ca. 9 km^2 in the Dollard), the most common being *Spartina anglica* (cordgrass), *Aster tripolium* (Sea aster), *Salicornia europaea* (Marsh samphire), *Suaeda maritime* (Annual seablite) and *Phragmites australis* (Common reed).

2.3.2 Algae

Three types of algae can be regarded as important elements of the system: Macroalgae phytoplankton, and microphytobenthos. All algae are primary producers, i.e. they use photosynthesis to convert nutrients in the water (nitrogen, phosphorus, silicate and carbon dioxide) into food that can be consumed by higher organisms. Macroalgae –or seaweeds-, like e.g. sea lettuce (*Ulva spp.*) and bladder wrack (*Fucus vesiculosus*), are mostly attached to hard substrates like rocks, stones or shells but can also be found afloat. They are a shelter and a direct (or indirect, via its detritus) food source for other organisms. Phytoplankton -small algae floating in the water column- is by far the most important primary producer. Its growth is strongly determined by temperature and the availability of nutrients and light, and therefore seasonal. Microphytobenthos are algae that dwell on tidal flats, where they can form a sticky protective layer that prevents erosion.
In the Ems-Dollard, nutrient concentrations (nitrate, phosphate and silicate) are generally above saturation levels, hence growth is light-limited due to the high turbidity (K_d=6.7 m^{-1}) in the outer area. Only in the outer reaches, where nutrient levels are lower and the water is less turbid (K_d=1.6 m^{-1}), nutrient-limitation can occur in critical periods in the season (May), when rapid growth of predominantly diatoms has lead to depletion (BOEDE-groep 1983).

Fauna

2.3.3 Mammals

Only three species of mammals are more or less at home in the estuary: the common seal, the grey seal and porpoises. Generally, these animals hunt for fish in deeper, more open waters with less shipping traffic. The presence of inter- and supratidal areas is favourable for seals however, which use these areas as a resting and breeding place.

Species and trends

The common seal (*Phoca vitulina*) occurs in the Ems-Dollard in larger numbers than some decades ago. In 2006, about 2500 seals were present, with resting places near the Reiderplaat in the Dollard, the Hond-Paap, and the Ra, Uithuizerwad and Horsbornzand near Rottumeroog. The grey seal (*Halichoerus grypus*) occur near Borkum in a small colony of some 20-30 individuals. Porpoises (*Phoecoena phocoena*) are only sighted rarely (van 't Hof 2006).

Health and threats

Being on top of the food chain, all mammals accumulate toxins from lower species. Presently, it is not known how dangerous this accumulation is to themselves on short (their lifetime) and long (next generations) timescales. Neither do we know which compounds are the most dangerous. Seals have to cope with viruses every few years. The effect of these viruses differs enormously; outbreaks in 1988 and 2002 practically halved the population, but recovery was rapid. Furthermore, fishery –especially standing nets (‘staand want’)-, disturbance by shipping traffic and underwater noise are harmful. There is not enough knowledge to quantify the effects of these threats on populations or habitat suitability.

2.3.4 Birds

Like in the western part of the Wadden Sea, the abundance and diversity (ca. 40 species) of birds in the Ems-Dollard area is high: The shallow water, intertidal areas and bordering salt marshes provide plenty of food, as well as nesting opportunities.

Species

All regularly occurring water-related birds are listed in Appendix C. Birds of prey are not discussed because these do not have a direct link to the estuarine system. This overview is based on reports by Prop (1998) and van 't Hof (2006) that only concern the Dollard area. Information on birds closer to sea (e.g. Hond-Paap and Eemshaven) can be found in Erftemeijer and Wijsman (2004) and on www.sovon.nl and www.wadvogel.avifaunagroningen.nl, but is less extensive.

Several groups of species can be identified: Ducks and geese, waders and gulls. In numbers, waders are the biggest group. Apart from some exceptions, most ducks and geese are herbivores, whereas most waders and gulls eat fish or invertebrates. The species most typical to the Dollard are the Barnacle Goose (*Branta leucopsis*), Graylag Goose (*Anser anser*), Common Teal (*Anas crecca*), Avocet (*Recurvirostra avosetta*), Spotted Redshank (*Tringa erythropus*) and Twite (*Carduelis flaviostris*).

Trends and targets

The comparison of bird countings between 1974 and 1995 by Prop (1998) showed that for 25 species, the average numbers over the years 1985-1995 were lower than those over 1974-1984. For the other 15 species, the numbers were equal or higher.

Within a year, the largest numbers of birds are present in March-May and September-November. Every group of species has its own peak: ducks are most abundant in fall, geese at the end of winter, gulls occur year-round in small numbers and waders peak in spring and fall. These seasonal patterns are governed by temperature and the availability of food in Ems-Dollard or elsewhere.

Health and threats

The number of birds strongly depends on the abundance of food. Particularly the biomass of polychaetes and molluscs is an important parameter, which varies over the years, somewhat depending on the discharge of organic waste. After circa 1980, the discharge of waste decreased, together with a decrease in polychaetes and molluscs, as well as less birds. The reduction was strongest in fall; the usual season for waste discharge Prop (1998). Locally, the opposite used to occur: the high organic content of the waste caused anoxic conditions, leading to a die-off of most sessile benthos, though some species became an easier prey as they surfaced for oxygen.

The availability of food not only depends on the quantity, but also how (easily) it can be found. In the Dollard 77 km^2 of intertidal area is available. With a benthic production of 24 g/m^2 and a consumption of 2.6 g/m^2, about 10% is consumed, which is an intermediate value in comparison to other coastal areas. Reduction of the intertidal feeding area by sea level rise, erosion or gas mining will increase this predation pressure. Strong winters also lead to reduced numbers of birds; an effect that can last several years. No information could be found on diseases among birds.

2.3.5 Fish

According to Elliot and Dewailly (1995) the number of fish species in the Ems-Dollard (see Appendix B for an overview) is comparable to other European estuaries. van 't Hof (2006) compared inventories by Lohmeyer (1907) from around 1900 with those by Hovenkamp and van der Veer (1993) from after 1960, and found 52 species in the most recent study; 20 less than at the beginning of that century. It would go too far to treat the numbers and trends of all species here, so this overview is limited to species that specifically occur in estuaries and commercially interesting or threatened species.

Due to the transition from fresh to salt water, the Ems-Dollard is an important area for diadromous fish, which live in the sea but spawn in fresh water or vice versa. Hence, they need suitable fresh water habitats of sufficient quality and a way to reach these. Along the Dutch Wadden Sea, the Ems-Dollard is the only transition without obstacles like weirs or pumping stations. However, the anoxic ETM might bother diadromous fish, but only when its occurrence coincides with their spawning season.

