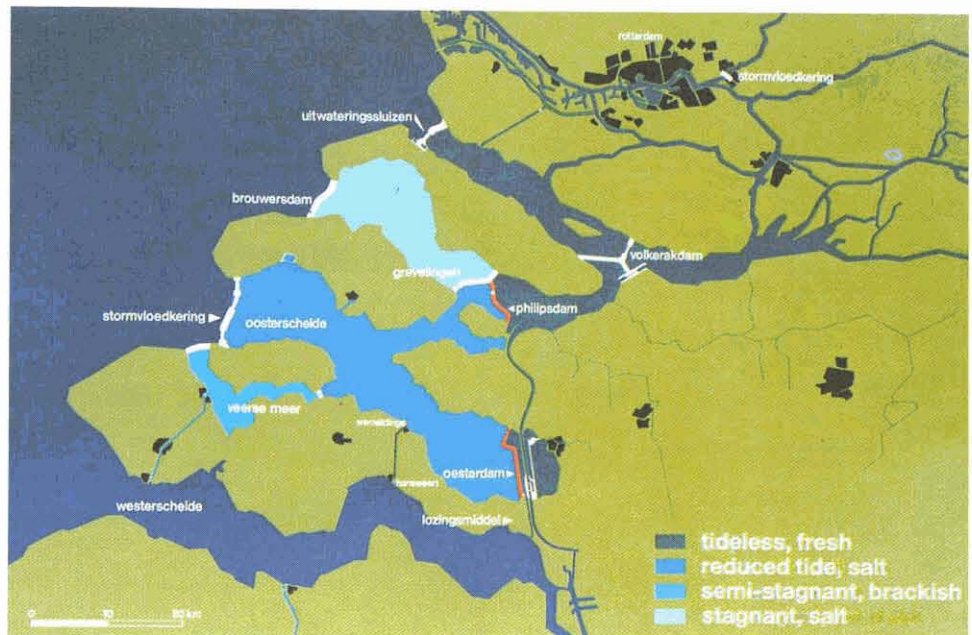


Hydro ecological relations in the Delta Waters of the South-West Netherlands

Proceedings and information No. 41
Verslagen en Mededelingen No. 41

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Editors
J.C. Hooghart
C.W.S. Posthumus

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INTRODUCTION

H. Engel

Before human interference in the Delta of the South-West Netherlands, the hydro-ecological relations in the waters of this Delta were taken very much for granted. As a result of the man-made changes, these natural relations disappeared. The construction of the Delta Works completely altered the face of the Delta. This was not the first occasion on which the relations between the waters of the Delta had been affected. Take for example the construction of the Sloe Dam and Kreekrak Dam in the latter half of the 19th century, which resulted in the loss of the connection between the Eastern and Western Scheldt. Nevertheless, the Delta in its present form is largely the brainchild of hydraulic engineers of the latter half of the present century.

The original Delta Project treated the Delta as a single entity, but purely from the point of view of safety and water control. At that time the integral approach of ecological interests had yet to be developed. Although ecological considerations have gained in importance over the years, the present compartmentalization of the Delta is still to a great extent the product of the original Delta Project.

The completion of the water management infrastructure of the Delta marks, for the time being at least, the end of an era of major hydraulic projects in the Delta. But while these works were being carried out, a new era had already begun; one which centred on careful supervision and responsible management of the newly-created systems.

This approach will put to use what has been learned about the behaviour of compartmentalized systems. If we respond to changes by making informed use of the scope for control and regulation presented by the Delta Works, we can develop these new systems to their full potential.

L. Bijlsma and J.W.M. Kuipers

ABSTRACT

Extensive hydraulic engineering projects have been carried out over the last 25 years in the Delta area formed by the rivers Rhine, Meuse and Scheldt. This has resulted in parts of the Delta being divided up (compartmentalized) while other parts have been closed off. The time at which many of the operations involved in dividing up these areas were carried out coincided with a period during which the pollution in the three rivers reached its maximum level (1970-1975).

Micropollutants (heavy metals and organic compounds) became attached to the fines in the sediment carried by the rivers, and this led to the Delta region also being affected by these contaminants. However, because of compartmentalization certain areas, namely Lake Grevelingen and the tidal basin of the Eastern Scheldt, escaped the wave of pollution. The quantities of micropollutants in these areas are very close to natural background levels. The explanation for this is that the compartmentalization of these areas was completed before the pollution in the Rhine and Meuse reached such high levels.

In contrast, the closure of the Haringvliet estuary led to the formation of new sedimentation areas just prior to the time at which the pollution in the Rhine and Meuse reached a peak. Thus layers of contaminated material have settled in these sedimentation areas. Almost 30% of the total amount of silt transported by the rivers Rhine and Meuse is deposited in these areas.

Estuaries that have not been influenced by closure operations can also undergo significant temporary sedimentation effects. An example of this is the Land of Saeftinghe in the Western Scheldt estuary. As a result of a rise in the sea level and a deepening of the shipping channel, the difference between low and higher water has increased which, in turn, has resulted in a significantly greater deposition of silt on the mudflats and salt marshes. Almost 25% of the silt transported by the river Scheldt settles in these areas.

Although relatively little is known about the effects that contaminated beds have on the aquatic ecosystem, there are clear signs that ecological communities which are directly dependent on the river bed environment can be disrupted. In addition, the amounts of pollutants found in certain organisms and plants now exceed the maximum acceptable levels for human consumption. Future clean-up operations could be considered for the contaminated sedimentation areas when the level of pollution from discharges into the river basins has been sufficiently reduced. In view of the scale and extent of the sedimentation layer concerned, no solutions have yet been found to this problem.

1 INTRODUCTION

The Delta region of the South-West Netherlands has been the scene of many extensive hydraulic engineering projects over the last few decades (Fig. 1). These operations were largely a reaction to the storm tide disaster of 1953, in which large areas of the Delta region were inundated. The plans which were drawn up after this catastrophe and which have now been implemented were primarily concerned with protecting the region against flooding. In addition, the plans also addressed specific water management objectives, in particular the need to control the problems of salinization. The basic approach was to close off the tidal gullies in the Delta and to create a series of freshwater lakes behind the dams.

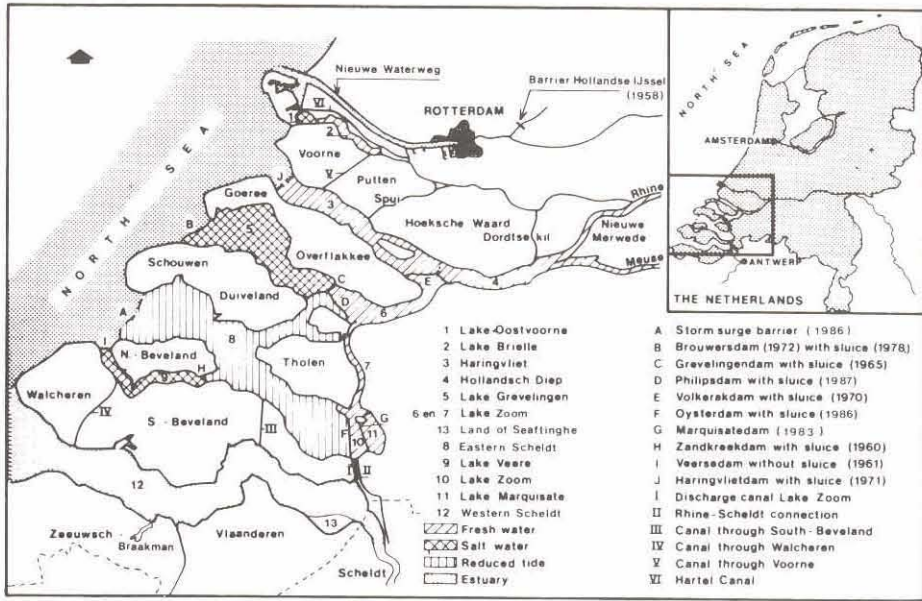


Figure 1 The Delta Plan

During the construction phase it was realised that it would be extremely undesirable to lose altogether the unique saltwater tidal system that existed in this region. Consequently, a decision was taken in the 1970's not to close off the Eastern Scheldt tidal basin as had originally been intended, but to install a storm surge barrier instead. This meant that the safety of the region could be guaranteed while still preserving the essential character of a saltwater tidal system.

While construction work on the Delta Project was in progress, pollution from the major rivers in the region rose to maximum levels. This created a further problem. Closure of the estuaries has disturbed the morphological balance and led to the formation of new sedimentation areas. The quality of the lake and river beds in the new sedimentation areas deteriorated rapidly as the suspended sediment carried by the water of the major rivers contained micropollutants such as heavy metals and organic compounds.

The Delta area was formed by the interaction of the rivers Rhine, Meuse and Scheldt and the tidal movements of the North Sea. The average discharges from the Rhine, Meuse and Scheldt are $2200 \text{ m}^3/\text{sec}$, $260 \text{ m}^3/\text{sec}$ and $100 \text{ m}^3/\text{sec}$ respectively. The original discharge distribution over the tidal gullies, prior to the Delta Project closures, is given in Figure 2. In the period before 1965, the influence of the Rhine and Meuse extended to the Eastern Scheldt estuary. At that time the Delta was in a state approaching morphological equilibrium. Until 1970, the amount of sand and silt brought down by the rivers Rhine and Meuse was roughly equal to that

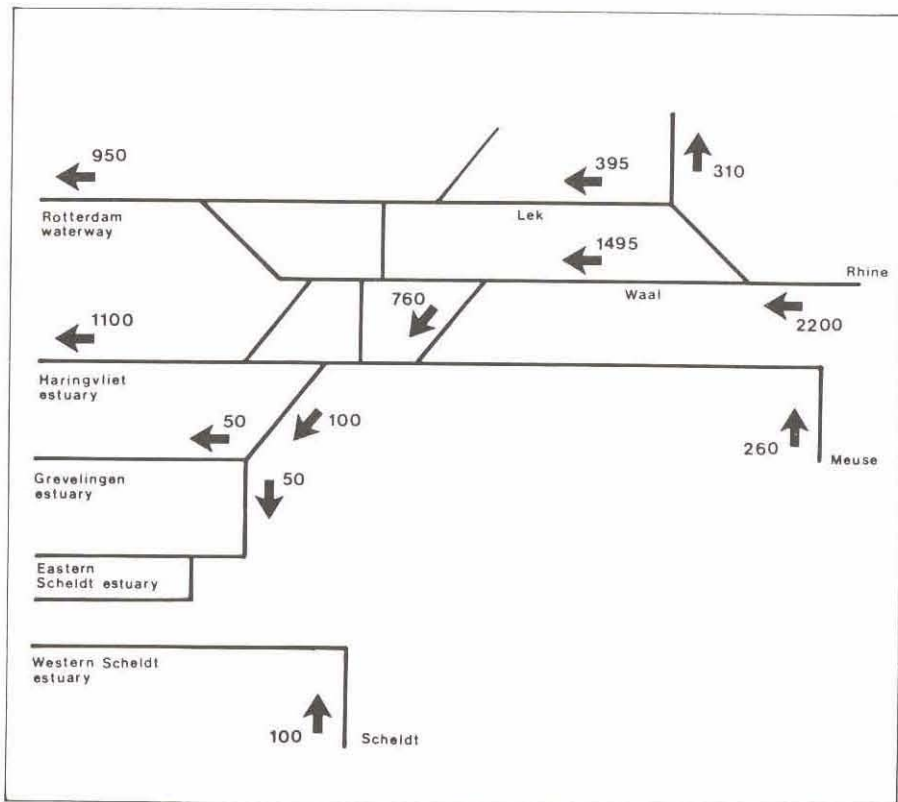


Figure 2 Discharge distribution over the major rivers 1965 (values in m^3/sec)

discharged through the mouths of the estuaries to the North. However, local variations were apparent, with further erosion taking place in the deeper tidal gullies and corresponding increases in sedimentation occurring in the shallows. Moreover, sea-borne sediment was deposited in the western part of the Delta. The finer type of fluvial sediment was only deposited in more sheltered locations, with the majority of it flowing through to the North Sea. Under the influence of the prevailing long-shore current this fine fluvial sediment was carried northwards, where some of it was deposited in the Wadden Sea, an extensive wetland area in the north of the Netherlands.

Successive closures in the Delta area produced changes in the flow distribution, while flow rates tended to decline as a result of the complete or partial loss of tidal motion. This led to the formation of new sedimentation areas within the Delta region. By 1965 the central section of the Delta was no longer subject to the influence of the Rhine and Meuse. In 1965 and 1969 respectively the Grevelingen and Eastern Scheldt estuaries were effectively decoupled from these two rivers. The closure of the Haringvliet estuary in the northern section of the Delta had the effect of reducing tidal motion over the whole of this area. In the south, the Western Scheldt estuary remained largely unchanged, although the sand bars in the estuary were dug out in the 1970's to improve the shipping route to Antwerp (Belgium). Finally, in 1987, work in the eastern part of the Delta led to the formation of a separate freshwater lake (Lake Zoom) in the Eastern Scheldt, with the specific aim of improving water supplies for agricultural purposes. Lake Zoom is being flushed out with fresh water from the Hollands Diep.

The overall effect of all these hydraulic engineering projects has been to change significantly the distribution of river water, which has had implications for the transport of fluvial sediment. Recent measurements of the transport of fine fluvial sediments are shown in terms of tons per year in Figure 3. This figure also gives the yearly accumulation of river sediment at particular locations. Region I represents the southern lower reaches of the Rhine and the lower reaches of the Meuse. Following the closure of the Haringvliet estuary, flow rates in the

area declined considerably, leading to extensive sedimentation. This has caused an inner delta to form at this location, which is gradually moving in a westerly direction. In the case of Region II, the Haringvliet, closure has led to a thin layer of silt being deposited over this area.

From 1987 onwards, a new sedimentation area is developing in Lake Zoom (Region III). The sedimentation in this region is essentially similar to that found in the Haringvliet area and will mainly consist of silt. Finally, comparisons can be made with the sedimentation area in the Western Scheldt (Region IV). In this region most of the silt carried by

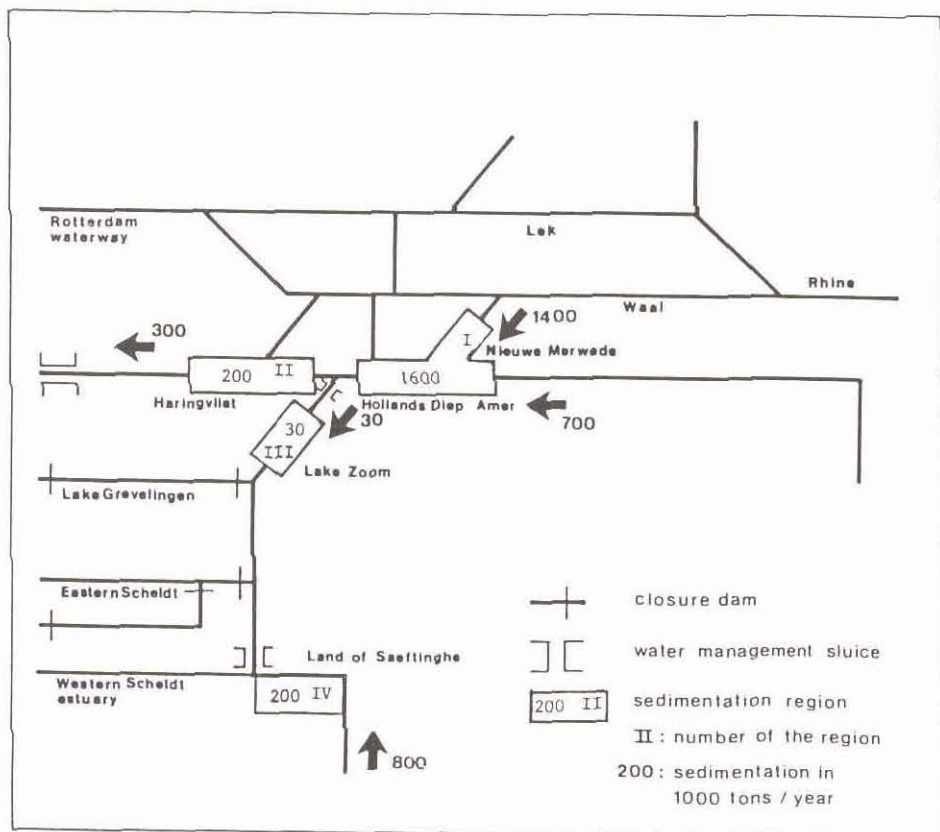


Figure 3 Transport rates of fine fluvial sediments 1987 (values in 1000 tons p.a.)

the river Scheldt is deposited in the mudflats known as the Land of Saeftinghe.

The sedimentation areas referred to above will be discussed further in the following sections.

3 THE QUALITY OF RIVER SEDIMENTS

From the turn of the century onwards, pollution in the Rhine, Meuse and Scheldt basins increased rapidly as a result of industrial expansion and further population growth (Salomons, 1981). The amount of pollution in these areas continued to increase until maximum levels were reached during the period 1970-1975. As a consequence large amounts of heavy metals and organic compounds have become attached to the river sediment.