Jager (1999) made an inventory of migrating fish. Out of eleven species, four (sturgeon, *Acipenser sturio*; houting, *Coregonus oxyrhynchus*; salmon, *Salmo salar*; allis shad, *Alosa alosa*) have disappeared, and five (sea lamprey, *Petromyzon marinus;* river lamprey; *Lampreta fluviatilis;* sea trout; *Salmo trutta* (does not occur in ED); twaite shad, *Alosa fallax*; eel, *Anguilla anguilla*) are on the red list with the status of being vulnerable or threatened. River lamprey occurs from August to winter, with a peak in November when it spawns. Its larvae spend some years in riverine mud before moving to sea, like those of sea lamprey that migrates early spring. Small twaite shad sporadically occur in the Dollard in summer (Jager 1999). Like allis shad, it normally migrates in spring but it is unclear whether the population is still reproducing. Eel migrates from March to May.

The three-spined stickleback (*Gasterosteus aculeatus*) is not threatened, but on estimate around 3-5 % (1.6 million) of the population is sucked in by the cooling water intake of the Eemscentrale. It is an important food source for many birds. Flounder (*Platichtys flesus*) reproduce around February in the North Sea, but the adult population predominantly lives in estuaries and the Wadden Sea for the rest of the year. Eggs and larvae drift towards the coast, where juveniles try to reach the fresh water; the Ems-Dollard serves as a nursery. In winter, smelt (*Osmerus eperlanus*) live in estuaries until April, when they move up the river to spawn. Smelt requires a high oxygen content (minimum 5 mg/l). Juveniles of the pelagic twaite shad and smelt need sufficient tidal movement to maintain their position in the estuary, rather than be washed out to sea. The temperature and salinity demands of most diadromous fish are ample, though rapid changes are endured badly by some. The bed composition is important for a number of species: some drop their eggs on a hard substrate or vegetation, where high accretion rates of fine sediment may lead to oxygen deficiency or burial, others (e.g. young flounder) prefer muddy substrates.

Apart from diadromous species, the area also houses estuarine residents (Viviparous blenny, *Zoarces viviparous*; Bull rout, *Myoxocephalus scorpius*; Goby, *Pomatoschistus microps*.; Butterfish, *Pholis gunnellus*; Sea-snail, *Liparis liparis;* Hooknose, *Agonus cataphractus*), marine juveniles (Plaice, *Pleuronectes platessa*; Sole, *Solea solea*; Herring, *Clupea harengus* and Sprat, *Sprattus sprattus*), seasonal marine species (Flounder, Sand goby, *Pomatoschistus minutus*; Five-bearded rockling, *Ciliata mustela*; Lumpsucker, *Cyclopterus lumpus;* Garfish, *Belone belone*; Snake pipefish, *Entelurus aequoreus* and Greater pipefish, *Syngnathus acus*) and occasionally occurring individuals (classification according to Elliot and Dewailly, 1995). Further sorting can be based on habitat type (pelagic, demersal or benthic), or reproduction type (viviparous, ovoviviparous or oviparous; the latter category is subdivided

further based on the location and care for the eggs). A complete overview of all occurring fish species can be found in Appendix B.
Jellyfish (macrozooplankton) are often ignored in studies because they are neither commercially interesting, nor are they a prey for other animals. They sometimes can occur in large numbers however, and as such they might play an important role in the cycle of nutrients. Furthermore, jellyfish plagues may block cooling water entrance points and fishing nets. At the moment, there is too little information available about their role and proliferation to include them in this study.

2.3.6 Invertebrates

The group of invertebrates that lives in or on top of the bed (also called benthic macrofauna) contains many different kinds of animals: molluscs, polychaetes and crustaceans. An extensive overview of all species of macrofauna in the Ems-Dollard area can be found in Ysebaert et al. (1998), a selection of species in Appendix D. The abundance of benthic fauna was monitored systematically at the Heringsplaat (Essink 1998).

Polychaetes and other worms

Lugworms (*Arenicola marina*), ragworms (*Nereis diversicolor*), paddleworms (*Eteone longa*) and *Marenzelleria* are the most abundant worms in terms of biomass, and thereby the most important prey for other animals. The invasive polychaete *Marenzelleria cf. wireni* was found in the Dollard for the first time in 1984 (Essink and Dekker 2002), with large numbers (2000 individuals per m^2) in the early nineties and smaller numbers (500 per m^2) in subsequent years. The cause of this trend, which is common for an invasive species, is unsure but might be related to a reduction of organic content. The abundance of *Nereis* and *Eteone* varies strongly, but the effects of reproduction success, competition and water quality could not be distinguished.

Crustaceans

Two species of large crabs are common in the area: the flying crab *Liocarcinus holsatus* and the green shore crab *Carcinus maenas*. Shrimps are also abundant, with the most prominent species the brown shrimp *Crangon crangon,* the mud shrimp *Corophium volutator* that feeds on benthic algae and sand dagger shrimps *Bathyporea spp.*

Molluscs

Most molluscs in the Ems-Dollard are suspension feeders: blue mussel *Mytilus edulis*, sand gaper *Mya arenaria*, *Spisula truncate* and cockle *Cerastoderme edule*. With more suspended food they grow more rapidly, though when this coincides with high concentrations of inedible particles the net energy intake is greatly reduced. Mussel and oyster banks occur on the Hond-Paap and in the Wadden Sea, banks of cockles occur at Voolhok. The japanese oyster (*Crassostrea gigas*) first occurred in 1998 in the Eemshaven, in 2001 it had reached the Punt van Reide and buoy 65, 5 km from Emden. Dankers et al. (2004) also found oysters between the mussels at Hond-Paap.
Other bivalves, like the Baltic tellin (*Macoma balthica*) and the Delicate tellin (*Tellina tenuis*) have a siphon, which they can use for suspension or surface-deposit feeding. Several species of gastropods also occur throughout the estuary, from which the Laver spire shell *Hydrobia ulvae* is the most abundant one. The abundance of the Baltic tellin, Peppery furrow shell and Sandgaper in the Dollard varies trough the years, as a result of winter conditions and the success of reproduction.

Threats

The large variety in the occurrence of macrofauna species means a large variety in threats too. The severity of the most relevant of these threats will become clearer in the course of this study, though the effects of combinations of threats are difficult to assess.