In order to monitor the situation over the last few decades, the associated levels have been measured at the points where the three rivers cross the borders. A detailed discussion of the distribution and changes in the levels of all the substances that are monitored is beyond the scope of the present paper. It has therefore been decided to consider the example of the heavy metal cadmium as a mean of illustrating the subject. This metal can be regarded as a tracer for other pollutants. The change in associated cadmium levels measured in suspended sediment is shown as a function of time in Figure 4. By using data from core samples taken from older sediments it has been possible to reconstruct the build-up of pollution in the Rhine in the first part of this century. Following the peak years of the early 1970's, clean-up measures in the Rhine basin have led to a spectacular reduction in the amount of cadmium pollution. Concentrations have now been reduced to those of the beginning of this century. In the case of the rivers Meuse and Scheldt, more moderate reductions in contamination levels have been detected.

If the upward trend in the wave of pollution in the major rivers is compared with the sequence of closure operations involved in the Delta

Plan, then it is apparent that the separation of the Grevelingen and Eastern Scheldt estuaries occurred prior to the peak pollution years of the early seventies. The formation of sedimentation regions I and II, a result of the closure of the Haringvliet, took place immediately before the major wave of pollution occurred, while sedimentation region III, which will be created by the flushing operations of Lake Zoom, will be affected now that contamination levels have been greatly reduced.

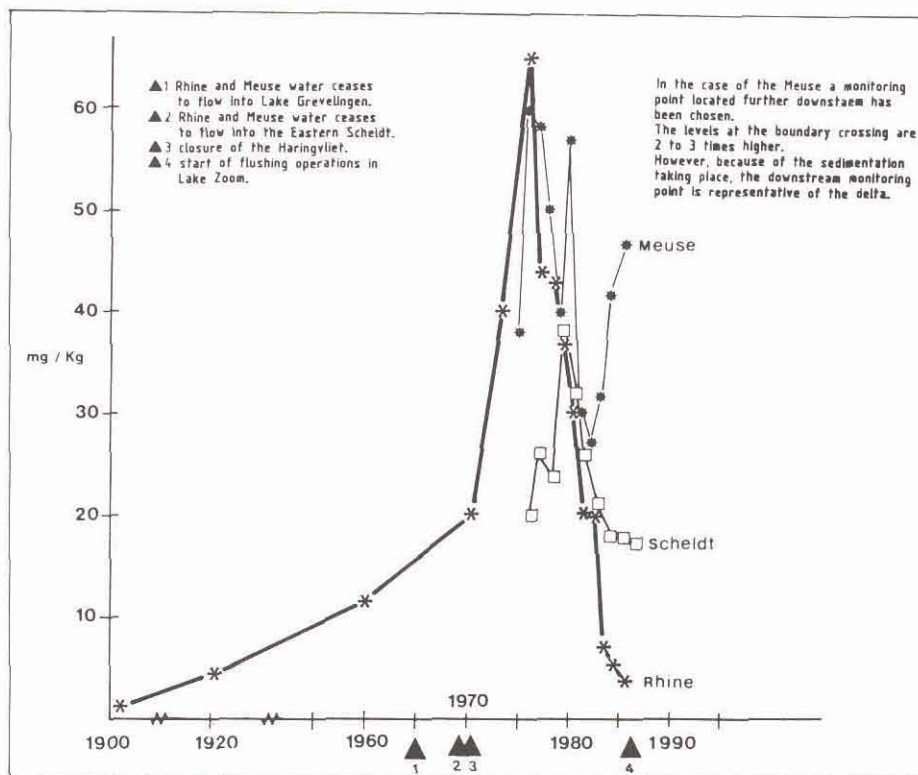


Figure 4 Associated cadmium in suspended river sediments at the points where the rivers Rhine, Meuse and Scheldt cross the border



Cormorant (*Phalacrocorax carbo*), a fish eating bird



Volkerak dam and locks



Tidal flats of the Eastern Scheldt with "golddiggers"



Flounder (*Platichthys flesus*) with abscesses

4 THE QUALITY OF LAKE BED AND RIVER BED SEDIMENTS IN THE SEDIMENTATION AREAS

The series of events, described above, has produced differences in the quality of lake beds and river beds in the sedimentation areas (Salomons, et al, 1981; Beefting, et al, 1982). The situation regarding cadmium levels is illustrated in Figure 5. A regression analysis has been used in order to compare the measured concentrations in the various samples.

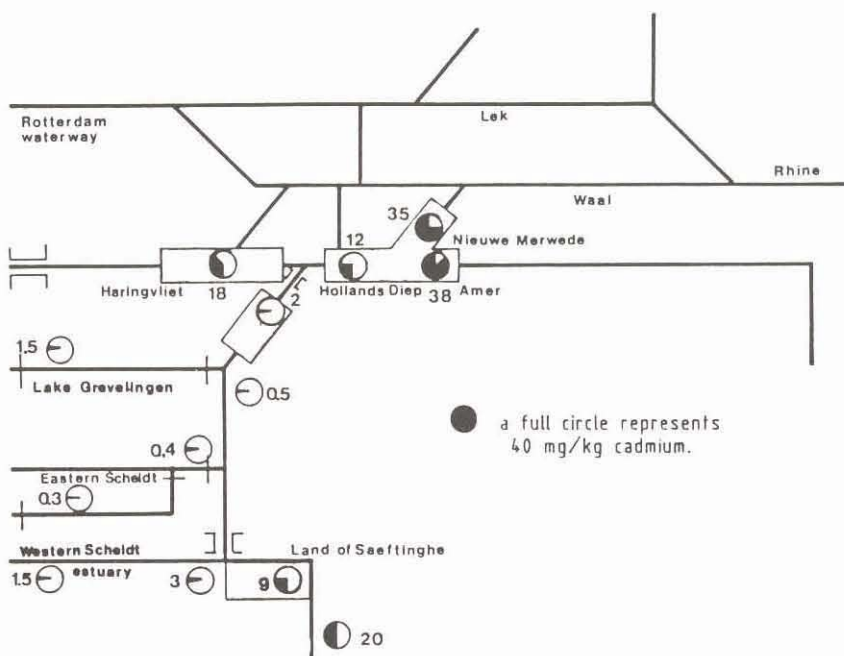


Figure 5 Cadmium concentrations in river bed sediments converted to an equivalent 50%-16 μ m top layer (1986 levels).

A relationship has been established between the measured concentration and the proportion of fines less than 16 μ m in the sediment. It was

Therefore possible to convert the absolute measured concentrations to an equivalent concentration that would be expected in a standard river bed with 50% of the grain fraction less than 16 μm .

The separation of the Eastern Scheldt and Lake Grevelingen from the water flowing in the rivers Rhine and Meuse has resulted in remaining extremely low concentrations in these areas. The values found in the Eastern Scheldt are thought to approximate to natural background levels. The concentration in Lake Grevelingen is known to be somewhat higher. Unlike the Eastern Scheldt, this lake became stagnant after its closure. As a consequence, there is less interaction between the water in the lake and the bed deposits (resuspension) in Lake Grevelingen than in the Eastern Scheldt. This explains why the concentration of contaminants in this lake still approaches the pre-1965 values.

The lake beds and river beds in the sedimentation areas in the northern part of the Delta are heavily polluted. In the eastern part (Nieuwe Merwede/Amer) high contamination levels have been detected, affecting a layer at least 2 metres thick. This material was deposited between 1970 and 1975. As an equilibrium has now developed between the hydraulic and morphological processes, it is unlikely that this layer will be covered by new sediments in the future.

The central section of the Delta (Hollands Diep) has a thick layer of less polluted river sediment that was deposited in the years after 1975. However, more contaminated material from the 1970-1975 period is contained below this layer. Underneath these layers can be found estuarine sediments from the period before 1970. The different layers referred to above can be clearly distinguished from core samples taken from the area (Fig. 6). It is recognized that the quality of the top layer of sediment will improve as the quality of the surface water improves.

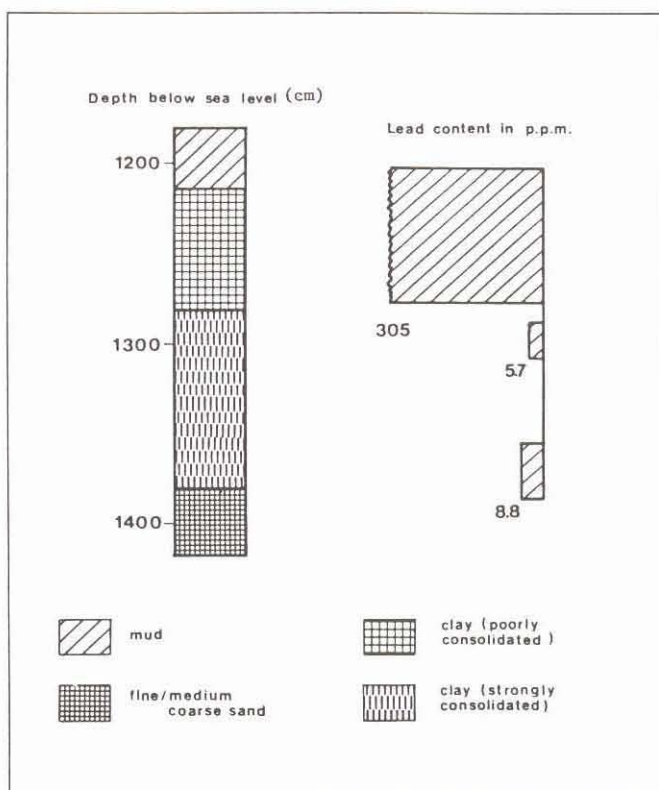


Figure 6 Contamination in the Hollands Diep. The recently deposited contaminated layer can be clearly distinguished by the lead content.

A relatively thin layer of polluted sediments (less than 0,1 m) is to be found in the western section of the Delta (Haringvliet) above older, mainly marine sediments. As sedimentation in this region takes place extremely slowly, no significant changes are expected in the near future (Fig. 7), although in the long term the quality of the top layer will improve as the main area of sedimentation shifts westward (Rijkswaterstaat, 1987).

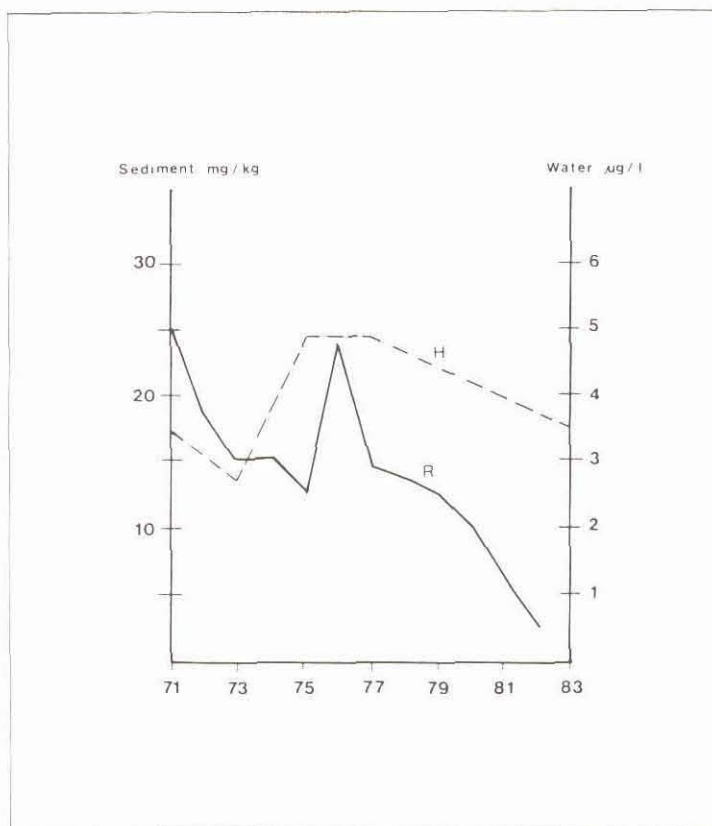


Figure 7 Changes in the cadmium content of the Rhine water (R) and in river bed sediment from the Haringvliet (H) over the period 1971-1983

As flushing operations are only scheduled to commence in 1987, the quality of the sediment in Lake Zoom is still the same as that found in other parts of the Eastern Scheldt. However, there is a small area behind the Volkerak locks which has been affected by the influx of water from the Hollands Diep. For water management purposes it has been decided to restrict the flushing operations in Lake Zoom to a minimum (the salinity level in the lake will not exceed 400 mg/l), to reduce the input of pollutants.

It is possible that in the future a more liberal flushing policy might be adopted in connection with the improved water quality in the rivers Rhine and Meuse. However, it should be borne in mind that not all the pollution parameters have been reduced to the same extent as cadmium.

In the Western Scheldt the situation is different from that described above since this region has not been influenced by the closure operations. However, significant amounts of sediment have been deposited over the last decades in the Land of Saeftinghe area, which consists of extensive salt marshes and mudflats. This has been caused by the deepening of the bars in the eastern part of the estuary for shipping purposes, which have increased the tidal difference and also the turbidity. Consequently, a layer between 0.2 and 0.4 m has recently been deposited in this area. Polluted silt from the river Scheldt is settling here together with uncontaminated sea-borne sediment, in the ratio 60% river silt to 40% sea silt.

As a result of the construction of the Delta Works, as described in the previous chapters, the central section of the Delta has been cut off from the influence of the major rivers to some extent. However, this does not necessarily guarantee the quality of the estuary and lake beds, which is affected both by past influences and by local sources of pollution. It is important to take this into account in view of the radical changes which the hydraulic and morphological configuration of the region had undergone. For instance, the compartmentalization of the Lakes Grevelingen, Veere and Volkerak-Zoom had considerably increased the residence time of water. The construction of the storm-surge barrier in the Eastern Scheldt has also led to a considerable reduction in the horizontal tide, as a result of which residence time had increased and the Eastern Scheldt has become a pure sedimentation area. In short, the central section of the Delta has become much more vulnerable to local pollution.

Local pollution mainly emanates from diffuse sources; the main ones are activities in the small harbours in this region and the discharge of water from the polders. It has been observed that the beds of all of these harbours are moderately to severely polluted. Clean-up and

prevention measures are desirable here to prevent the diffusion of pollution to adjacent waters.

5 EFFECTS ON THE ENVIRONMENT

Relatively little is known about the impact polluted beds have on aquatic ecosystems, partly because these areas are not directly observable. Future research strategies will therefore be mainly concerned with addressing these shortcomings. There are, however, various indications that pollution may be a hazard to public health and may influence the functioning of aquatic ecosystems. The presence of heavy metals and organic micropollutants in benthic organisms is clearly higher in polluted areas than in less contaminated areas. This has been verified for various organisms such as Dreissena polymorpha, Tubifex spec., Chiomid larvae and also zooplankton (Urk, 1987). There are, of course, specific differences between individual species with regard to the type and amount of heavy metals found. In molluscs, for example, contamination levels are higher in species that live in the top layer of sediment than surface dwellers.

Relatively low levels of pollution are found in the eastern part of the Haringvliet basin (Hollands Diep), whereas higher levels can be detected in the western part of the Haringvliet. This is a consequence of the sedimentation process, which has influenced the quality of river sediments in the areas, as outlined in the previous section. These gradients are also reflected in the concentration of contaminants found in specific organisms. Figure 8 shows how the cadmium content in the gills of Anadonta anatina varies at different locations. The levels in the western part of the basin (Haringvliet) are two to three times higher than those found in the eastern part (Hollands Diep). Similar problems have been encountered with organic micropollutants. For instance, from 1977 to 1985, PCB levels in eels from the different surface waters in the Netherlands were monitored by the State Institute for Fishery Research (RIVO). At the end of the seventies PCB levels in eels from the Haringvliet basin were extremely high, probable as a result of local discharges, some of them illegal. Since this time, the

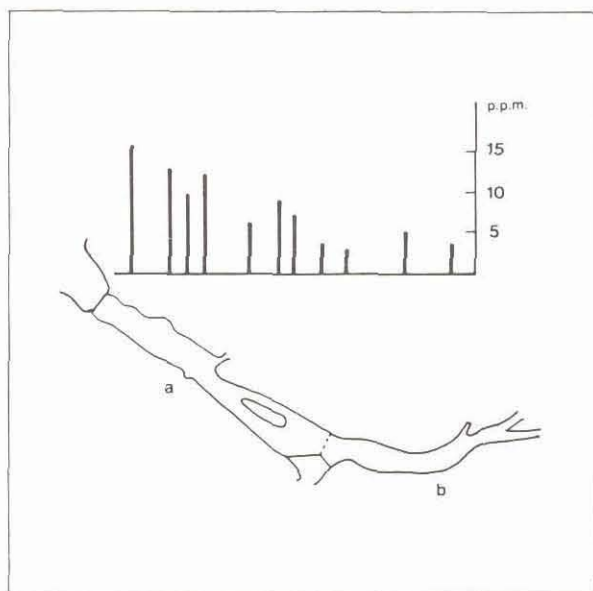


Figure 8 Cadmium content in the gills of *Anadonta anatina* found at several places in the Haringvliet (a) and the Hollands Diep (b)

level had decreased to about the same value as that normally found in the upstream areas of the Rhine. Nevertheless, the level in eels from the Haringvliet basin is still above the recommended limit specified for human consumption. To give another example, table 1 shows PCB levels measured from the Haringvliet basin and some clean reference areas. The accumulation is clearly discernible.

The amount of contaminants in plant and animal tissues does not throw very much light on the functioning of the ecosystem. Pollution may be regarded as a form of stress imposed upon the environment. Its effects vary from species to species and may manifest themselves in stunted growth, a fall in the reproduction rate and an increased mortality rate. Given that certain animal species are more vulnerable to pollution than others, it may lead to shifts in the competitive

relationships between different species. The more vulnerable species will decline and finally disappear, while the less vulnerable species will become established or increase in particular areas. In general, the total number of species will decline, thus impoverishing the ecosystem, possibly to a severe degree.

In the Haringvliet basin the levels are so high that specific environmental effects are to be expected. Inventories carried out in the area have shown that the ecosystem in the Hollands Diep is functioning much better than that of the Haringvliet. For instance, the biomass of fauna found on the river bed has been shown to be higher in the Hollands Diep. This also applies to the number of fish and to the number of birds that feed on fish and fauna, living on the river bed, such as cormorants, grebes and tufted ducks (Boudewijn, et al, 1986). The differences observed between the Hollands Diep and the Haringvliet may be explained partly in terms of the difference in quality of the beds. But even, the ecosystem of the Hollands Diep is poorly developed by comparison with other large freshwater systems in the Netherlands. For example, large water plants are scarce in the whole area, even though slight increases have been detected over the last few years. As far as individual species are concerned, some of the effects are probably connected with the contamination of the river bed. A link has been established between deviations in the chitin structure of the head of chironomid larvae and the degree of pollution found in the sediment. Laboratory research has indicated that the reproduction rate of tufted ducks fed on freshwater mussels from the Haringvliet is considerable lower than that of tufted ducks fed on mussels from less polluted areas (Marquenie, et al, 1987). Moreover, the eggs of tufted ducks and grebes from the Haringvliet area appear to have much higher levels of organic micropollutants than those of birds from less contaminated reference areas (Table 1).

Table 1 PCB levels in eggs of grebes from the Haringvliet basin and some clean reference areas (values in µg/kg)

	Haringvliet basin	reference areas
PCB 138	4 900 - 10 500	120 - 1 450
PCB 153	9 400 - 16 500	205 - 2 450
PCB 186	1 850 - 3 450	10 - 195

Recent research also shows that cormorants, a fish-eating species at the end of the food chain, are reproducing far less successfully in the northern part of the Delta region (Biesbosch) than in other areas (Boudewijn, et al, 1989). In a number of colonies along the major rivers (IJssel, Rhine and Waal) the reproduction rate is two to three times higher than in the Biesbosch, and it is four times higher in areas with a relatively low level of pollution. (See Table 2).

Table 2 Number of young leaving the nest per clutch, in a number of cormorant colonies in 1988.

Areas with a relatively low level of pollution		Major river areas					Biesbosch
OV	BW	W	O	P	H		DB
2.2	1.7	1.3	1.7	1.2	1.3		0.5

OV Oude Venen (Friesland)

BW Brede Water (Voorne)

W Wijhe (Gelderse IJssel)

O Olst (Gelderse IJssel)

P Pannerden (Upper Rhine)

H Haaften (Waal)

DB Dordtse Biesbosch

Bio-assay experiments with polluted sediment from one of the smaller harbours in the Delta region (Breskens) revealed effects on oyster larvae (Crassostrea Angulata) and a crustacean (Bathypreia). Even when a large proportion of clean sediment was added to the polluted harbour sludge, mortality rates were demonstrably affected by pollution (Hurk, 1988).

The effects of increasing pollution in water and riverbeds are also noticeable in the Western Scheldt estuary. The population of harbour seals (Phoca vitulina) has now disappeared. Food chains in the eastern part of the estuary have been disturbed and the number of benthic organisms significantly reduced. It is acknowledged that the amounts of cadmium now exceed acceptable levels for human consumption, particularly in flounder (Platichthys flesus), in shellfish such as mussels (Mytilus edule) and in sea plants such as Aster tripolium and Salicornia spec., found in the Land of Saeftinghe area.

6 CONCLUSIONS AND FINAL REMARKS

Although water quality and the condition of the beds were not taken into consideration at the time of the original decisions concerning the phasing and implementation of the Delta Plan, it is now recognized that the separation of parts of the Delta from the waters of the Rhine and Meuse, as part of the compartmentalization programme for the region, has played a significant role in maintaining a satisfactory level of quality in the majority of the beds in the Delta. As a result, the quality of the sediment in the central section of the estuary is close to natural background levels. However, the closure of an estuary such as the Haringvliet can lead to large amounts of polluted river silt settling in new sedimentation areas. An other method of controlling the distribution of contaminated material is to limit the throughput of water if sluices for water management are available in the compartmentalization-dams. This idea has, for instance, been incorporated into the plan for managing the quantity of water of Lake Zoom.

In the sedimentation areas, there are clear signs that the ecological communities that are directly dependent on the quality of the bed have been disrupted. The long-term policy aims of the Netherlands government are to improve the quality of river beds and lake beds to such a degree that the aquatic ecosystems can function satisfactorily, guaranteeing optimum use of the water systems. Short-term policy objectives are to obtain further information about the present quality of the river beds, the causes and effects of pollution and possible means of prevention. Furthermore, uniform standards for the assessment of all types of soils and clean-up methods for the most polluted locations are being developed. In the last fifteen years almost 80 million m³ of polluted river sediment have been deposited in the lower reaches of the Rhine, Meuse and Scheldt. The south-western region of the Netherlands can therefore justly be referred to as the sedimentation pit of these rivers. It is essential that clean-up operations in the river basins be implemented quickly. However, the cleaning-up of the river beds can only really be considered when the contamination in the three rivers has been reduced to an acceptable level. As a result of consultation at international level, the Rhine riparian states have agreed measures to halve the discharge of a number of major pollutants in the Rhine basin between 1985 and 1995. If necessary, additional measures will be taken after 1995, in the event of failure to achieve the aims laid down in the agreements (such as the elimination of depositions of pollutants in sediment). The states bordering on the North Sea have arrived at similar agreements with respect to the rivers and these will have most effect on the Delta in this regard. Once the transport of polluted sediment has been halted, a decision may be taken on the cleaning up of the estuary and lake beds.

Those areas, where the sediment is of an unacceptable quality in view of the uses to which the water is put, are first in line for a clean-up operation. Other important criteria are whether or not: the polluted sediment is gradually being covered by cleaner sediment as a result of natural processes, the effect which the polluted area has upon the surrounding environment and the practicability of a clean-up operation from the technical and administrative points of view. As such operations are invariably costly, it will be necessary to give

considerable thought to drawing up the list of priorities.

Clean-up operations are probably unnecessary in areas where a cleaner top layer is being deposited as a result of continuing sedimentation, as is happening in the Hollands Diep and the Land of Saeftinghe. However, in cases where pollutants remain in the top layer and may be released and spread further afield, such measures must be considered. The degree of priority to be accorded to cleaning up the area is determined by the gravity of the effect of taking no action and by whether the source of pollution has been removed or continues to exist. The polluted harbours in the Eastern Scheldt region are to be cleaned up in the course of 1989. It is certainly worth considering cleaning up the polluted sediment in the Amer, the Nieuwe Merwede and the Biesbosch, as virtually no further deposits of cleaner sediment can be expected in these areas in future. The need is all the more pressing because it has been proven that pollution seriously detracts from the function of this area as a nature reserve.

Since similar problems with polluted river sediments are likely to accompany the building of dams in other parts of the world with industrialized catchment areas, the experience gained in the Dutch Delta Project should prove to be generally applicable.

7 SUMMARY

Extensive hydraulic engineering projects have been carried out over the last 25 years in the Delta area formed by the rivers Rhine, Meuse and Scheldt. This has resulted in parts of the Delta being divided up (compartmentalized) while other parts have been closed off. The time at which many of the operations involved in dividing up these areas were carried out coincided with a period during which the pollution in the three rivers reached its maximum level (1970-1975).

Micropollutants (heavy metals and organic compounds) became attached to the fines in the sediment carried by the rivers, and this led to the Delta region also being affected by these contaminants. However, because of compartmentalization, certain areas, namely Lake Grevelingen and the tidal basin of the Eastern Scheldt, escaped the wave of pollution. The quantities of micropollutants in these areas are very close to natural background levels. The explanation for this is that the compartmentalization of these areas was completed before the pollution in the Rhine and Meuse reached such high levels.

In contrast, the closure of the Haringvliet estuary led to the formation of new sedimentation areas just prior to the time at which the pollution in the Rhine and Meuse reached a peak. Thus layers of contaminated material have settled in these sedimentation areas. Almost 30% of the total amount of silt transported by the rivers Rhine and Meuse is deposited in these areas.

Estuaries that have not been influenced by closure operations can also undergo significant temporary sedimentation effects. An example of this is the Land of Saeftinghe in the Western Scheldt estuary. As a result of a rise in the sea level and a deepening of the shipping channel, the difference between low and higher water has increased which, in turn, had resulted in a significantly greater deposition of silt on the mudflats and salt marches. Almost 25% of the silt transported by the river Scheldt settles in these areas. Although relatively little is known about the effects that contaminated beds have on the aquatic ecosystem, there are clear signs that ecological communities which are directly dependent on the river bed environment can be disrupted. In addition, the amounts of pollutants found in certain organisms and plants now exceed the maximum acceptable levels for human consumption. Future clean-up operations could be considered for the contaminated sedimentation areas when the level of pollution from discharges into the river basins has been sufficiently reduced. In view of the scale and extent of the sedimentation layer concerned, no solutions have yet been found to this problem.

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EUTROPHICATION OF THE FRESH WATERS OF THE DELTA

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ABSTRACT

A number of stagnant and semi-stagnant water systems came into being as a result of the recently completed hydraulic engineering works in the Delta area of the Netherlands.

Eutrophication can occur in these waters as a result of the input of nutrient-rich river water. This paper describes the eutrophication situation of two water systems in the Delta area: the Hollands Diep/Haringvliet and the Volkerak-Zoom lake system.

In the Hollands Diep/Haringvliet the residence time of the water depends on the discharge of the river Rhine. In years of low discharge the residence time is relatively long and, especially in the western part of the Haringvliet, a large biomass of algae can appear as a result of eutrophication. In years of moderate or higher discharges of the river Rhine this water system behaves like a slowly flowing river with relatively short residence times and a small biomass of algae.

The Volkerak-Zoom lake system came into being in 1987 and after a period of desalinization changed from a saline tidal area into a fresh-water stagnant reservoir. The most important input of water is from the Hollands Diep and the river Dintel. Computer modelling indicates that the lake will develop into an eutrophic lake unless adequate measures

are taken. The first year after the desalinization proved more favourable than predicted (the biomass of algae was relatively small and transparency was good), but the input of nutrients needs to be limited still further in order to arrive at an enduring favourable water quality. In addition, "active biological management" should be considered, i.e. the application of biological management measures to obtain a healthy water system with clear water, an abundance of aquatic plants and a stock of predatory fishes that will keep the whitefish within bounds and hence allow sufficient zooplankton to remain to graze on the algae.

1 INTRODUCTION

Eutrophication is the enrichment of a water system with plant nutrients (also simply called nutrients), of which nitrogen and phosphate are the most important. Eutrophication is partly a natural process: erosion and leaching wash nutrients into rivers, which transport them to the lower reaches. Therefore, delta areas are naturally eutrophic, and the Dutch Delta area is a good example.

In the last 100 years humanity has greatly exacerbated the natural process of eutrophication. The installation of drains and sewers, the use of detergents and fertilizers and the increasing intensification of livestock farming have led to the amounts of nutrients in the rivers being increased many times over.

In stagnant water the enrichment with plant nutrients can lead to an increase in the growth of algae, which can result in high densities of algae. Large numbers of algae in the water results in a low transparency; when the algae die anaerobism can occur and this in turn can lead to fish mortality and a bad smell. Furthermore, toxic species of algae can occur (blue-green algae). Some species form floating mats.

Sections 2 and 3 of this paper describe the eutrophication situation of two semi-stagnant water systems in the Delta area: the Hollands Diep/Haringvliet and the Volkerak-Zoom lake system. The eutrophication state

of the latter is compared with that of Lake Brielle, which is comparable in terms of morphology and residence time. Figure 1 shows the location of these water systems.

Section 4 discusses the possible management measures with which the eutrophication problem of the Volkerak-Zoom lake system can be prevented or limited.

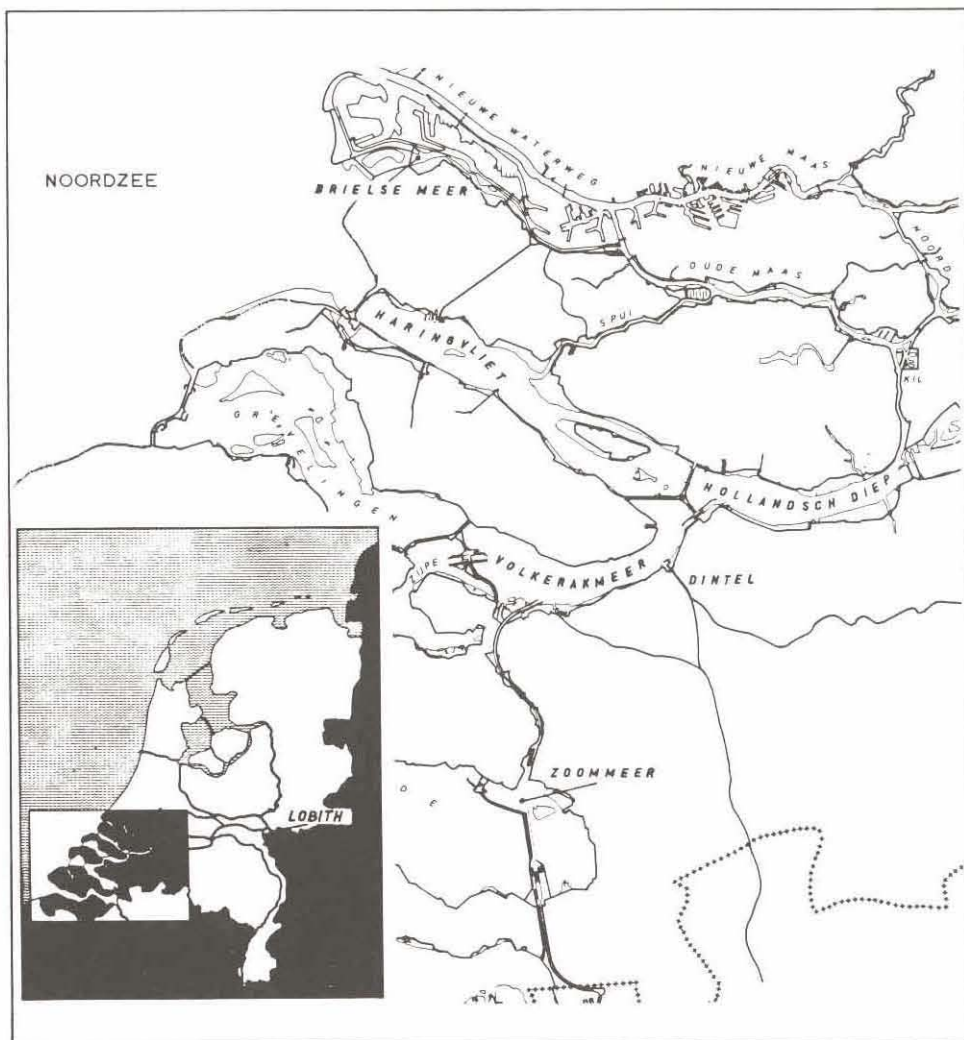


Figure 1 Location of Hollands Diep/Haringvliet and Volkerak-Zoom lake system

THE HOLLANDS DIEP/HARINGVLIET

The Hollands Diep/Haringvliet is part of the northern Delta basins, also called the lower area of the great rivers. This is the area where two large Western European rivers, the Rhine and the Meuse, discharge into the sea. The river water enters the area from the east along three river channels and can, in principle, reach the sea via two routes. When the Rhine discharge is less than $1700 \text{ m}^3/\text{s}$ the Haringvliet sluices in the west remain closed and all the river water enters the sea via the New Waterway. At Rhine discharges above $1700 \text{ m}^3/\text{s}$ the Haringvliet sluices are also used to discharge the river water. These sluices are, however, only opened at low tide. This management of the Haringvliet sluices obviously has repercussions on the water movement in the Hollands Diep/Haringvliet and hence also on the eutrophication situation.

The eutrophication situation of the basins can be characterized as follows. Large amounts of nitrogen and phosphate are brought in by the rivers, thus the concentrations of nutrients are high. However, it is striking that in these waters a low biomass of algae is usually found. Also, the biomass of algae usually decreases from east to west; as a rule, the fewest algae are found near the Haringvliet sluices. Generally, few blue-green algae occur in these waters and the transparency is reasonable on the whole; near the Haringvliet sluices a transparency of 1 to 1.5 m is regularly found.

The relatively low biomasses of algae are often attributed to the influence of toxic substances. It will be shown below that the water movement provides a plausible explanation. Figure 2 shows the changes in mean summer level of chlorophyl along the traject from Lobith to the Haringvliet sluices for the year 1982. Chlorophyl is an indicator of the amount of algae in the water.

From Figure 2 it can be seen that there is a clear decrease in the biomass of algae along the traject. However, the picture changes if we look at figures from other years. Figure 3 shows the mean summer levels of chlorophyl between Lobith and the Haringvliet sluices in 1976, 1982 and 1987.