Some species are mobile and can evade some local threats, whereas others are sessile and have to cope with them. Local anoxic conditions, high sedimentation or erosion rates or high temperatures can be lethal to sessile animals, while they are only a nuisance to others. Toxic substances, including extreme salt concentrations, can be lethal to all kinds of animals on short (i.e. immediately) or long (i.e. accumulation over months/years) term. A decrease in the available food probably decreases carrying capacity for a population, i.e. it will decrease the population and therefore increase the risk of becoming extinct, but it will not directly lead to complete absence.

Fisheries can have a negative effect on the occurrence of the species itself, but also on the abundance of its predators. Furthermore, the disturbance caused by fishing (noise, increase of turbidity, reworking or partial removal of habitats) affects more species than the one fished on. The direct effects of dredging are partly similar to that of fishing (i.e. disturbance), but may go further due to the permanent change in habitat: changes in depth, tidal range, salt content and turbidity. Invasive species can also be threatening, either by predation or competition for food or space.

3 Directives, regulations and impact studies

This chapter gives a brief overview of directives and regulations that apply to the management and use of the Ems-Dollard estuary, as well as some other studies concerning the area. Since Imares has been contracted to report on the applicable directives, these are only mentioned here but not discussed.

3.1 Water Framework Directive, Bird Habitat Directive and Natura2000

Imares will report on these subjects. The 'Stroomgebiedsbeheersplan Eems-Dollard' will come into effect December 22, 2009.

3.2 Effects of cooling water

Hartholt and Jager (2004) and Hadderingh and Jager (2002) report on the effect of cooling water intake by the Eemscentrale power plant on fish, crustaceans and water temperature nearby.

Since 1975, the standards of the ABK (Algemene Beraadsgroep Koelwater) have been used, which simply state that in marine waters, the difference between intake and outfall temperature may not be more than 10°C. In 2004, the CIW (Commissie Integraal Waterbeheer) set up a new guideline for the use of cooling water, based on three criteria:

1. *Subtraction criterion*: Minimise impingement; no intakes in spawning or nursery areas or migration routes. For marine systems, this should be verified in biological spring (1 February – 1 May) and fall (1 September – 1 December);
2. *Mixing zone criterion*: For estuaries, a maximum of 25% of the wetted cross-section may have a temperature up to 25°C.
3. *Heating criterion*: The maximum heating of the receiving water system after complete mixing over the vertical and horizontal, compared to the background temperature, is limited to 3°C for “water for cyprinids”, 2°C for “water for shellfish”, and 1.5°C for “water for salmonids”. The maximum water temperature is set to 28°C for “water for cyprinids”, 25°C for “water for shellfish”, and 21.5°C for “water for salmonids”.

Limitations on the use of biocides against fouling of the cooling system are subject to another guideline. On average, through-flow cooling systems (as opposed to recirculation systems) in marine or brackish water use 400 kg/MW active chlorine per year (Bijstra 1999). Actual values can be found in the environmental yearly reports ('milieujaarverslag') of companies of interest.

3.3 HARBASINS

The INTERREG IIIB project HARBASINS (HARBASINS, 2008) aims to enhance international cooperation and integrated management of estuaries and coastal waters in the North Sea region by harmonisation of management strategies and compatible instruments. The basis for HARBASINS is the Ecosystem Approach, which considers the ecosystem as a whole instead of a number of separate water bodies and considers scientific, (socio-)economic and ecologic aspects from a transnational point of view. Apart from stimulating international networks and cooperation, standardisation and normalisation of monitoring procedures (e.g. the Trilateral Monitoring and Assessment Program, TMAP), (recommendations for) the development of evaluation tools for estuarine habitat restoration such as a Fish-index and criteria for assessment of Heavily Modified Water Bodies are important results of the project.

3.4 Scientific measurements and monitoring

Along the Ems River, long term monitoring of velocity, sediment concentration, turbidity, salinity, water level, temperature, pH and oxygen concentration is performed at nine locations in 3-30 minute intervals by NLWKN and WSA Emden. Rijkswaterstaat measures biological and chemical parameters near Borkum and in the Dollard at biweekly to monthly intervals.

The NWO-BOA project (1995-1997) studied the effect of biological processes on mud in intertidal areas, combining instrumentation on mudflats with a bridge across a tidal channel near the Herringsplaat. This data was used by De Deckere in his thesis (de Deckere 2003). The BOA project ran together with the European Community project INTRMUD that studied the morphological behaviour of intertidal mudflats.

Several studies have been performed to map the effect of the closure of the Emssperrwerk, some before closure in 2001 (University of Siegen, Jensen et al. 2001) and some during a summer closure in 2008 (NLWKN 2008).

4 System analysis

The Ems-Dollard houses many kinds of organisms that interact with each other and their physical and chemical environment. In order to identify the key factors in the system, an interaction matrix has been made (Table 4.1). The marks are a rough estimate of whether a factor on the left affects a factor in a column directly, and whether this is occurs in a considerable part of the estuary. For example: The amount of suspended sediment does not directly affect the amount of algae, therefore this value is 0. The turbidity (i.e. light availability) does affect algae directly, as a result this value is 1. Of course, the suspended sediment does affect the turbidity.

Note that this matrix was constructed with the aim of being an aid in the modelling process, and that it does not result from the effect-chain study. One can argue about the correctness of several values in the matrix, but the general picture remains similar in case some values are changed.

Table 4.1 Interaction matrix of biotic and abiotic factors in the Ems-Dollard estuary.

effect of (hor) on (ver)	Bed	Suspended sediment	Turbidity	Salinity	Oxygen	Nutrients	Hydrodynamics	Seagrass	Salt marsh plants	Algae	Birds	Mammals	Fish	Invertebrates	*effectors*	*keys (added)*
Bed		1	0	0	0	0	1	1	1	1	1	1	0	1	8	13
Suspended sediment	1		1	0	1	1	0	0	0	0	0	0	0	0	4	10
Turbidity	0	0		0	0	0	0	1	0	1	1	0	1	0	4	6
Salinity	0	1	0		0	0	0	0	0	0	0	0	1	1	3	5
Oxygen	0	0	0	0		0	0	0	0	0	0	0	1	1	2	5
Nutrients	0	0	0	0	0		0	1	0	1	0	0	0	0	2	5
Hydro-dynamics	1	1	0	1	1	1		1	1	0	0	0	0	0	7	8
Seagrass	1	1	0	0	0	0	0		0	0	0	0	0	0	2	6
Salt marsh plants	1	1	0	0	0	0	0	0		0	1	0	0	0	3	6
Algae	0	0	1	0	1	1	0	0	0		0	0	1	1	5	8
Birds	0	0	0	0	0	0	0	0	1	0		0	0	1	2	6
Mammals	0	0	0	0	0	0	0	0	0	0	0		1	0	1	4
Fish	0	0	0	0	0	0	0	0	0	0	0	1		1	2	8
Invertebrates	1	1	0	0	0	0	0	0	0	0	1	0	1		4	10
affected	5	6	2	1	3	3	1	4	3	3	4	2	6	6	3,5	7,0

Some remarks regarding the construction of the table:

- 'Bed' means both bed level and bed composition, 'Hydrodynamics' both waves and currents, the factor 'Algae' contains phytoplankton, microphytobenthos and macroalgae, and 'Invertebrates' comprises crustaceans, molluscs and worms.
- The values to the right, under 'effectors' indicate factors that have a strong effect. The factors at the bottom ('affected') are the ones that are affected strongly.
- To identify key factors in the system, i.e. factors that are both strongly affected and induce strong effects, their values are added in the rightmost column.
- A yellow box means that the value is more than 10% above the average, orange means 20% higher and red means 50% higher, i.e. a stronger effect.