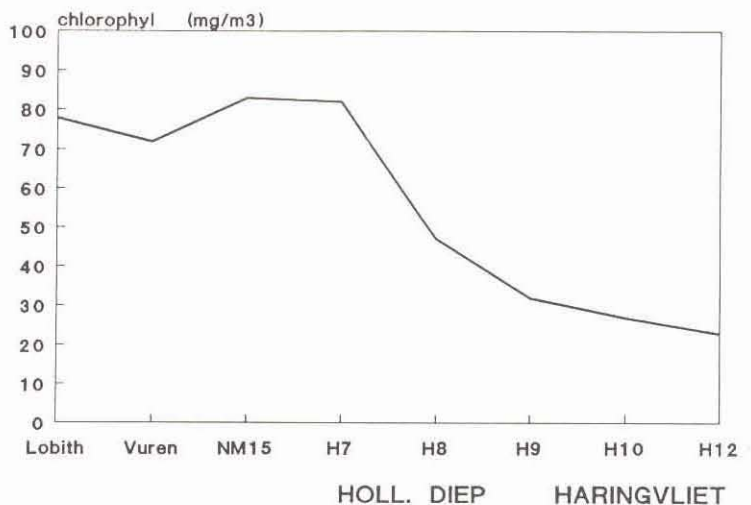


Figure 2 Mean summer level of chlorophyll in 1982 along the Lobith-Haringvliet sluices traject

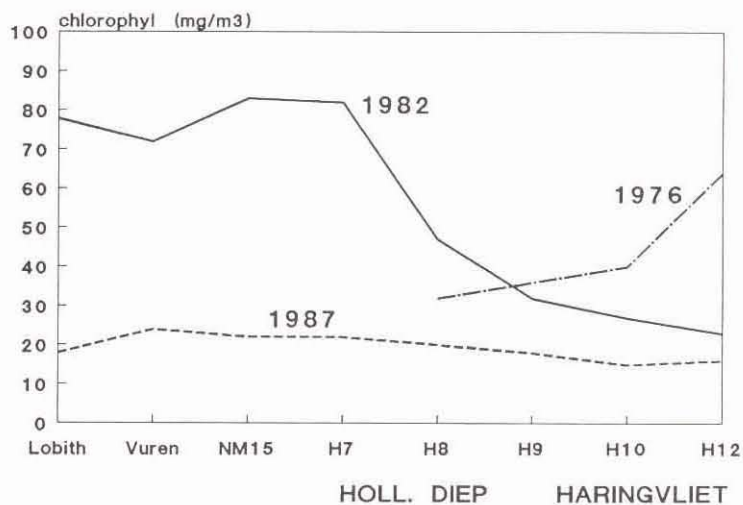


Figure 3 Mean summer chlorophyll levels in 1976, 1982 and 1987 along the Lobith-Haringvliet sluices traject

In 1976 the determination of chlorophyl levels was still in its infancy, but the few data available indicate that in that exceptionally dry year there was an increase in the biomass of algae towards the Haringvliet sluices. The picture was very different in 1987: in that year there was very little difference in the amounts of algae along the entire trajet from Lobith to the Haringvliet sluices.

This disparity can be explained by studying the river discharges of the various years.

In 1976 the mean summer Rhine discharge was well below 1700 m³/s; in that year the Haringvliet sluices were scarcely used the whole summer. In 1982 the mean summer Rhine discharge was approximately 2200 m³/s; therefore in that year the sluices were regularly in use. In the summer of 1987 the Rhine discharge was well above the mean discharge, and therefore the sluices were used almost daily to discharge the river water into the sea (Table 1).

Table 1 Mean summer chlorophyl level and Rhine discharge in 1976, 1982 and 1987.

	chlorophyl (mg/m ³)	Rhine discharge (m ³ /s)
1976	64	1114
1982	23	2221
1987	16	2994

Computer simulations done at Delft Hydraulics have also shown that the behaviour of algae in these waters greatly depends on the water movement in this area. The eutrophication in 1976 and 1982 was simulated with the DELWAQ-BLOOM model. As input the model requires data on the water movement in the various river channels, the concentrations of nutrients and algae in the incoming river water, climatological factors and properties of algae. As output the model supplies the algal biomass for each location in the area and for each day of the year.

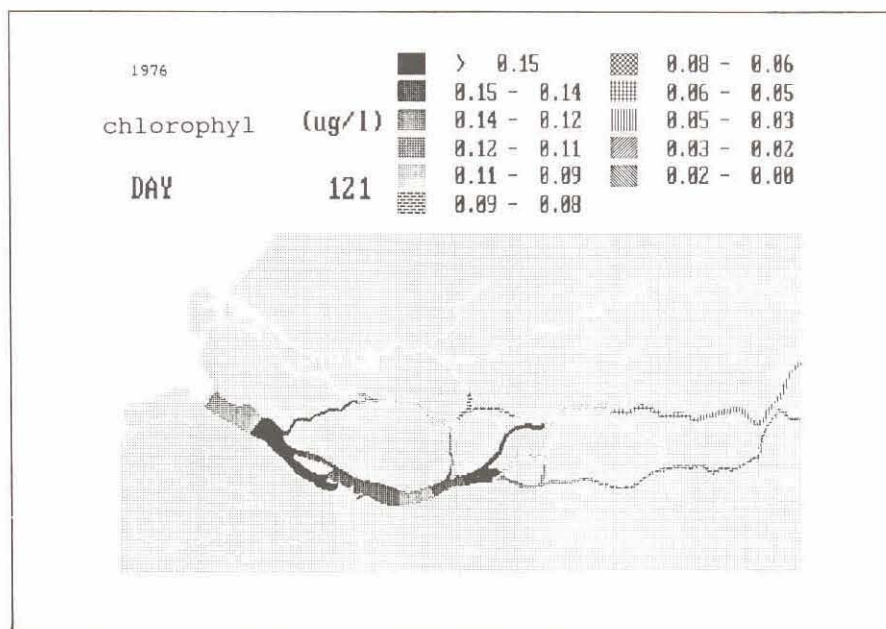


Figure 4 Simulation produced by DELWAQ-BLOOM model for day 121, 1976.

Figure 4 shows the result produced by the model for day 121 (the end of April) in 1976. It indicates that there are appreciably fewer algae in the Hollandse Diep at the Volkerak sluices than in the river channels upstream, and that very high levels of chlorophyll occur near the Haringvliet sluices.

The picture is different for 1982 (see Fig. 5). In the Hollandse Diep the chlorophyll levels are lower than in the river channels, but towards the Haringvliet sluices they decrease even further. This is fully in agreement with the picture of measured chlorophyll levels in that year.

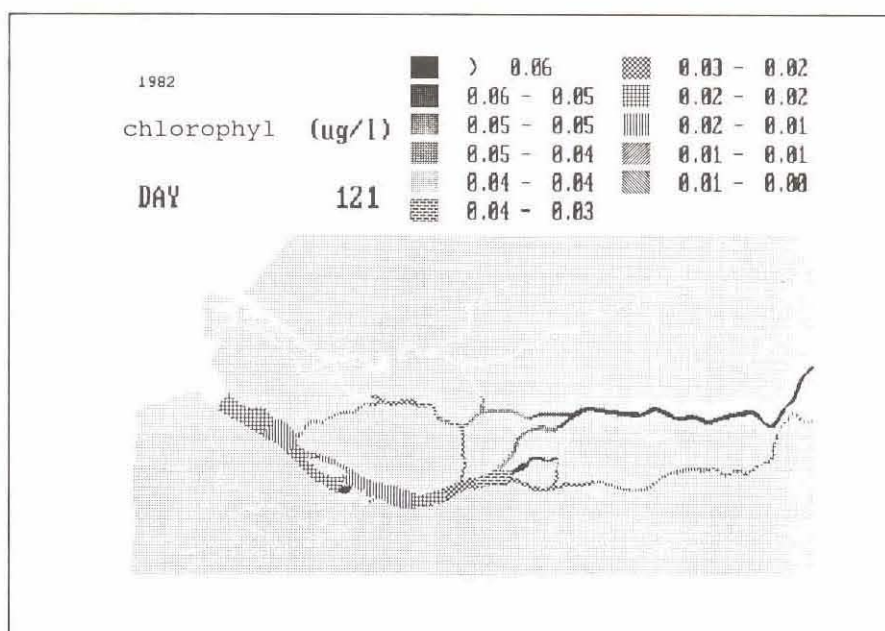


Figure 5 Simulation produced by DELWAQ-BLOOM model for day 121, 1982

Table 2 Summarized results of research on eutrophication in Hollands Diep/Haringvliet

	1976	1982	1987
residence time	long approx. 60 days	short approx. 6 days	v. short 1 - 2 days
system	lake	transition lake-river	river
behaviour of algae			
Hollands Diep	settling out	settling out	transported
Haringvliet	growing	settling out	transported

Table 2 summarizes the most important results of the research on eutrophication in the Hollands Diep/Haringvliet. From this table it can be seen that in 1976 the residence time in the Hollands Diep/Haringvliet was long; 60 days on average. The system behaved like a lake. The algae in the Hollands Diep settled out, but in the Haringvliet they were able to grow well.

The residence time was much shorter in 1982: approximately 6 days on average. The system behaved like a transition between a river and a lake system. Algae settled out both in the Hollands Diep and in the Haringvliet.

In 1987 the residence time was very short; the system behaved like a slow-flowing river. The algae transported with the water were carried along towards the sea.

The water movement thus offers a very acceptable explanation for the behaviour of algae in this system. Hence, other reasons, such as toxological effects, seem less probable.

3 THE VOLKERAK-ZOOM LAKE SYSTEM

The Volkerak-Zoom lake system came into being in April 1987 after the closure of the Philips dam. From a saltwater tidal area this area has gradually changed, first into a brackish lake. During 1987 the desalinization was accelerated by allowing an extra intake of fresh water via the Volkerak sluices. The Dintel, a small river that drains much of West Brabant and a small part of Belgium, is another important source of fresh water for this lake.

Before the lake was created predictions were made about the eutrophication that could be expected. Table 3 gives an impression of this and also shows the eutrophication observed in 1987 and 1988.

Table 3 Eutrophication of the Volkerak-Zoom lake system and Lake Brielle

	Lake Brielle	Volkerak-Zoom lake system		
		predicted	1987	1988
chlorophyl (mg/m ³)	20-70	60-100	60	20
total P (mg/l)	0.2-0.4	0.2-0.35	0.28	0.17
transparency (m)	approx. 1	approx. 1	1	2.2

The general tendency of the forecasts was that the Volkerak-Zoom lake system, with a residence time of 2-3 months, would develop into a eutrophic water body with a chlorophyl level of 60-100 mg/m³, a total P-level of 0.20-0.35 mg/l and a transparency not exceeding 1 m. It is not possible to compare the actual situation in 1987 with the predictions, because in that year there was a sharp fall in the chloride level during the growth season and hence there was no equilibrium situation. However, the values measured in 1987 fall within the range of forecast values.

The situation in 1988 was clearly different. That was the first year in which the lake was largely fresh water: the measured values were far more favourable than predicted. The mean summer chlorophyl level was approximately 20 mg/m³, the total P-level was 0.17 mg/l and the mean transparency was 2.2 m.

For comparison, the values measured in Lake Brielle have been included in Table 3. This lake is reasonably comparable with the Volkerak-Zoom lake system in terms of morphology and residence time. The mean chlorophyl levels in Lake Brielle are relatively low, but the

occurrence of floating mats of blue-green algae often causes a nuisance in this lake. The mean transparency does not exceed 1 m.

Figure 6 shows the changes in the chlorophyll level in both parts of the lake system in 1988.

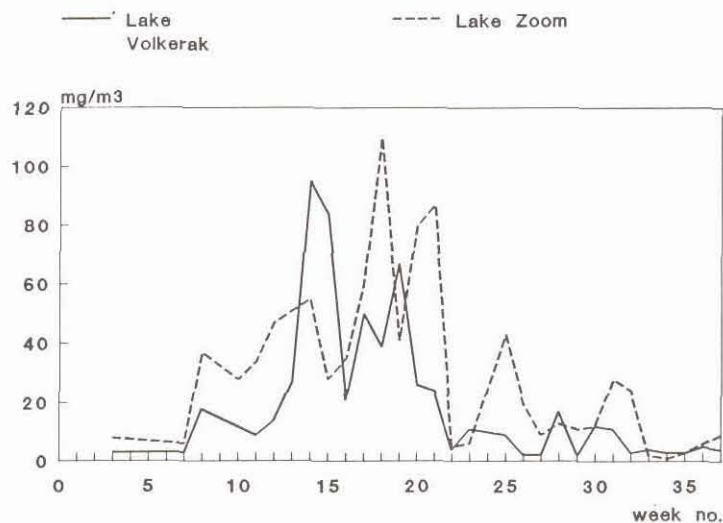


Figure 6 Chlorophyll level in Lake Volkerak and Lake Zoom in 1988

From this Figure it can be seen that peaks of up to 100 mg/m^3 occur in the spring. There is an abrupt downturn at the end of May/beginning of June, and in the rest of the summer the chlorophyll levels remain very low - especially in Lake Volkerak.

The next two figures (Fig. 7 and 8) show the changes in the total P-level and the transparency.

There was a clear decrease in the level of total phosphorus in the spring. In the period of the sharp decline in the chlorophyll level towards the end of May there is a clear increase in transparency, first in Lake Volkerak and later in Lake Zoom too. In both lakes a transparency of almost 4 m was measured in August - a unique situation for fresh water in the Netherlands.

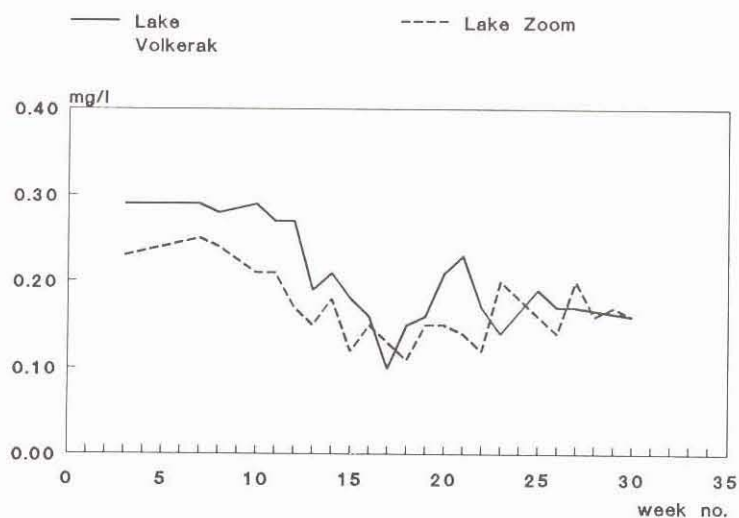


Figure 7 Total P-level in 1988

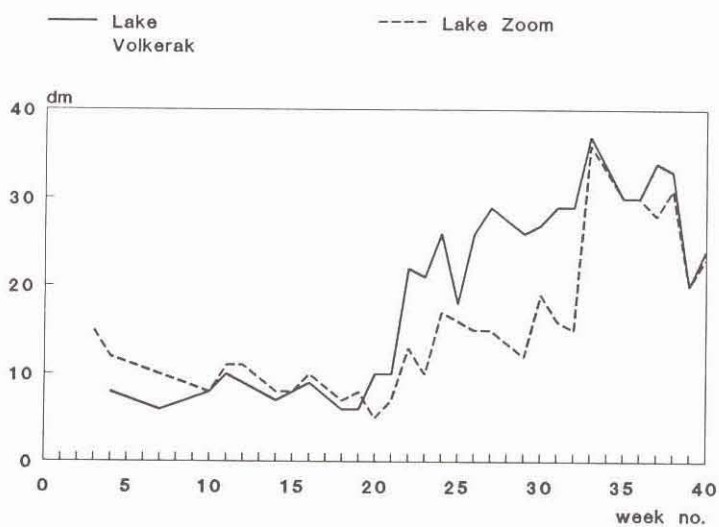


Figure 8 Transparency in 1988

Figure 9 shows the numbers of Cladocera (an order of zooplankton which includes the water fleas) in Lake Volkerak and Lake Zoom in 1988.

The unusual transparency can be attributed to the intensive consumption of algae by zooplankton.

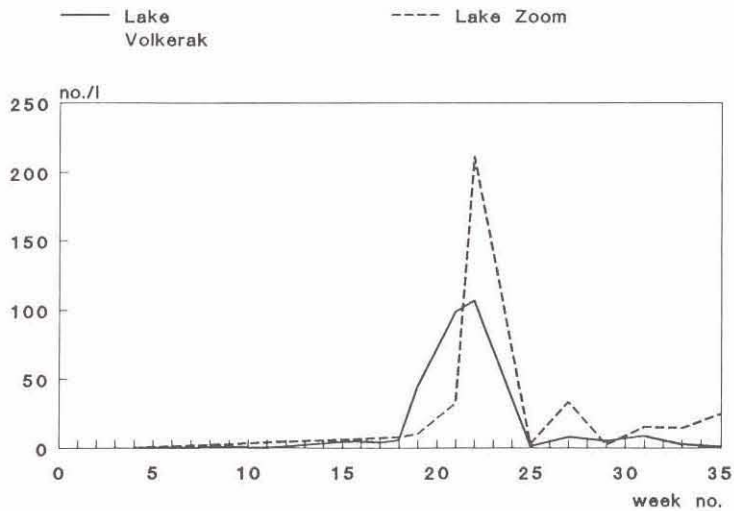


Figure 9 Numbers of Cladocera in Lake Volkerak and Lake Zoom in 1988

The fact that this group of zooplankton peaks in May/June indicates that the clear decline in the biomass of algae may be caused by intensive grazing by the zooplankton. Although not shown in Figure 9, during the rest of the summer it was striking that a relatively high number of large water fleas were present. Just these water fleas can create an effective grazing pressure on algae.