The table hints that the abiotic factors hydrodynamics and bed are probably the strongest drivers of the system, while mammals, birds and fish have only minor effects on other parts of the system. Fish and invertebrates are probably the most affected by changes, followed by the bed, suspended sediment, seagrasses and birds. Salinity and hydrodynamics are affected relatively little. The presence of mammals probably depends more on factors not included in this matrix, like disturbance and populations elsewhere.
When looking at key factors (that both are affected and affect others), the importance of the bed level and composition, suspended sediment and invertebrates becomes clear. Hydrodynamics, algae and fish also seem central. The presence of mammals seems less crucial to the functioning of the system, albeit it is for the assessment of natural value of the area. Figure 4.1 shows the main factors in the estuary, including human and climate factors, and the most important relations between them.

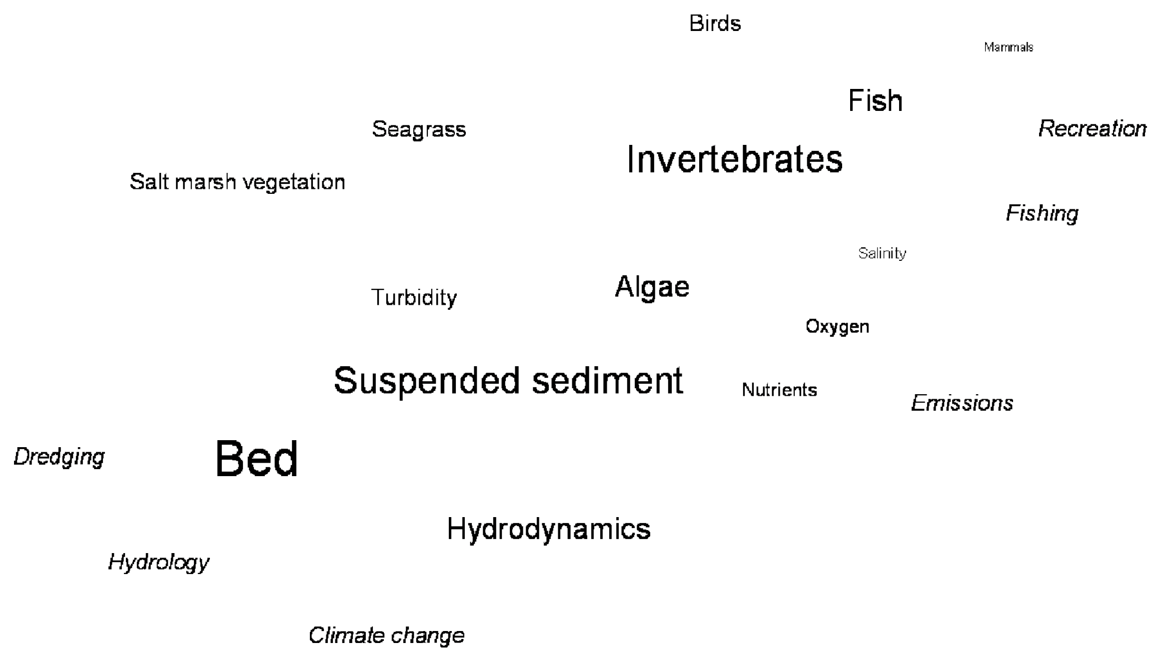

Figure 4.1 *The most important human influences, physical and chemical entities and organisms in the Ems-Dollard estuary. The larger the word, the more it is considered to be a key factor. External influences are in italics, all in the same size as their importance is still to be assessed.*

5 Model setup

In this chapter, the choice for the type of ecological model and the selection between relevant and irrelevant or impossible factors are discussed. This is followed by the description of input parameters to be used in the ecological model and the required output parameters from the physical- and water quality parts of the model. Only the reasoning behind the selection of most interesting or representative species is discussed here, as the actual selection is still proceeding. Although several simulations have been made as a test, these are not reported here because there are too many uncertainties in this phase of the project.

5.1 Type of modelling approach

When choosing a modelling approach, we should keep in mind that the aim of this project is to improve understanding of the effect-relationships between physics, water quality, biota and biota themselves in the Ems-Dollard area. Regarding ecology, several modelling approaches are available: e.g., one can create an ecotope map, determine habitat suitability, make a dynamic population model for individual species or follow a statistical approach. The definition of an ecotope is a spatially limited, relatively homogeneous combination of physical and chemical conditions and characteristic flora and fauna, for example a salt marsh or sand bank. Since this definition is not species-specific and therefore not very transparent in showing the chain of effects, an ecotope map is not always the best output. Such a map is useful however to present aggregated information, and to say something about possibilities for species for which little information exists. Moreover, the ecotope-classification corresponds to the Natura2000 legislation. Population models require a lot of knowledge and data and are only suitable for a limited number of species and relatively short timescales. A habitat, a type of environment in which an organism or population occurs, is species-specific and changes in the environment will be reflected in the suitability index: this index does not say how many specimen will be present at a certain time, but it does say how suitable the environment will be for a certain species. This suitability not only depends on abiotic factors but can also be due to the presence of organisms lower in the food chain. By including such factors step-by-step, it is possible to indicate the driving and limiting factors per species, which makes this approach transparent and matching with the effect-chain approach. What is more, habitat loss or gain is easy to quantify. Therefore, habitat modelling seems a suitable method to clarify the effect-chain in the Ems-Dollard, though combinations with other ways of modelling might be considered if questions about more details or numbers arise.

Habitat modelling needs data at a high spatial resolution, which is difficult to measure in the field but easily obtained from numerical models. Temporal resolution however, important for e.g. drying/flooding times, the abundance of food and the passage of fish through temporally anoxic zones can be more complicated to incorporate.

To asses the present potential for habitats and the possible future changes, we use the GIS-based model ‘Habitat’. Based on a number of user-specified relations, this model calculates a habitat suitability index (HSI; 0-1) for each grid cell. One can specify a response curve for suitability based on parameters like depth, sediment composition or turbidity, but also the presence or absence of other vegetation or animals. This chapter describes how response curves will be determined, and how ecology will be linked to the sediment transport and water quality part of the model. A more detailed discussion of the species selection and the determination of response curves shall be included in next year’s report, since this is work in progress.

5.2 Exclusion of factors

In a complex system like the Ems-Dollard estuary, so many processes with so many unknown influences occur that not everything can be included in this study. As the project progresses over the years, more and more detailed processes will be included. A number of factors will not be incorporated for two reasons: 1) we estimate that they are not crucial to the system as a whole, 2) we do not know enough about them to model them reliably.

Lack of knowledge about processes or data:

- Spreading of contaminants and nutrients buried in old deposits, by dredging.
- Spreading of contaminants and nutrients by air (like NO_x, SO_x and NH_3).
- Effects of ship waves on turbidity.
- Effects of noise (construction, engines) on animals.
- Ground water levels.

Complicating or far-fetched:

- Accidents that involve leakage of chemical substances can occur at too many places with too many chemicals.
- The occurrence of diseases or plagues (botulism, viruses).
- The introduction of invasive species.
- Breaches of coastal defences; flooding.
- Near-field spreading of thermal pollution (cooling water); this is only locally relevant and requires a much finer grid and a detailed configuration of intake and outflow structures.

Combinations of effects can be included in the model to some extent, though not as in reality because it is unknown how species react to a number of stressors at the same time. For example, when studying breeding birds one can look at the effect on habitat area of a decreasing salt marsh area and a decrease in food simultaneously, but the model will not automatically incorporate the fact that the birds are in a lesser condition than under normal conditions.
Very long-term changes to the system, like a possible weakening of the gene-pool of certain species by a strong selection pressure or limited exchange with other populations, cannot be studied with this model either.

5.3 Use and determination of Habitat Suitability Indices

‘Habitat’ is a spatial analysis tool based on GIS, especially designed for ecological assessments. Per species, Habitat uses a set of response curves (Habitat Suitability Indices or HSI’s) to determine the suitability of the area of interest for this species. A HSI indicates this suitability on a scale of 0-1 (0=unsuitable, 1=maximum suitability). High suitability does not necessarily mean that a species is actually present, because actual occurrence also depends on factors outside this model.
The input of Habitat consist of these response curves for each relevant parameter (e.g. temperature, flow velocity, water depth, salinity) combined with maps of each of these parameters. The total habitat suitability is calculated as the minimum suitability for all parameters combined. Figure 5-1 illustrates this with an example of an animal that requires shallow and clear water. The shallower the water the better, but the animal does not care if the water is deeper than 4 m (upper curve). Better visibility also means higher suitability until 1m, which is more than sufficient. Note that this is an example only; not a representation of a real animal.

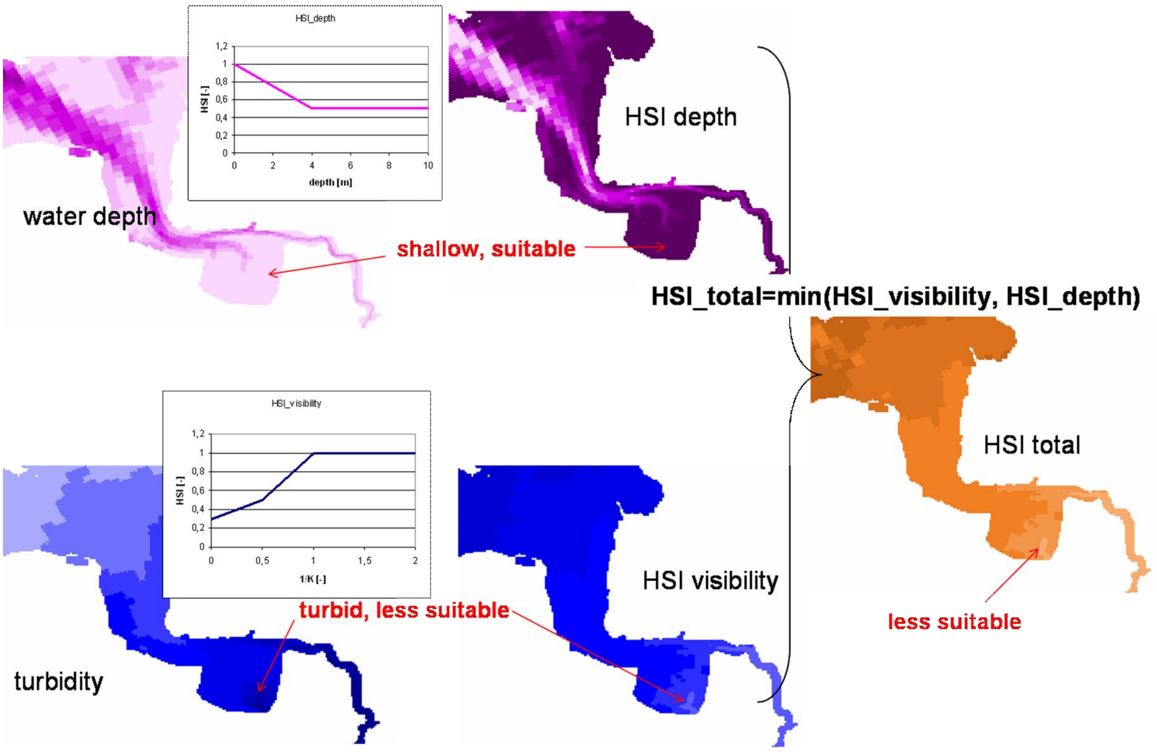

Figure 5.1 An example of determining total habitat suitability based on two criteria.

In the study area, there are simply too many different species of plants and animals present to include them all with sufficient detail. Besides, for some species there is not enough information available to do so reliably. Therefore, most species will be grouped along simple, shared characteristics like required inundation time, salinity or feeding preferences. However, for each group of organisms a few valuable species will be treated specifically, as these require specific attention or as a means to add some more detail to this study. This selection process and the determination of the HSI's is still ongoing, hence not described in this report. The determination of the relevant (groups of) species, relevant parameters and the actual response curves will be described elaborately in next year's report. That report will also contain an analysis of the sensitivity of the results to deviations in both the HSI's and the input parameters, since these are both a source of uncertainty.
Sources taken into account in this processs are: the Habitat-database at Deltares, various reports (Erftemeijer and Wijsman 2004; Haasnoot and van de Wolfshaar 2006; Kleef and Jager 2002; Ruardij 1980; van 't Hof 2006) and information on specific species from sovon.nl, soortenbank.nl, vogeltrackers.nl and wadvogel.avifaunagroningen.nl. Based on the work so far, an identification of the parameters required by Habitat can be found in Appendix A. These input parameters are also an indication of the required output parameters from the hydrodynamic and water quality models. The actual number of output parameters required depends on the necessary level of detail. Also, some Habitat input parameters can be derived from other sources.