In turn, the large numbers of water fleas can be explained by the still limited numbers of plankton-eating fish.

Floating mats of blue-green algae occurred very locally on Lake Volkerak and Lake Zoom in autumn 1988.

4 MANAGEMENT MEASURES TO PREVENT OR LIMIT THE EUTROPHICATION OF THE VOLKERAK-ZOOM LAKE SYSTEM

A large number of goals have been formulated for the management of the Volkerak-Zoom lake system. They include the prevention or reduction of eutrophication. Two types of management measures could be used to achieve this goal:

- reducing the nutrient load;
- active biological management.

It must be stressed that these are not alternatives. Active biological management complements the reduction of nutrient load.

4.1 Dealing with nutrients

When reducing the nutrient load the accent will lie on phosphate, because in the fresh waters in the Netherlands this is the natural limiting factor to the growth of algae. For lakes like Lake Brielle and the Volkerak-Zoom lake system the phosphate is only limiting for algal growth if the phosphate load is below 2-4 g/m² per year.

From Table 4 it can be seen that the phosphate load of Lake Brielle has been drastically reduced since 1972. However, this has not yet led to a reduction of the eutrophication problem. The fact that the bed of this lake has meanwhile been accumulating phosphates that, in principle, could again cause an internal load, is unquestionably important here. In this lake, large-scale occurrences of drifting mats can be limited to some extent by interim extra flushing in the summer period.

In the Volkerak-Zoom lake system the phosphate load has turned out lower than the forecast, but in 1988 it was still far too high to be limiting for the growth of algae. The option of extra flushing to combat drifting mats is not considered here, because it conflicts with another goal of water management, i.e. trying to prevent the water system from being loaded with toxic substances from the Hollands Diep.

Furthermore, it is questionable whether such flushing would be effective, given the shape and size of the lake system.

Table 4 Phosphate load in Lake Brielle and the Volkerak-Zoom lake system

	g/m ² .year
Lake Brielle	
1972-1976	16.5
1980-1982	9.5
1983	5.6
1987-1988	approx. 5
Volkerak-Zoom lake system	
predicted	16-20
1987	14
1988	7.5
guide value	
P-limitation	2-4

Table 5 Phosphate load in the Volkerak-Zoom lake system in 1987 and 1988

	1987		1988	
	m ³ /s	ton P	m ³ /s	ton P
Volkerak sluices	28	250	16	140
Brabant rivers	15	460	12	240
Other	5	60	5	60
Total	48	770	33	440

Table 5 gives estimates of the phosphate load originating from the most important sources in 1987 and 1988.

The difference between the two years for the Volkerak sluices is caused by the extra amount of water needed to desalinize the lake in 1987. Much less phosphate was brought in by the Brabant rivers in 1988 because in May 1988 the effluent from the sewage treatment plant at Breda, Nieuwveer, was diverted from the Dintel to the Hollands Diep. When, in the future, water is extracted from the lake for agriculture, the phosphate load will be higher because more water will have to be admitted via the Volkerak sluices.

The phosphate load in the Volkerak-Zoom lake system could be reduced by:

- diverting water from the Nieuwveer sewage treatment plant from the Dintel to the Hollands Diep (this was done in May 1988);
- the Rhine Action Plan (RAP);
- the North Sea Action Plan (NAP);
- optimizing the intake from:
 - * water losses from locks;
 - * agriculture;
- treating intake water;
- reducing agricultural emissions;
- reaching agreement with Belgium on the reduction of the load in the Belgian part of the Dintel catchment;
- drastic dephosphatization in sewage treatment plants.

It is expected that the implementation of the Rhine Action Plan and the North Sea Action Plan will result in a halving of the phosphate load in the Volkerak-Zoom lake system too. However, this will not happen before 1995.

If the above-mentioned measures are implemented vigorously, it seems possible that phosphate limitation for algal growth could be achieved in the medium term; in the short term this is not expected.

4.2 Active biological management

If it is considered desirable to have clear water in the next ten years too, then "active biological management" could be employed.

Furthermore, experience elsewhere (e.g. in the Veluwe lakes) and computer modelling indicate that it is difficult for a lake that is already in "turbid equilibrium" to be made clear again.

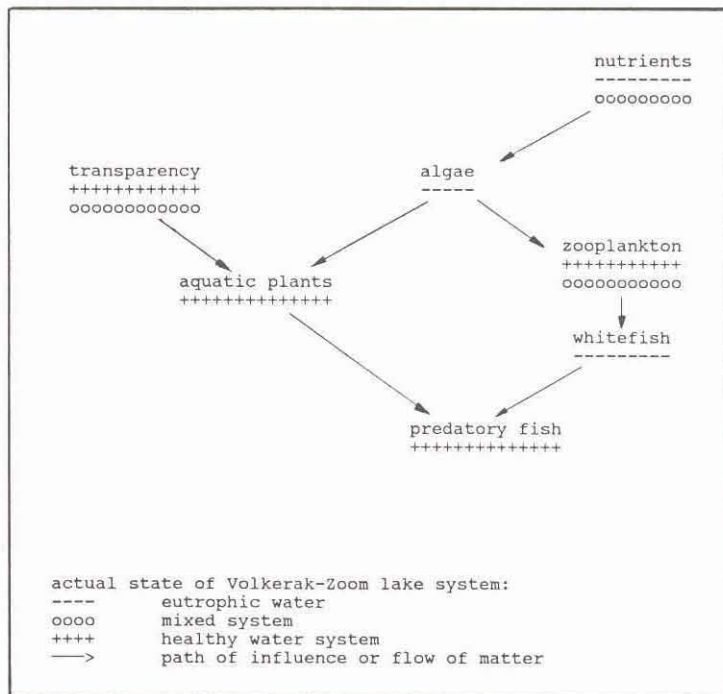


Figure 10 Schematic representation of ecosystem relationships in a eutrophic water body

Figure 10 shows the most important relationships between the various components of a lake ecosystem. Nutrients enhance the growth of algae; algae are eaten by zooplankton; zooplankton are eaten by whitefish; whitefish are eaten by predatory fish; predatory fish, particularly pike, require aquatic plants for shelter and for breeding, and the occurrence of aquatic plants depends on the transparency of the water and thus also on the absence of algae.

In principle, two states of equilibrium are possible in such a system. One is an eutrophic, relatively turbid system dominated by many nutrients, many algae and many whitefish; this is indicated by ---- in Figure 10. The other possibility is a healthy functioning system with transparent water, many aquatic plants, a predatory fish population that keeps the whitefish population in check, and sufficient zooplankton to be able to graze the algae effectively. In Figure 10 this is indicated by ++++.

In 1988, contrary to all predictions, the Volkerak-Zoom lake system contained elements from both possible equilibrium situations - many nutrients, transparent water and many zooplankton: this is indicated by oooo in Figure 10.

In 1988 aquatic plants started to develop, but not sufficiently to offer shelter and a breeding environment for predatory fish. The few data available on stocks of fish suggest that the bream, a whitefish that often causes problems in other eutrophic waters, is not present here in large numbers. Predatory fish, especially pike-perch, are present in the system.

The most obvious way of actively intervening in the biology of the system is to stimulate the development of aquatic plants as much as possible. Few propagules of freshwater aquatic plants will be present in the system, and therefore it is advisable to introduce material from the desired species into the system on a large scale. It is also important to ensure the presence of sheltered shallows, because in principle here it is that aquatic plants can develop the best on a large scale.

Proper management of fish stocks requires agreement between the water authority and the persons with fishing rights. Quantitative monitoring is necessary to be able to properly anticipate developments towards an excess of bream.



Floating mats of blue-green algae (*Microcystis aeruginosa*)



Benedensas, before the enclosure of Lake Zoom



Zooplankton (*Alona affinis*)



Pike (*Esox lucius*) in its natural habitat

Breeding areas for pike can be provided by the large-scale installation of defences in front of the banks and by making creeks suitable.

If monitoring shows that the numbers of bream threaten to become excessive, then predatory fish could be introduced, or whitefish could be netted and removed.

Stimulating the growth of freshwater mussels is a third type of measure appropriate to active biological management. These mussels are not shown in Figure 10, but they fulfil more or less the same role as the zooplankton: they filter suspended matter from the water and thereby also contribute to the grazing pressure on the algae. Mussels require a hard substrate. This could be provided by dumping large amounts of shells in suitable places.

5 CONCLUSIONS

In general, the damming off and compartmentalization of the Delta waters leads to stagnant or semi-stagnant waters whose very location makes them susceptible to eutrophication problems.

In the Hollands Diep/Haringvliet eutrophication problems can be kept within limits by focusing management on preventing long residence times in the summer. The critical level seems to be around three weeks.

In the Volkerak-Zoom lake system the starting point is favourable: the water is transparent. At present the phosphate level is too high to limit eutrophication, but active biological management offers good prospects for keeping the water transparent. The phosphate load needs to be reduced further. It is likely that in the next few years blue-green algae will occur regularly in the autumn. It will probably be possible to tackle the symptoms of this in areas that suffer greatly from the problem.

EUTROPHICATION OF ESTUARIES AND BRACKISH LAGOONS IN THE SOUTH-WEST NETHERLANDS

P.H. Nienhuis

ABSTRACT

Eutrophication of the saline waters in the South-West Netherlands is mainly not caused by water from the rivers Rhine and Meuse, contrary to the nutrient enrichment of freshwater bodies (Nieuwe Waterweg, Hollands Diep, Haringvliet) and the western Wadden Sea. Eutrophication of the Westerschelde, Oosterschelde, Grevelingenmeer and Veerse Meer is connected to the specific hydrography and geomorphology of these isolated waters; except for the Westerschelde, nutrient loading mainly occurs through agricultural run-off and drainage channels. The Westerschelde, a heavily eutrophicated estuary, has only an insignificant impact on Dutch coastal waters, owing to the very limited discharge (4% of Rhine discharge) and long residence time of the watermass. The resilience of saline waters for eutrophication by nitrogen is presumably connected to the process of denitrification, removing N to the atmosphere, and the filter feeding activities of bivalves, depositing N on the bottom sediment, and enhancing the regeneration of nutrients. Low N-load may be compensated by denitrification. The vulnerability of stagnant, saline waters with a long residence time is expressed by the fact that a load of approximately $10 \text{ g N m}^{-2} \text{ y}^{-1}$ or more presumably exceeds the resilience capacity of the ecosystem. The contrast between the Grevelingenmeer (load $4 \text{ g N m}^{-2} \text{ y}^{-1}$) and the Veerse Meer (load $34 \text{ g N m}^{-2} \text{ y}^{-1}$) is significant: next to highly productive phytoplankton, macro-algae play a dominant and unpredictable role in the carbon budget of the Veerse Meer lagoon.

INTRODUCTION

Eutrophication of marine coastal waters and estuaries is increasingly regarded as a nuisance for the near future (Rosenberg, 1985). Eutrophication is defined here as the process of increasing concentration and load of inorganic nutrients, inducing changes in the aquatic communities. In general terms the large European rivers provide the main stimulus for nutrient enrichments in coastal waters. The main rivers loading the surface waters of the South-West Netherlands are Rhine, Meuse and Scheldt (Fig. 1).

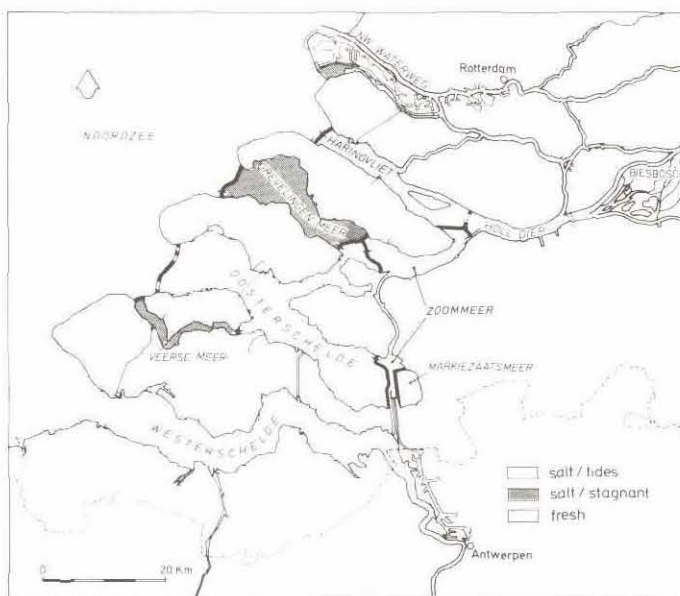


Figure 1 The South-West Netherlands with the estuaries Oosterschelde and Westerschelde and the brackish lagoons Grevelingenmeer and Veerse Meer. The Biesbosch, Hollands Diep, Haringvliet and Nieuwe Waterweg form the lower reaches of the Rhine and Meuse. The Westerschelde estuary is connected to the river Scheldt. The Delta Works started in 1960 and were finished in 1987. The Volkerakdam was closed in 1969 between Hollands Diep-Haringvliet and Zoommeer, and blocked the main southern exit of Rhine water.

The average discharge of Rhine and Meuse together is $2578 \text{ m}^3 \text{ s}^{-1}$ (De Ruyter, et al, 1987) and the nitrogen (ammonium and nitrate) load of these rivers has increased over the period 1950–1980 with a factor 2–4, whereas the phosphorus load has increased with a factor 5–7 (Van der Veer, et al, 1988). Contrary to the nitrogen load, the phosphorus load decreased slowly after 1980. The concentrations of plant nutrients increased even more markedly than the load: a fivefold increase for N and a tenfold increase for P, with recently a slight decrease (Fig. 2). The increased concentrations of nutrients in the Rhine-Meuse resulted in a 3- to 5-fold raise of N- and P-concentrations in the Dutch coastal waters. The increase of nutrient concentrations and -loads in the Westerschelde estuary showed the same dramatic trend over the past 30 to 40 years (Van Buuren, 1988).

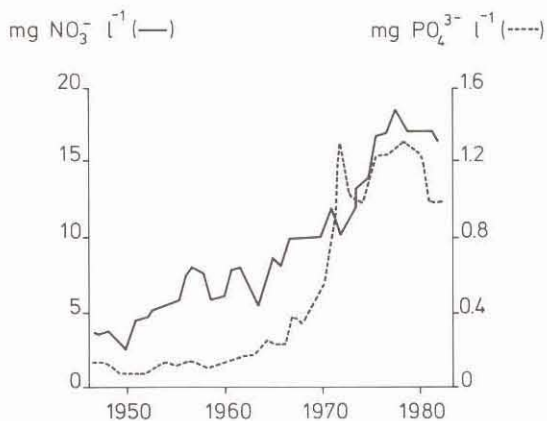


Figure 2 Nitrate- and orthophosphate concentrations of Rhinewater near the Dutch-German border, during the period 1946–1982 (RIWA Annual Report 1982, in Slooff, 1983).

Approximately 15% of the Rhine run-off flows into northerly directions, via IJssel and IJsselmeer, and finally enters the western Wadden Sea, causing considerable eutrophication to that estuarine area (Van der Veer, et al, 1988). More than 50% of the Rhinewater runs via the Nieuwe Waterweg (Fig. 1) directly into the North Sea. About 30% flows into the

Haringvliet and finally also enters the North Sea, depending on the management regime of the Haringvlietsluices (Fig. 1). Owing to the residual currents along the Dutch coast the Rhine water is mainly transported in a 50 to 70 kilometers wide zone into northerly directions (Fig. 3). The average nutrient loadings of the Dutch coastal

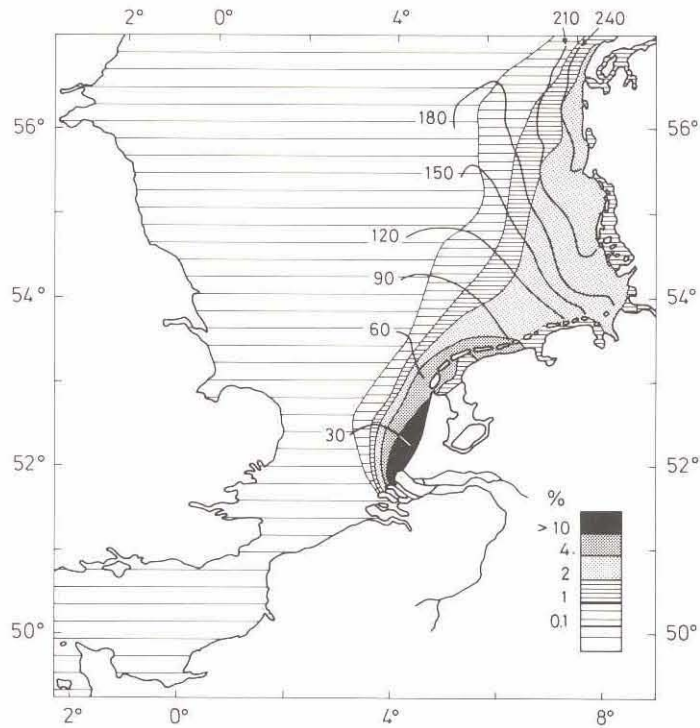


Figure 3 Flow of Rhine-Meuse water along the coasts of the Netherlands, Germany and Denmark; SW wind 4.5 m s^{-1} , water mass fractions in %, age distribution indicated as solid lines in days (derived from De Ruyter, et al, 1987). At NW winds a maximum fraction of 10% of Rhine-Meuse water enters the Oosterschelde estuary.

waters reflect the discharges of marine and riverine water: the Rhine and Meuse (including the Noordzeekanaal) contribute roughly 60% of the total N- and P-load, the residual current of Channel water adds 30%

and only 1-2% comes from the River Scheldt (Fig. 4). The Scheldt has an average discharge of only $112 \text{ m}^3 \text{ s}^{-1}$ (De Ruyter, et al, 1987) which is only 4% of the Rhine-Meuse discharge.