5.4 Incorporation of time: seasons

Given the nature of the system and the goal of this study, it is necessary to model developments over a longer period rather than instantaneously. The daily and spring-neap cycles are important abiotic forcings of the system, as are the seasons that force biotic development to a large extent. On the other hand, as modelling developments in time

requires a lot of time and many separate cause-effect relationships have to be studied, it is impossible to make all calculations for extended periods.
As a compromise between calculation time and temporal resolution, while maintaining the essential dynamics of the system over the year, four ‘seasons’ will be used. Each season comprises a set of representative conditions (temperature, irradiance, wave climate, river discharge, presence of species, etc.) for the duration of a spring-neap cycle, which is in most cases long enough for both biologic and morphologic processes to establish a trend. Important but intermittent ‘events’ like spawning, seed establishment, dredging or a storm may happen outside these season-windows, but can be simulated either at the beginning or the end.

6 Scenarios

Many anthropogenic and natural changes are expected to occur in the Ems-Dollard estuary over the coming years or decades. Some will have an intermittent nature, others will occur gradually. The list below is just a preliminary overview of what might happen; a selection of the most relevant (combinations of) events should be made in deliberation with the actual managers. The order of the list is a rough indication for the estimated extent of the impact, combined with the likelihood of occurrence. Natural changes and human-induced alterations are listed separately here, but combinations of several factors are likely to occur and may have more severe impacts.

Climate:

- Sea level rise; up to 1 m per century
- Increase in storm frequency and intensity; unsure how much
- Hydrology, discharge regime Ems and Westerwoldsche Aa; dryer periods and more intense rainfall
- Increase in water temperature; up to 2 degrees in 50 years
- More severe winters

Capital dredging; effect on turbidity, contaminants, benthos, habitat area and tidal propagation

- An LNG-terminal in the Eemshaven requires a deeper and wider channel
- Deepening of the channel to Emden
- Deepening of the Ems River
- Harbour construction near Rysumer Nacken

Maintenance dredging; effect on turbidity, contaminants and benthos

- Eemshaven
- Delfzijl
- Emden
- Ems River

Harbour expansion and construction works

- Eemshaven: LNG terminal
- Rysumer Nacken
- Emden?
- Construction and maintenance of pipelines and cables

Effluents:

- Reduction (more likely than increase) of nutrient input (mainly nitrates); from North Sea / Wadden Sea or fresh water (Ems, Westerwoldsche Aa)
- Draining of brine from salt caverns, near Rysumer Nacken; concentration and duration unknown

Power plants increase thermal pollution, mechanically disturbance of fish and the intensity of shipping traffic
Increasing shipping traffic means more ship-generated waves, more noise and a higher chance of accidents (spoilage)

Fishing activities in the area may increase or decrease; impacts differ according to the type of fishing (mussels, shrimps, standing nets).

Measures to improve ecological status:

- Improve/create breeding areas for birds
- Construction of fish passage possibilities near sluices (salt/fresh transitions)
- Reduce salt marsh erosion by ‘kwelderwerken’

Incidental anthropogenic impacts:

- Ems barrier closure; more or longer closures
- Toxic waste; accidents, dumping or reworking by dredging

Miscellaneous:

- Introduction of invasive species
- Soil subsidence by gas mining
- A regime shift: a combination of the factors above may lead to an entirely different trophic system

7 Conclusions

Cannot be drawn yet.

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A Input parameters for Habitat Suitability Indices

Habitat suitability indices can be based on physical or chemical factors, or the presence of other species.

		Abbreviation	Unit
Physical			
Turbidity/light	Light attenuation coefficient	K	m-1
	Light penetration depth	Lp	m
	Light at the bed	Lb	%SI*
Sediment concentration		C	gl-1
Temperature		T	°C
Inundation time		I	hr
Wave height		W	m
Flow velocity		U	ms-1
Sediment size		D50	mm
Sediment composition	Silt content	SC	%
	Hard substrate	SH	-
Erosion/deposition rate		E	mmd-1
Water depth		H	m
(Ground water level)		G	m
Chemical			
Salinity		S	gl-1
Oxygen content		O2	mgl-1
Nutrients	silicon	NS	mgl-1
	phosphate	NP	mgl-1
	nitrate	NN	mgl-1
pH (benthic or pelagic)		pH	-
Pollutants, toxic		X	mgl-1
Other species			
Food source	phytoplankton	FP	-
	zooplankton	FZ	-
	detritus	FD	-
	microphytobenthos	FB	-
	macrofauna	FM	-
	fish	FF	-
	plants	FV	-
Plants for shelter or nesting		V	-

*=Surface Irradiation

B Fish species of the Ems-Dollard estuary and their ecological characteristics

The overview below is based on van 't Hof 2006), p. 62-63, which is a summary of various other studies, like those of Jager 1998. The abbreviations in the last four columns mean:

Group	ER=estuarine resident; CA=catadromic/anadromic; MJ=marine, juvenile; MS=marina, seasonal; MA=marine, 'accidentally'; FW=fresh water
Habitat	P=pelagic; B=benthic; D=demersal
Food	I=invertebrates; F=Fish; P=Plankton; J and V are unclear
Reproduction	V=viviparous; W=ovoviviparous; O=oviparous; p=pelagic; b=benthic; g=guarded; v=vegetation; s=shelter

English name	Dutch name	Scientific name	Group	Habitat	Food	Reproduction
Hooknose	Harnasman	*Agonus cataphractus*	ER	B	I	Ov
Twaite shad	Fint	*Alosa fallax*	CA	P	P,F	Ob
Lesser sand eel	Zandspiering	*Ammodytus tobianus*	ER	B	P,F	Ob
Eel	Paling	*Anguilla anguilla*	CA	B	P,I,J,F	Op
Transparent goby	Glasgrondel	*Aphia minuta*	ER	P	P	Os
Sand smelt	Koornaarvis	*Atherina presbyter*	MJ	P	I,F	Ov
Garfish	Geep	*Belone belone*	MS	P	I,F	Ov
Dragonet	Pitvis	*Callionymus lyra*	MA	B	I	Op
Thick-lipped grey mullet	Diklipharder	*Chelon labrosus*	MS	D	P,I,D	Op
Five-bearded rockling	Vijfdradige meun	*Ciliata mustela*	MS	B	F	Op
Herring	Haring	*Clupea harengus*	MJ	P	I,F	Ob
Lumpsucker	Snotolf	*Cyclopterus lumpus*	MS	B	I,F	Og
European seabass	Zeebaars	*Dicentrachus labrax*	MJ	D	I,F	Op
Lesser weever	Kleine pieterman	*Echiithys vipera*	MA	B	I,F	Op
Anchovy	Ansjovis	*Engraulis encrasicolus*	MS	P	P	Op
Snake pipefish	Adderzeenaald	*Entelurus aequorus*	MA	D	?	W
Grey gurnard	Grauwe poon	*Eutrigla gurnardus*	MS	B	I,F	Op
Cod	Kabeljauw	*Gadus morhua*	MJ	D	I,F	Op
Three-spined stickleback	Driedoornige stekelbaars	*Gasterosteus aculeatus*	CA	P	I,F	Og
Ruffe	Pos	*Gymnocephalyus cernua*	FW	P	I,J,V	Ov
River lamprey	Rivierprik	*Lampreta fluviatilis*	CA	B	F	Os
Dab	Schar	*Limanda limanda*	MJ	B	I,F	Ob
Sea-snail	Slakdolf	*Liparis liparis*	ER	B	I,F	Ov
Pearlsides	Lichtend sprotje	*Maurolicus muelleri*	MA	P	I	Op
Whiting	Wijting	*Merlangius merlangus*	MJ	D	I,F	Ob
Lemon sole	Tongschar	*Microstomus kitt*	MJ	B	I	Op
Bull rout	Zeedonderpad	*Myoxocephalus scorpius*	ER	B	I,F	Og
Sparling	Spiering	*Osmeranus eperlanus*	CA	P	I,F	Ob
Perch	Baars	*Perca fluviatilis*	FW	P	P,I,F	Ov
Sea lamprey	Zeeprik	*Petromyzon marinus*	CA	B	F	Os
Gunnel	Botervis	*Pholis gunnellus*	ER	B	I	Og
Flounder	Bot	*Platichthys flesus*	ER	B	I,F	Op
Plaice	Schol	*Pleuronectes platessa*	MJ	B	I	Op
Pollack	Pollak	*Pollachius pollachius*	MJ	D	F	Op

Coalfish	Koolvis	*Pollachius virens*	MA	D	I,F	Op
Goby	Brakwatergrondel	*Pomatoschistus microps*	ER	B	I	Op
Sand goby	Dikkopje	*Pomatoschistus minutus*	ER	B	I	Op
Ten-spined stickleback	Tiendoornige stekelbaars	*Pungitius pungitius*	FW	P	I	Og
Lesser fork-beard	Vorskwab	*Raniceps raninu*	ER	B	I,F	Ob
Sea trout	Zeeforel	*Salmo trutta*	CA	P	I,J,F	Os
Mackerel	Makreel	*Scomber scombrus*	MA	P	I,F	Op
Tarbot	Tarbot	*Scophthalmus maximus*	MJ	B	F	Op
Kite	Griet	*Scophthalmus rhombus*	MJ	B	I,F	Ob
Sole	Tong	*Solea solea*	MJ	B	I	Op
Sprat	Sprot	*Sprattus sprattus*	MS	P	P	Op
Zander	Snoekbaars	*Stizostedion lucioperca*	FW	D	I,F	Ob
Greater pipefish	Grote zeenaald	*Syngnathus acus*	ER	B	I,F	Os
Lesser pipefish	Kleine zeenaald	*Syngnathus rostellatus*	ER	B	I	Os
Sea scorpion	Groene zeedonderpad	*Taurulus bubalis*	MA	B	I,F	Ov
Horsemackerel	Horsmakreel	*Trachurus trachurus*	MA	D	I,F	Op
Tub gurnard	Rode poon	*Trigla lucerna*	MJ	D	I,F	Ob
Pout	Steenbolk	*Trisopterus luscus*	MJ	D	I,F	Ob
Poor cos	Dwergbolk	*Trisopterus minutus*	MA	D	I,F	Ob
Viviparous blenny	Puitaal	*Zoarces viviparous*	ER	B	I	V

C Birds in the Ems-Dollard estuary and their ecological characteristics

Season: W=winter, Sp=spring, S=summer, F=Fall, P=perennial
Species marked with an asterisk are on the red list of the Ministry of LNV.

English name	Dutch name	Latin name	Season	Breed	Breeding ground
Pintail	Pijlstaart	*Anas acuta**	W	N	
Common Teal	Wintertaling	*Anas crecca**	F/W	N	
Eurasion Widgeon	Smient	*Anas penelope*	F, W	N	
Mallard	Wilde eend	*Anas platyrhynchos*	P	Y	vegetated areas
Greater White-fronted Goose	Kolgans	*Anser albifrons*	W	N	
Graylag Goose	Grauwe gans	*Anser anser*	F	N	
Bean Goose	Rietgans	*Anser fabalis*	W	N	
Barnacle Goose	Brandgans	*Branta leucopsis*	Sp	N	
Dunlin	Bonte Strandloper	*Calidris alpina*	F/W	N	
Red Knot	Kanoetstrandloper	*Calidris canutus*	S/F	N	
Curlew Sandpiper	Krombekstrandloper	*Calidris ferruginea*	S	N	
Purple Sandpiper	Paarse strandloper	*Calidris maritima*	W	N	
Twite	Frater	*Carduelis flaviostris*	F/W	N	
Great Ringed Plover	Bontbekplevier	*Charadrius hiaticula**	Sp, S	Y	open areas, roofs
Common Oystercatcher	Scholekster	*Haematopus ostralegus*	P	Y	roofs, isles
Herring gull	Zilvermeeuw	*Larus argentatus*	P	Y	little vegetation
Common gull	Stormmeeuw	*Larus canus*	P	Y	little vegetation
Great Black-backed Gull	Grote mantelmeeuw	*Larus marinus**	P	Y	little vegetation
Black-headed gull	Kokmeeuw	*Larus ridibundus*	P	Y	little vegetation
Bar-tailed Godwit	Rosse grutto	*Limosa lapponica*	S	N	
Black-tailed Godwit	Grutto	*Limosa limosa**	Sp, S, F	Y	marshes, grasslands
Savi's Warbler	Snor	*Locustella luscinioides**	Sp, S	Y	reedlands
Bluethroat	Blauwborst	*Luscinia svecica cyanecula*	Sp, S	Y	reedlands
Goosander	Grote zaagbek	*Mergus merganser*	W	N	
Red-breasted Merganser	Middelste zaagbek	*Mergus serrator**	W	N	
European Curlew	Wulp	*Numenius arquata*	P	Y	dense vegetation
Whimbrel	Regenwulp	*Numenius phaeopus*	S	N	
Great Cormorant	Aalscholver	*Phalacrocorax carbo*	Sp, S, F	Y	trees, reedlands
Ruff	Kemphaan	*Philomachus pugnax**	W	N	
European golden plover	Goudplevier	*Pluvialis apricaria**	S	N	
Grey plover	Zilverplevier	*Pluvialis squatarola*	P, mainly W	N	
Avocet	Kluut	*Recurvirostra avosetta*	P, most F	Y	Mudflats
Common Eider	Eidereend	*Somateria mollissima*	S	~N	
Common Tern/Arctic Tern	Visdief/Noordse stern	*Sterna hirundo*/paradisea*	Sp/S	Y	little vegetation
Common Shelduck	Bergeend	*Tadorna tadorna*	F	~N	rabbit holes
Spotted Redshank	Zwarte Ruiter	*Tringa erythropus*	P	N	
Common Greenshank	Groenpootruiter	*Tringa nebularia*	S	N	
Common Redshank	Tureluur	*Tringa totanus**	P	Y	salt marshes
Northern Lapwing	Kievit	*Vanellus vanellus*	P	Y	marshes, dunes