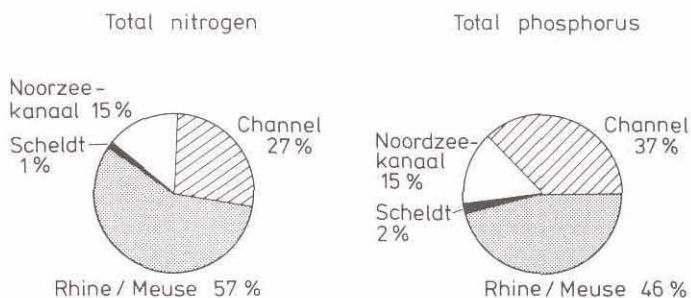


Figure 4 The shares of Rhine-Meuse load, Channel load and Scheldt load in the total concentration of N and P Dutch coastal waters (Van Buuren, 1988).

Only a very small percentage of the original Rhine-Meuse water reaches directly (or indirectly via the North Sea) the estuaries and brackish lagoons in the South-West Netherlands. Especially the construction of the Volkerakdam in 1969 (Fig. 1) deprived the saline waters of the direct influx of fresh river-water. The Oosterschelde, Grevelingenmeer and Veerse Meer are mainly loaded with nutrients from diffuse sources such as agricultural run-off, treated waste water and drainage canals. The saline water bodies in the South-West Netherlands have been separated spatially (compartmentalization) owing to the Delta Works. Consequently each of these waters has its own eutrophication history and its own specific characteristics, excluding an integrated approach to manage the nutrient loadings of these systems.

2 NUTRIENT CONCENTRATIONS AND LOADINGS

Table 1 summarizes a number of system parameters. The residence times of the water masses in the stagnant, non tidal Grevelingenmeer and Veerse Meer are long, compared to the same characteristic in the tidal

estuaries. The net freshwater load directly from the rivers Rhine and Meuse is extremely small (1% of the discharge). The Veerse Meer lagoon experiences almost permanent stratification, whereas the Grevelingenmeer has only a few deep channels, stratified during summer. The Westerschelde and Oosterschelde estuaries are completely mixed tidal systems.

Table 1 System parameters of the saline waters in the South-West Netherlands, derived from Wollast, 1988, and Bokhorst, 1988, for the Westerschelde; Projectgroep Balans, 1988, and Wetsteyn and Peperzak, 1988, for the Oosterschelde; Nienhuis, 1985, and De Vries, et al, 1988, for the Grevelingen; Daemen, 1985, and Stronkhorst, et al, 1985, for the Veerse Meer. Load = direct water load from Rhine-Meuse.

	Westerschelde	Oosterschelde	Grevelingen	Veerse Meer
residence time (d)	30-90	5-40	180-360	± 180
load (m^3s^{-1})	-	50-20	5	-
tides	+	+	-	-
stratification	-	-	±	+
extinctioncoef. (m^{-1})	0.5-7	0.4-1.5	0.2-0.5	0.3-1.4

The Westerschelde is extremely turbid (extinction coefficient 0.5-7) and the Grevelingenmeer contains very clear water (extinction coefficient 0.2- 0.5), with the Oosterschelde and Veerse Meer in between.

The range in nutrient concentrations in the saline Delta waters differs greatly (Fig. 5). The Oosterschelde and Grevelingen reach only seldom values above 1 mg l^{-1} for N, P and Si; nutrient values frequently approach zero concentrations during heavy blooms of phytoplankton. The Veerse Meer has higher maximum values for N and Si, but depletion occurs during the growing season. The Westerschelde has far out the

highest trophic potential: nutrient concentration values never approach zero during spring and summer and reach high levels during winter ($8 \text{ mg l}^{-1} \text{ N}$; $4 \text{ mg l}^{-1} \text{ P}$ and $9 \text{ mg l}^{-1} \text{ Si}$). Compared to the nutrient concentrations in the river Rhine (Fig. 2), P-concentrations are two times lower and N-concentrations are ten times lower in the saline water bodies (Fig. 5), except for the Westerschelde.

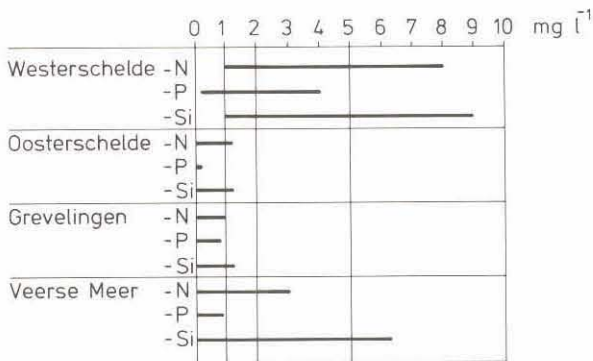


Figure 5 Range in nutrient concentrations in estuaries and brackish lagoons in the South-West Netherlands.

See legend Table 1 for sources.

The question arises which factor acts as the limiting constituent for the productivity of algae in the saline Delta Waters. In the turbid Westerschelde it seems obvious that the availability of light is limiting phytoplankton dynamics. In brackish coastal waters phosphate may be a potentially limiting factor (Veldhuis, 1987). It is generally assumed that nitrogen is the limiting factor for phytoplankton development in the Oosterschelde and Grevelingen and occasionally also in the Veerse Meer. Knowledge about phytoplankton and macrophyte kinetics in the South-West Netherlands, however, is scanty. Especially in polluted estuaries like the Westerschelde other factors than nutrients and light availability may be responsible for the limitation of algal photosynthesis. It is now becoming increasingly obvious that antagonistic effects between metals on phytoplankton exist, whereby an organism may tolerate high concentrations of a given metal in the

presence of sufficient quantities of another metal but not in the absence or at low concentrations of the second metal (Raven and Richardson, 1986).

Table 2 Nitrogen and chlorophyll in Dutch coastal waters, estuaries and brackish lagoons (data derived from De Vries et al, 1988, and Smoes - Oosterschelde model calculations; H. Scholten, personal communication).

	load	winter conc.	chlorophyll conc.
	$(\text{g N m}^{-2} \text{y}^{-1})$	$\text{NO}_3 + \text{NH}_4$ (mg l^{-1})	summer (mg Chl m^{-3})
North Sea (coast.)	40	0.5	15
Wadden Sea	50	1.2	30
Westerschelde	235	4.6	30
Oosterschelde	5	1.0	5
Grevelingenmeer	4	0.7	5
Veerse Meer	34	3.0	100

Table 2 shows a large variation in total nitrogen loads ($4 - 235 \text{ g N m}^{-2} \text{y}^{-1}$) in Dutch coastal waters, estuaries and brackish lagoons, whereas N-concentrations only show a range of $0.5 - 4.6 \text{ mg l}^{-1}$. Obviously, a nitrogen load of $40 - 200 \text{ g N m}^{-2} \text{y}^{-1}$ does not give rise to extremely high chlorophyll concentrations during summer, neither in North Sea coastal water, nor in the Wadden Sea and the Westerschelde estuary. It is assumed that light availability is the limiting factor in these turbid coastal and estuarine waters, and not nitrogen, explaining the relatively low phytoplankton (chlorophyll) biomass in summer. Contrary, in the clear water of the Veerse Meer lagoon a N-load of $34 \text{ g m}^{-2} \text{y}^{-1}$ results in high chlorophyll concentrations ($100 \text{ mg Chl m}^{-3}$ or even higher; Table 2). This large production of phytoplankton biomass in the Veerse Meer lagoon, and consequent deposition of particulate organic carbon on the bottom sediments, resulted during the

period 1980-1983 in an increase of the anaerobic sediment surface area of 4 to 25% of the entire bottom surface (Stronkhorst, et al, 1985). Obviously, the Veerse Meer is vulnerable to eutrophication, owing to the long residence time of water masses, the low extinction coefficient and the almost permanent stratification.

The Oosterschelde estuary has a very low N-load resulting in low chlorophyl concentrations (Table 2). Owing to the execution of the Deltaplan (Fig. 1) the Oosterschelde estuary has mainly been deprived recently from its Rhinewater loading (Table 1). Model calculations revealed that a reduction of 50% of the nitrogen load of the river Rhine would only lead to a reduction of less than 6% for nitrogen concentrations in the Oosterschelde estuary (Smoes-model; H. Scholten, personal communication). The Oosterschelde estuary is mainly influenced by marine coastal water, containing low concentrations of total nitrogen (less than 0.5 mg N l^{-1} ; Brockmann, et al, 1988).

Contrary to the Veerse Meer lagoon, the Grevelingen lagoon has an extremely low N-load ($4 \text{ g N m}^{-2} \text{ y}^{-1}$; Table 2). The GREWAQ-model (De Vries, et al, 1988) revealed that the production of phytoplankton in the Grevelingen is limited by nitrogen availability and not by light availability. The N : P ratio of the dissolved nutrients in the watercolumn of the Grevelingenmeer during winter is 2-4, pointing into the direction of a large surplus of phosphate, notwithstanding the dominance of nitrogen in the discharge water, loading the lagoon (N : P = 22 : 1). Model calculations showed a high turnover of nitrogen in the watercolumn. The chain of processes: nutrient uptake by phytoplankton - formation of organic matter in algal cells - mineralization of dead algae - regeneration of nutrients etc., occurs 8 times a year. About 90% of the annual primary production of phytoplankton occurs on the basis of regenerated nutrients, especially NH_4 (De Vries, et al, 1988).

In the GREWAQ-model calculations (De Vries, et al, 1988) it is hypothesized that in the Grevelingen lagoon the process of eutrophication is prevented by the rate of the denitrification process. Denitrification is undoubtedly a significant process in marine and estuarine ecosystems. Rates of gaseous losses of nitrogen in the range of $5-70 \text{ mg N m}^{-2} \text{ d}^{-1}$ were determined in Belgian, Dutch and Danish coastal sediments, representing 8-23% of the amount of nitrogen mineralization in the benthic subsystem (Billen and Lancelot, 1987). Notwithstanding the fact that no actual measurements exist on denitrification rates in the Grevelingenmeer, it is assumed in the GREWAQ-model that denitrification compensates the load of nitrogen, especially in the benthic boundary layer in the sediment, where aerobic and anaerobic 'patches' of sediment join each other.

In many shallow estuarine waters the main food chain is dominated by phytoplankton and benthic filterfeeders (mussels, cockles), just as is the case in the Grevelingenmeer, Oosterschelde and Wadden Sea. The turnover rate of nutrients in these ecosystems is determined by the filtering capacity of benthic filterfeeders. Theoretically, every 5 to 10 days the entire volume of water of the estuaries circulates through the filtering apparatus of suspension feeders. Filterfeeders act as natural controllers of the eutrophication process (Officer, et al, 1982): they deposit organic material from the watercolumn onto the bottom sediments. Moreover, they accelerate the regeneration of nutrients from the deposited particulate organic carbon, thereby enhancing the primary production of phytoplankton, as was assumed for the Grevelingenmeer (De Vries, et al, 1988).

The chain of processes - partly measured, partly theoretical - from biodeposition to regeneration of nutrients and the coupling between nitrification and denitrification is limited by the load of organic material to the sediment. When the increasing load of organic material runs faster than the process of heterotrophic mineralization, anaerobic conditions will prevail in the sediment leading to death of bottom fauna and a disconnection of nitrification and denitrification. GREWAQ-

model calculations reveal that a nitrogen loading of approximately $10 \text{ g N m}^{-2} \text{ y}^{-1}$ or more uncouples the eutrophication controlling processes (De Vries, et al, 1988).

In the Veerse Meer lagoon, experiencing a N-load of $34 \text{ g m}^{-2} \text{ y}^{-1}$ and having a long residence time of the water, permanent stratification mainly in the eastern section and clear water during considerable parts of the year, obviously, the chlorophyll concentration cannot be controlled by the bottom fauna, although a fluctuating but substantial benthic biomass is available.

In the recent literature (Beukema and Cadee, 1986; Cadee, 1986a, b; Cadee and Hegeman, 1986; Nelissen and Steffels, 1988) a number of biological effects of increasing eutrophication have been mentioned for the Dutch coastal waters and the western Wadden Sea: (1) increasing primary production; (2) dominance of flagellates over diatoms; (3) increasing biomass of benthic macro-fauna; (4) increasing catches (biomass ?) of demersal fish and shrimps. It is beyond the discussion of this paper whether or not these effects of eutrophication are proven causal facts or just assumed tendencies. The question arises whether the correlations mentioned for Dutch coastal waters can also be revealed for the estuaries and lagoons in the South-West Netherlands. The answer is negative, for several reasons: (1) long terms series, such as published for the Wadden Sea by Beukema and Cadee, 1987, are not available for the Oosterschelde and Westerschelde estuaries; (2) any possible trend in eutrophication of the Delta estuaries has been obscured (except for the Westerschelde) by the execution of the Delta Works, changing the hydrography of the area drastically. The Veerse Meer and Grevelingen have their own eutrophication story, starting respectively in 1961 and 1971 when the basins were closed off from the sea (cf. Fig. 1).

In Figure 6 a restricted dataset on the occurrence of the flagellate Phaeocystis pouchetii in the western part of the Oosterschelde estuary is compared with data from the western Wadden Sea. The Wadden Sea data reveal a relation between increasing eutrophication and increasing incidence of Phaeocystis blooms. The Oosterschelde data show a

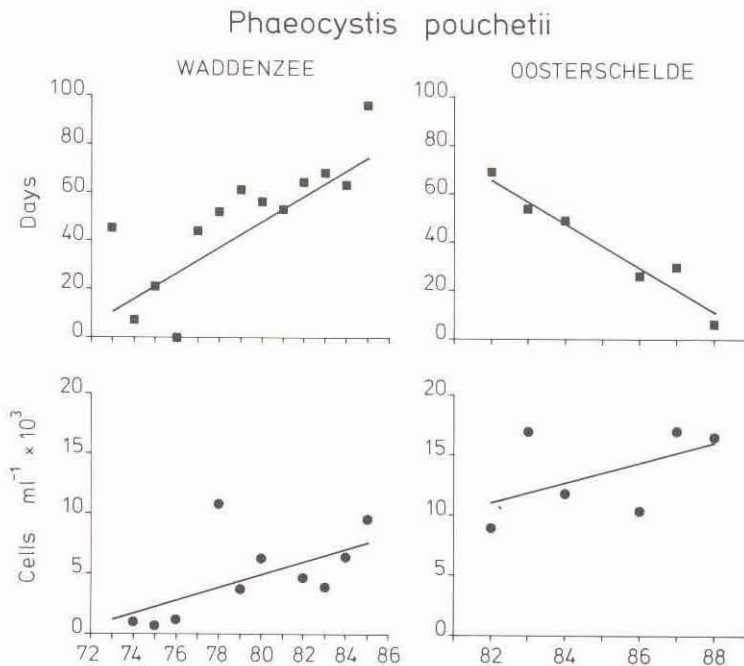


Figure 6 Duration of the springbloom of *Phaeocystis pouchetii* expressed as number of days with concentrations of cells above 1000 ml^{-1} , and average concentration of cells, expressed as number of cells ml^{-1} , for the western Waddenzee (Cadee and Hegeman, 1986) and the western Oosterschelde (data from C. Bakker, DIHO). For the Oosterschelde: number of days: $y = 819 - 9.178x$, $R^2 = 0.94399$, $P < 0.01$; cells ml^{-1} : $P > 0.05$.

significant decrease in the length of the period of the *Phaeocystis* bloom, but an increase in bloom intensity. These partly contradictory results question the position of *Phaeocystis pouchetii* as an indicator for increasing eutrophication of Dutch coastal waters in general. Older records from before the second World War also reveal incidental heavy *Phaeocystis* blooms in the southern North Sea (personal communication C.H.R. Heip) which make the position of the flagellate as an indicator even weaker.

Table 3 Preliminary carbon budget of primary producers in estuaries and brackish lagoons in the South-West Netherlands (expressed in $\text{g C m}^{-2} \text{y}^{-1}$).

Westerschelde: phytoplankton data derived from Billen, et al, 1988, and Heip, 1988; microphytobenthos data roughly, based on biomass estimates, DGW, Middelburg; data on above-ground production of saltmarsh plants - both for the Westerschelde and Oosterschelde - derived from Groenendijk, 1984, and Huiskes, 1988. Oosterschelde: phytoplankton data based on Wetsteyn and Peperzak, 1988, and Vegter and De Visscher, 1987; microphytobenthos data from Nienhuis and Daemen, 1985; data on seagrasses and macro-algae on soft and hard substrates - both for the Oosterschelde and Westerschelde - derived from Nienhuis, 1980, and Nienhuis and Daemen, 1985. Grevelingen: data from Nienhuis, 1985, and De Vries, et al, 1988. Veerse Meer: data for phytoplankton from Daemen, 1985 and Stronkhorst, et al, 1985, for microphytobenthos based on best professional judgement; data on macrophytes of soft substrates derived from Hannewijk, 1988, and Sybesma, 1980, and unpublished DIHO records; data on seagrass production derived from personal communication F. Van Lent, DIHO.

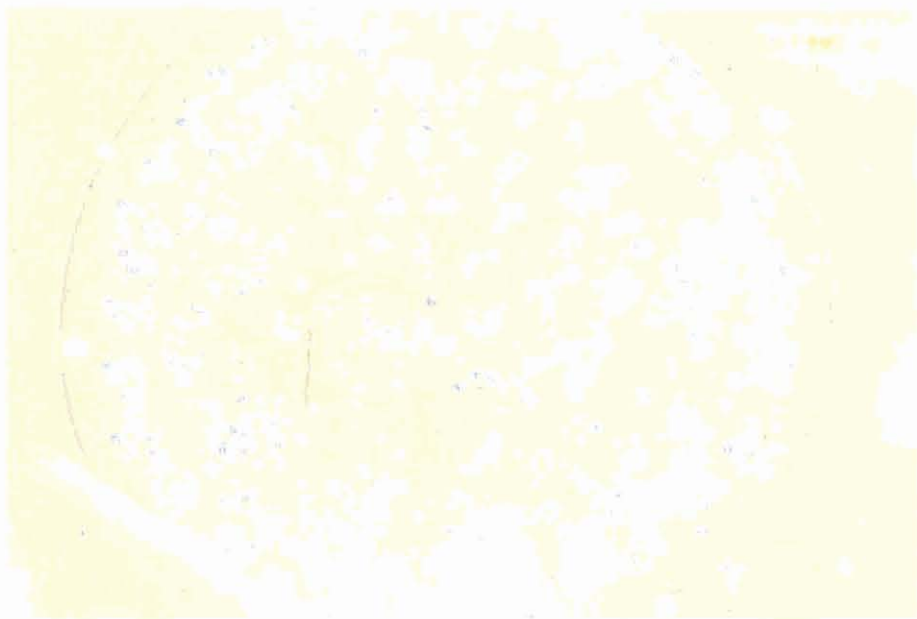
	Westerschelde		Oosterschelde		Grevelingen		Veerse Meer	
	system habitat		system habitat		system habitat		system habitat	
Phytoplankton	125	150	170	220	190	190	240	300
Microphytobenthos	90	280	50	140	75	150	80	160
Macrophytes (soft)								
Seagrasses	< 1	< 5	< 5	120	45	150	5	200
Macro-algae	< 1	< 5	< 5	60	5	200	120	500
Macrophytes (hard)	< 1	300	< 5	650	< 5	400	< 5	300
Saltmarsh plants	60	470	10	470	-	-	-	-
Total	ca. 275		ca. 240		ca. 320		ca. 450	

In Table 3 a tentative carbon budget of the 4 saline Delta Waters is given, as an expression of the transformation of inorganic nutrients into organic carbon of primary producers. Table 3 does not give information about the turnover of nutrients between the successive generations of plants. Notwithstanding the large differences in nutrient loadings of the separate waters, primary production of phytoplankton only shows a difference of a factor 2 between the light limited, turbid Westerschelde ($125 \text{ g C m}^{-2} \text{ y}^{-1}$) and the clear, presumably not nutrient limited Veerse Meer ($240 \text{ g C m}^{-2} \text{ y}^{-1}$). The Oosterschelde and Grevelingenmeer hold intermediate positions. Production of microphytobenthos (benthic diatoms, green algae etc.) is roughly one third of the production of phytoplankton. In the Westerschelde estuary, however, the relative share of benthic microphytes is considerably higher, based on P/B ratio's derived from high biomass data, taken on intertidal flats (personal communication D.J. de Jong, DGW).

Owing to the relatively large surface area of supratidal wetlands, the contribution of above-ground primary production to the carbon budget in Westerschelde estuary ($60 \text{ g C m}^{-2} \text{ y}^{-1}$) is about 20%. The larger part of the saltmarsh plants is produced in the eastern section of the Westerschelde estuary (Verdrongen Land van Saeftinghe) and is not transported over the entire estuary. In contrast with the Westerschelde, the Oosterschelde salt marshes pay only an insignificant contribution (less than 5%) to the system metabolism of the entire estuary.

Macrophytes growing on hard substrates (i.e. seaweeds attached to seawalls and stone-clad dikes) have only a minor contribution to the carbon budgets of the entire water bodies, notwithstanding their high production per square metre habitat.

High turbidity and exposure to waves and tides prevents the potential sediment habitats in the Westerschelde estuary from being invaded by macrophytes. The Oosterschelde estuary has only local growth of macrophytes on sediment substrates in sheltered regions (Zandkreek, Krabbenkreek, eastern part). In the sheltered, stagnant lagoons



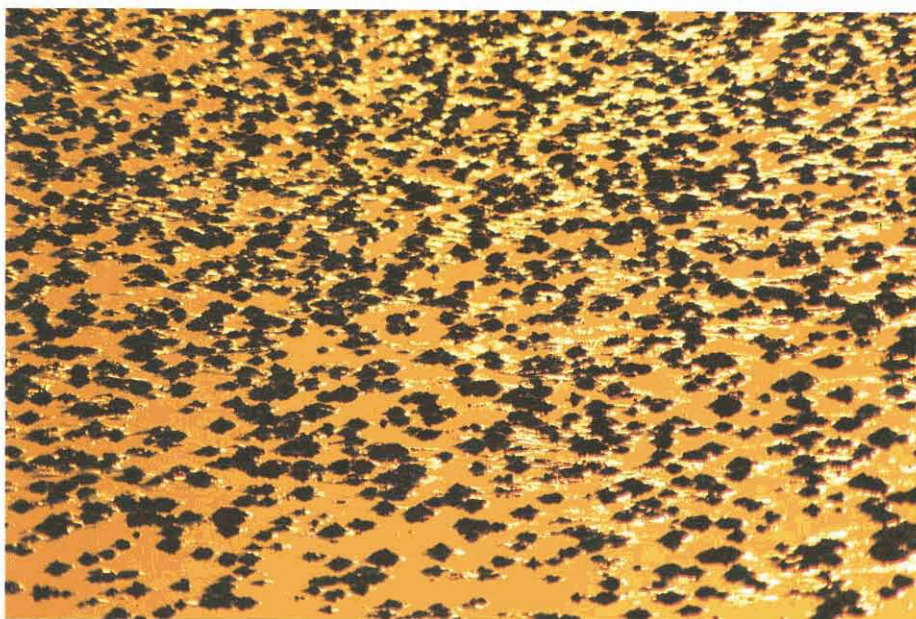
Phaeocystis (200x)



Water life of Lake Grevelingen



Foam of algae as a result of eutrophication



Gold (flats of the Eastern Scheldt)

macrophytes living on or rooting in sediment, respectively macro-algae (mainly green algae) and seagrasses, offer a significant share to the carbon budget. In the Grevelingenmeer the seagrass Zostera marina dominates, covering 30% of the surface area of the lagoon, but contributing only 14% to the annual carbon budget, owing to the low P/B ratio of 3.

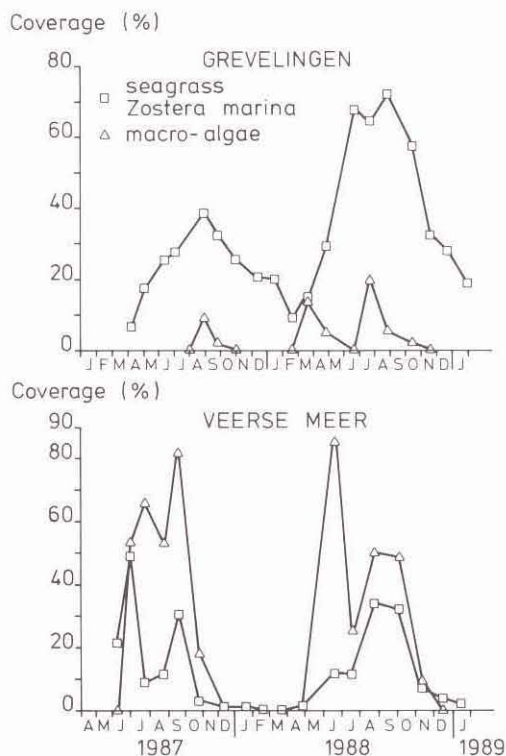


Figure 7 Percentage coverage in vertical projection on the sediment of Zostera marina and macro-algae in permanent sample plots in the Grevelingen and Veerse Meer. Size of sample plot is 15 x 15 m², waterdepth in both localities is 1.25 m (data borrowed from F. Van Lent, DIHO).

The Veerse Meer offers a different picture. Seagrasses cover only 3% of the surface area of the lagoon (Hannewijk, 1988) and have to compete with opportunistic green algae (mainly Ulva) for space and light. The lagoon is dominated by Ulva during the summer season, showing a roughly

estimated primary production of $500 \text{ g C m}^{-2} \text{ y}^{-1}$ in shallow areas. The contribution to the annual carbon budget of the Veerse Meer is roughly $120 \text{ g C m}^{-2} \text{ y}^{-1}$, which is 27% of the lagoons' budget. The high nitrogen load not only leads to a relatively high production of phytoplankton, but also to intensive and undesirable mass growth of Ulva in shallow areas.

Figure 7 reveals the increase and decrease in biomass, expressed as percentage coverage, in a permanent sample plot in the Grevelingen and in the Veerse Meer. In the Grevelingenmeer the annual cycle of changes in biomass of seagrass is not disturbed by macro-algae, which have only a low presence. In the Veerse Meer the seagrass plot becomes completely dominated by quickly growing Ulva, suppressing the growth of Zostera.

Table 3 shows that the eutrophicated Veerse Meer has the highest total primary production (roughly $450 \text{ g C m}^{-2} \text{ y}^{-1}$) and that the nutrient limited Oosterschelde estuary has the lowest values (roughly $240 \text{ g C m}^{-2} \text{ y}^{-1}$).

For freshwater ecosystems a tentative model has been developed, describing the relation between the relative dominance of primary producers connected to the availability of nutrients, and the successive phases in the process of increasing eutrophication (Phillips, et al, 1978; Van Vierssen, et al, 1985; De Nie, 1987; Fig. 8, upper panel). The model for estuarine and lagoonal situations (Fig. 8, lower panel) is adapted, based on data from the Grevelingen and Veerse Meer. The model is only applicable to stagnant brackish lagoons and extremely sheltered parts of tidal estuaries. In "healthy" saline waters, waterplants - such as seagrasses - dominate. Nitrogen load and concentrations are low and the relative importance of phytoplankton in the shallow seagrassbeds is insignificant; the Grevelingenmeer is an example of phase I. In brackish waters where eutrophication increases, revealed by higher nitrogen loads and concentrations and lower, instable salinities, waterplants are outcompeted by macro-algae. Epiphyte growth on seagrasses increases considerably together with the relative dominance of phytoplankton. The resilience of the aquatic communities decreases, which makes the system less constant in time and

less predictable for water managers; the Veerse Meer is an example of phase II.

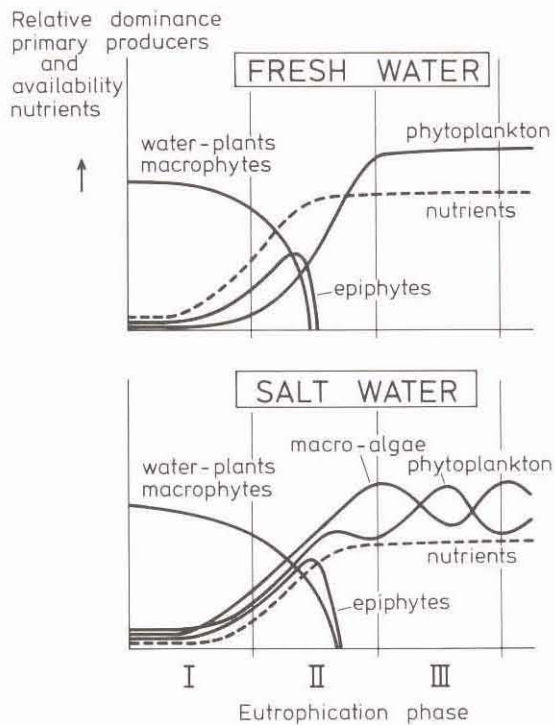


Figure 8 Tentative model for the relation between primary producers and nutrients and the successive stages in the eutrophication process. Explanation see text.

In hypereutrophicated systems (phase III) heavy uncontrolled phytoplankton blooms alternate with mass growth of macro-algae. Nutrient concentrations are continuously high. Rooting waterplants have completely disappeared. Bottom sediments suffer from permanent anoxia. The lagoon of Venice is an example of phase III, where *Ulva* biomass reaches values of $1.5 \text{ kg dry weight m}^{-2}$ (Sfriso, et al, 1987; Sfriso, et al, 1988) which is 6 times higher as in the Veerse Meer.

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THE CHANGING TIDAL LANDSCAPE IN THE DELTA AREA OF THE SOUTH-WEST NETHERLANDS

J.P.M. Mulder

ABSTRACT

Implementation of the Delta Project has initiated a process of major changes in the tidal landscape of the South-West Netherlands.

The main geomorphological developments are described in comparison with the historic evaluation of the Delta area and in relation to changes of the major natural driving forces.

1 INTRODUCTION

Channels, sandy shoals, mudflats and salt marshes make up the characteristic elements of the landscape in the (formerly) tidal waters of the South-West Netherlands. Over the last decades this landscape has become subject to dramatic changes. Main causes: implementation of the Delta Project, aimed at securing the South-West Netherlands against flooding, and in the Westerschelde, large scale dredging for the sake of free shipping to the harbours of Antwerp. Consequences: the coherent geomorphological system of ebb tidal deltas, tidal inlets and estuaries, has been divided into several more or less independent subsystems. The tendencies towards a dynamic equilibrium between the tidal landscape and natural driving forces - tides, waves and fluvial currents - have been disturbed.

In this paper (Section 2) first the historic evolution of the tidal landscape is analysed, resulting in some 'hypotheses' on general response mechanisms to changes in the natural driving forces. Then (Section 3) the major changes of the tidal landscape in the respective basins of the Dutch Delta area over the last decades are broadly reviewed. The observed phenomena are confronted with the general 'hypotheses' of Section 2 and discussed in relation to the specific shift in natural driving forces. Finally a short outlook on future developments is given.

2 EVOLUTION OF THE TIDAL LANDSCAPE DURING HISTORIC TIMES

2.1 Helinium and Oosterschelde

During Roman times the coastline of the South-West Netherlands only showed two main tidal inlets (Fig. 1).

At that time the northernmost inlet, known in Roman writings as Helinium, was the main distributary of the rivers Rhine and Meuse, and partly of the river Scheldt (Zagwijn, 1987). During the next centuries the importance of this estuary continually diminished, in favour of the development of the early Haringvliet, Grevelingen and Oosterschelde estuaries.

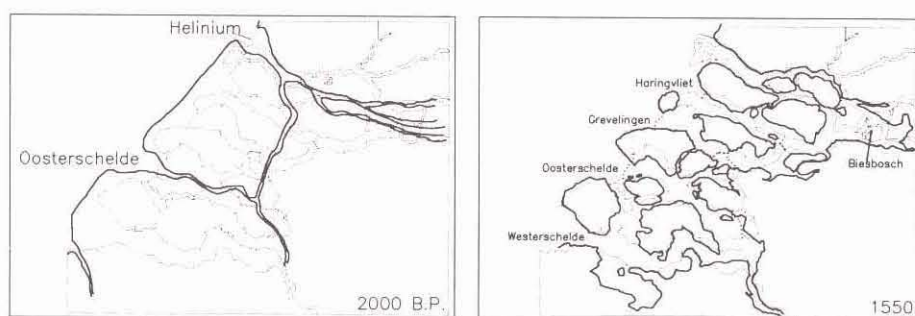


Figure 1 The South-West Netherlands 2000 B.P. (Zagwijn, 1987) and circa 1550

The storm surge of 1421 A.D., known as St. Elisabeth's flood, had a big impact in this respect. It caused a drastic change in the courses of the main rivers and considerable losses of land (Fig. 1). Due to these land losses - the extensive tidal marsh lands of the Biesbosch originate from this flood - the tidal prisms of the early Haringvliet, Grevelingen and Oosterschelde increased considerably, resulting in a further deepening and widening of these basins. The former Helinium on the contrary showed a decrease of tidal prism and as a result silted up. This process of siltation still was continuing during the 19th century, leading to the need of constructing the Rotterdam Waterway (1868) in order to ensure access to the Rotterdam harbours (Van den Berg, 1987).