Latin name	Living ground	Feeds on	Elevation of feeding
*Anas acuta**	grasslands, water	grasses, roots, small animals	shallow and >MSL
*Anas crecca**	mudflats, water	waterplants, snails, shrimps	MSL -2 to MSL
Anas penelope	shallow water	grasses, roots	>MSL or water
Anas platyrhynchos	shallow water	Everything	-2 to >MSL
Anser albifrons	grasslands	Grasses	>MSL
Anser anser	grasslands, marshes	grasses, roots	>MSL
Anser fabalis	grasslands	Grasses	>MSL
Branta leucopsis	grasslands	Grass	>MSL
Calidris alpina	mudflats	Invertebrates	intertidal
Calidris canutus	mudflats	Invertebrates	intertidal
Calidris ferruginea	intertidal, muddy	Invertebrates	intertidal -0.2
Calidris maritima	rocky shores	Invertebrates	intertidal and a bit higher
Carduelis flaviostris	open field, salt marshes	seeds, insects	>MSL
*Charadrius hiaticula**	intertidal	Invertebrates, bivalves	intertidal and higher
Haematopus ostralegus	intertidal	Bivalves	intertidal
Larus argentatus	everywhere	Everything	everywhere
Larus canus	everywhere	Everything	everywhere
*Larus marinus**	everywhere	Everything	everywhere
Larus ridibundus	everywhere	Shrimps	everywhere
Limosa lapponica	mudflats	Invertebrates	intertidal
*Limosa limosa**		worms	>MSL
*Locustella luscinioides**	reedlands	small invertebrates	intertidal and higher
Luscinia svecica cyanecula	reedlands	small invertebrates, seeds	intertidal and higher
Mergus merganser	large open water	small fish	-4 to MSL
*Mergus serrator**	open water	small fish	-3.5 to MSL
Numenius arquata	intertidal	bivalves	intertidal
Numenius phaeopus	mudflats	Invertebrates	intertidal
Phalacrocorax carbo	shallow water	Fish	-9 to MSL
*Philomachus pugnax**	mudflats	Invertebrates	intertidal and higher
*Pluvialis apricaria**	grasslands	Invertebrates, seeds	>MSL
Pluvialis squatarola	intertidal, muddy	invertebrates	intertidal
Recurvirostra avosetta	Mudflats	small invertebrates	intertidal -0.2
Somateria mollissima	water	bivalves, shrimps	-4 to MSL
Sterna hirundo/paradisea*	near coast	crustaceans, fish	intertidal and deeper
Tadorna tadorna		snails; peringia ulvae, macrofauna	intertidal, shallow
Tringa erythropus	mudflats	insects, small fish, invertebrates	intertidal -0.2
Tringa nebularia	mudflats	invertebrates, small fish	intertidal
*Tringa totanus**	intertidal, marshes	small invertebrates	intertidal and a bit higher
Vanellus vanellus	marshes, grassland	worms	>MSL

D Selection of macrofauna in the Eems-Dollard and their ecological characteristics

English name	Dutch name	Latin name	feeding	sediment type	depth
Molluscs					
Blue mussel	Mossel	*Mytilus edulis*	filter	sandy, with hard substrate	intertidal,
Cockle	Kokkel	*Cerastoderma edule*	deposit and filter	muddy to fine gravel	intertidal to -15
Japanese oyster	Japanse oester	*Crassostrea gigas*	filter	hard substrate but also muddy to sandy	intertidal to -10, occasionally -40
Common oyster	Platte oester	*Ostrea edulis*	filter	hard substrate	intertidal to -50
Baltic tellin	Nonnetje	*Macoma balthica*	deposit	mud to muddy sand	intertidal to -20
Sand gaper	Zandgaper	*Mya arenaria*	filter	sand to muddy sand	intertidal to -15
Peppery furrow shell	Platte slijkgaper	*Scrobicularia plana*	filter and deposit	mud	intertidal
Gastropods					
Laver spire shell	Wadslakje	*Hydrobia ulvae*	deposit; diatoms	sand and mud	intertidal
Crustaceans					
Brown shrimp	Gewone garnaal	*Crangon crangon*	everything	sand, shells, gravel	-50 to intertidal
Mud shrimp	Slijkgarnaal	*Corophium volutator*	plankton, detritus	mud	intertidal
Green shore crab	Strandkrab	*Carcinus maenas*	carrion		-200 to intertidal
Flying crab	Zwemkrab	*Liocarcinus holsatus*	invertebrates		-350 to MSL
Sand dagger shrimp	Knikprietkreeft	*Bathyporea sp.*	detritus, plankton	fine to coarse sand	-5 to MSL
Polychaetes					
Ragworm	Zeeduizendpoot	*Nereis diversicolor*	everything?	sandy mud	intertidal
Lugworm	Zeepier	*Arenicola marina*	sand with detritus	sand to muddy sand	intertidal to -5
Paddleworm	Groengele wadworm	*Eteone longa*	carnivorous	fine and muddy sand (100-500 micrometer)	intertidal to -30m
		Marenzelleria cf. wireni	deposit feeder	mud	
		Lanice conchilega			
Oligochaetes					
		Tubifex costatus	filter, organic	mud	