The Oosterschelde inlet hardly did not change position since Roman times. However, the shape of the estuary ever since has changed considerably. Originally the Oosterschelde was the main distributary of the river Scheldt. From about 700 A.D. the more southerly Westerschelde estuary developed from a small tidal inlet, during Roman times located approximately at the present Dutch-Belgian border (Fig. 1; Leenders, 1986). The Westerschelde gradually took over the discharge of the river Scheldt. At the end of the 16th century the Oosterschelde practically had lost all importance as a distributary of Scheldt waters. Nevertheless, in contrast to the silting up of the Helinium after diversion of the main courses of the rivers Rhine and Meuse, the Oosterschelde showed intensified erosion. An explanation for this remarkable different behaviour is the dramatic increase of the Oosterschelde's tidal prism due to extensive land losses. Apart from the effects of the earlier mentioned St. Elisabeth's flood, it is estimated that as a result of another notorious storm surge (St. Felix's flood of 1530), the Oosterschelde basin was enlarged to such extent that its tidal prism must have increased by at least 50% (Van den Berg, 1986). The erosive response to this increase of tidal prism still is visible during the 19th century (Fig. 2).

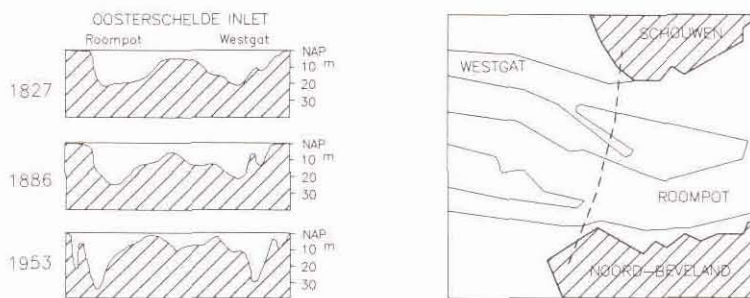


Figure 2 Cross sections of the Oosterschelde inlet in different periods, illustrating the deepening of channels and expansion of sandy shoals (Van Vechgel, 1977; DMB, 1976)

However, the erosion process during this period cannot be explained as a sole reaction to the medieval land losses. During the 19th and 20th century the tidal prism of the Oosterschelde increased further due to a series of civil engineering works, each favouring a more landward propagation of tides (Table 1; Van den Berg, 1987; Van Vegchel, 1977).

Table 1 Civil engineering works in the landward parts of the Oosterschelde 1850-1970 (DMB, 1970)

1851-1885	construction of the Nieuwe Merwede
1888-1907	construction of the Bergse Maas; normalisation of the Amer
1931	construction of the Hellegatdam
1965	construction of the Grevelingen Dam
1969	construction of the Volkerak Dam
1850-	dredging and sandmining

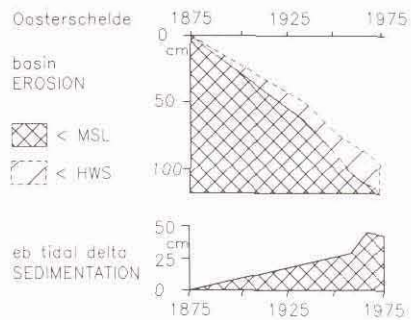


Figure 3 Opposite trends in Oosterschelde basin and ebb tidal delta (1875-1975), and net sedimentation of shoals (zone between mean sea level MSL and mean high water slack HWS) in an overall eroding basin (DMB, 1975; Van Vechgel, 1977)

2.2 Hypotheses and preliminary conclusions

Changes in tidal volume play a key role in the geomorphological history of the South-West Netherlands. The well documented changes of the Oosterschelde over the last 100 years clearly illustrate the general response of sandy estuaries to an increase of tidal volume:

- the basin as a whole shows a tendency of erosion; at the same time the connected ebb tidal delta is growing (Fig. 3);
- morphological differences within the basin are accentuated; channels deepen, sandy shoals expand (Fig. 2 and 3). In general this response might be visualized as given in Figure 4A.

The history of the Helinium shows the general response to an opposite trend in tidal volume: the basin starts silting up. Unfortunately, in contrast to the Oosterschelde, detailed information on the historic development of Helinium's ebb tidal delta or of single channels and sandy shoals is lacking. Nevertheless, in negative analogy to the Oosterschelde case, the effects of a decrease of tidal volume might be stated as:

- the basin as a whole shows a tendency of sedimentation; the connected ebb tidal delta is eroding;

- morphological differences within the basin are smoothed; channels silt up, sandy shoals degrade (Fig. 4B).

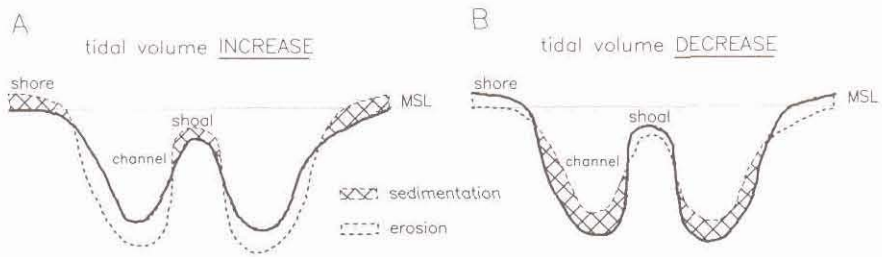


Figure 4 General response mechanisms of the tidal landscape in coastal and estuarine environments to changes in the tidal volume

These statements on general response mechanisms provide useful 'hypotheses' to be tested on observations of the major changes in the tidal landscape over the last 30 years (Section 3).

The response mechanism to changes of tidal volume trends to create a new dynamic equilibrium between the tidal volume and the shape and dimensions of the tidal landscape. The continuing siltation of the Helinium and erosion of the Oosterschelde during the 19th century, in response to drastic changes of their tidal volume during the 15th and 16th century (see section 2.1), indicates the time scale of geomorphological reactions: a new dynamic equilibrium takes centuries.

The impact of human interference on developments of the tidal landscape becomes increasingly apparent through the ages.

During the Late Middle Ages man was a major cause of the land losses along the Helinium and Oosterschelde estuaries. The construction of polders (since about 1100 A.D.), the artificial improvement of drainage and extensive salt mining initiated large scale lowering of the land level. Consequently the land became a more easy prey to storm surges (Van den Berg, 1986). Man indirectly initiated major changes in the tidal volumes of the estuaries.

During the 19th century man starts interfering directly by engineering works of ever increasing dimensions. The last decades are marked by a human influence of unprecedented scale and intensity.

3 MAJOR CHANGES IN THE TIDAL LANDSCAPE OVER THE LAST DECADES

3.1 Different categories

After completion of the Delta Project in 1987, the waters of the South-West Netherlands may be divided into four categories (Fig. 5):

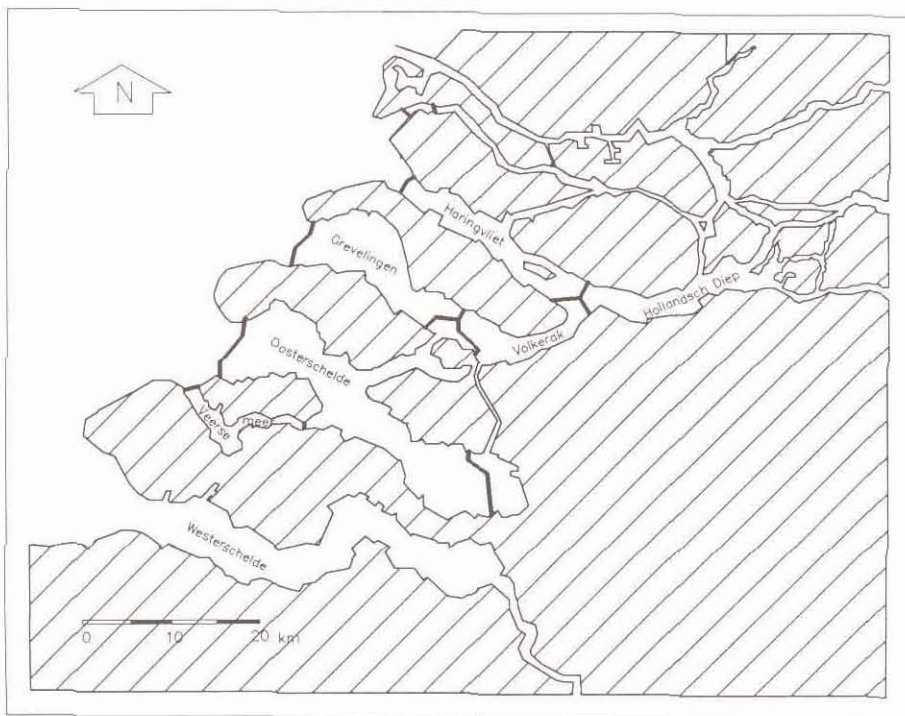


Figure 5 The South-West Netherlands after completion of the Delta Project

- category Haringvliet: basins with only a closure dam at the seaward side, almost totally disconnected from tidal influences but with a substantial direct fluvial inflow (Haringvliet - Hollandsch Diep, Brielse Meer);

- category Grevelingen: basins with closure dams at two sides, disconnected from tidal influences and without any (Grevelingenmeer, Veerse Meer) or with very limited fluvial influences (Volkerak - Zoommeer);
- Oosterschelde: a basin with a half open dam at the seaward side and closure dams at the landward side, with reduced tide and disconnected from fluvial influences;
- Westerschelde: an estuary in the true sense, with both tidal and fluvial influences.

Construction of the seaward closure dams has disrupted the former morphological unity of estuary and ebb tidal delta into two distinct subsystems: a basin and a (relict) ebb tidal delta.

In general, tidal currents and -ranges have been reduced and fluvial influences limited, while wave impacts have remained unchanged.

3.2 Category Haringvliet

Within the Haringvliet basin fluvial currents and waves are the only geomorphologically active forces left after finishing of the Haringvliet Dam in 1971. The tidal range has been diminished from ca. 2 m to a negligible 0.2-0.35 m. The almost total disconnection from tidal influences has invoked large scale sedimentation in the channels (Fig. 6) and erosion of shoals and mudflats; the shorefaces of several

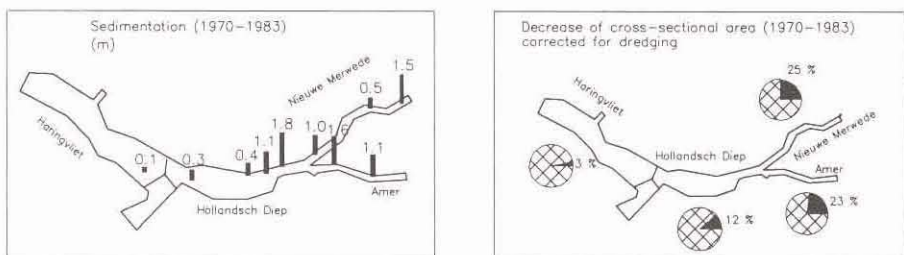


Figure 6 Channel sedimentation in the Haringvliet-Hollandsch Diep basin over the period 1970-1983 (Van Otterloo, et al, 1987)

mudflats have retreated some 100-200 m within 10 years (Van Otterloo, et al, 1987). Generally these developments agree with the hypothesized changes according to Figure 4B.

Sedimentation of the channels mainly is due to sand and mud transported by the rivers. The change in channel depth (Fig. 6) indicates that the channels successively silt up from East to West. The siltation process will continue until all over the basin a new equilibrium has been established between the discharge volume and cross sectional area of the channels.

Erosion of the mudflats is caused by waves. Now that tidal waterlevel variations no longer exist, wave attacks are concentrated in a narrow zone; at the same time this erosion no longer is compensated by sediments deposited by tidal currents during high tides. The result is an increased net erosion. Until 1988 the shores of two areas (Beninger- and Korendijksche Slikken) effectively have been protected against erosion (Van Otterloo, et al, 1987). A program has been defined to protect all remaining shoals and mudflats before the year 1994.

Since 1971 tidal currents on Haringvliet's ebb tidal delta mainly are determined by the North - South directed tidal wave on the North Sea. East - West directed tidal currents, previously flowing into and out of the estuary, have reduced dramatically. Fluvial currents nowadays are restricted to periods around low water slack, when excess water from Meuse and Rhine is being discharged through the Haringvliet sluices. Wave activity has not changed significantly over the last period. According to the hypotheses of Section 2.2, a reduction in tidal volume of the estuary generally will induce erosion of the ebb tidal delta and sedimentation of the tidal channels. Observations of geomorphological developments since 1971 (Fig. 7) generally confirm this picture.

Erosion of the ebb tidal delta is most obvious along the deltafront around the NAP -5 m depth contour (Fig. 7). Here the landward directed wave induced sand transport no longer is compensated by sand transport in a seaward direction induced by ebb tidal currents: the result is a net erosion of the deltafront. The eroded sediments are deposited

partly in longshore sandbars at the edge of the ebb tidal delta, and partly in the channels, especially where these have lost their role as distributaries of ebb currents from the estuary.

It is to be expected that these processes will continue in the future at a reducing rate, until a new equilibrium has been established. The longshore bars, stagnating at a height level of around mean sea-level (NAP), will continue to stretch in a direction parallel to the coast, at the same time moving further landward (Kohsiek, et al, 1989).

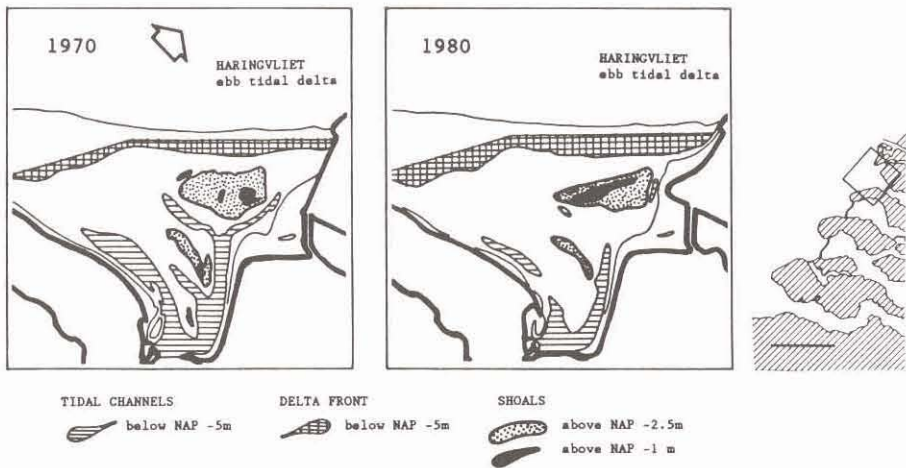


Figure 7 Development of the Haringvliet ebb tidal delta over the period 1970-1980 (Van der Spek, 1987)

3.3 Category Grevelingen

After construction of the Grevelingen Dam (1965) and the Brouwers Dam (1971), the Grevelingen basin must be characterized as a stagnant saltwater basin, without any tidal or fluvial influence. Waves are the only geomorphologically active driving force that has been left. Theoretically changes of such nature will induce erosion of the sandy shoals and mudflats, and sedimentation of the channels (conform Fig. 4B). Developments over the last 20 years broadly confirm this.



Development of longshore bars in the Voordelta



Western Scheldt and Saeftinghe



Dry shoal with gully



Side of dry shoal

Erosion by waves of sandy shoals (conform Section 3.2) was very common from 1971 onwards; shore faces retreated at a rate of maximum 10 m/year. After most of the shores successively have been protected against erosion, the total loss of shoals and mudflats in 1988 has been calculated as 54 ha or 6 percent of the original total area (Leeuwestein and Schoot, 1988; Fortuin, 1989).

Although the former tidal channels tend to silt up, hardly any sedimentation is observable since the only source of sediment, represented by the sandy shoals and mudflats, largely has been protected against erosion. Consequently future changes of the basin's tidal landscape will be very limited.

The shift in driving force on Grevelingen's ebb tidal delta since 1971 largely is comparable to that previously described at the Haringvliet (see Section 3.2). As to be expected a similar morphological development initiated by similar mechanisms has been observed. Erosion of the deltafront related to an expansion of sandy shoals and silting up of former tidal channel over the last 20 years clearly is illustrated by Figures 8 and 9.

The tendencies of future changes of the ebb tidal delta are comparable to the Harinvliet case.

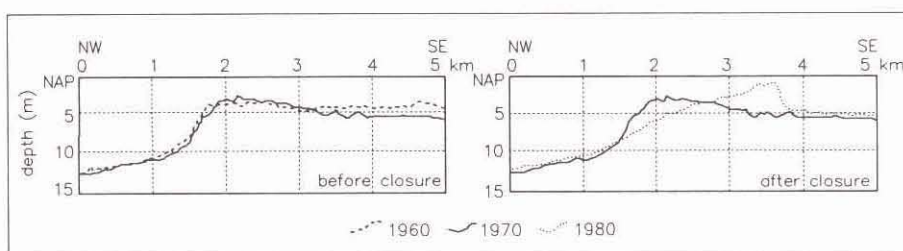


Figure 8 Cross sections of the deltafront on the Grevelingen ebb tidal delta (1960-1980), illustrating the impact of closing the estuary in 1971 (Kohsiek and Mulder, 1989)

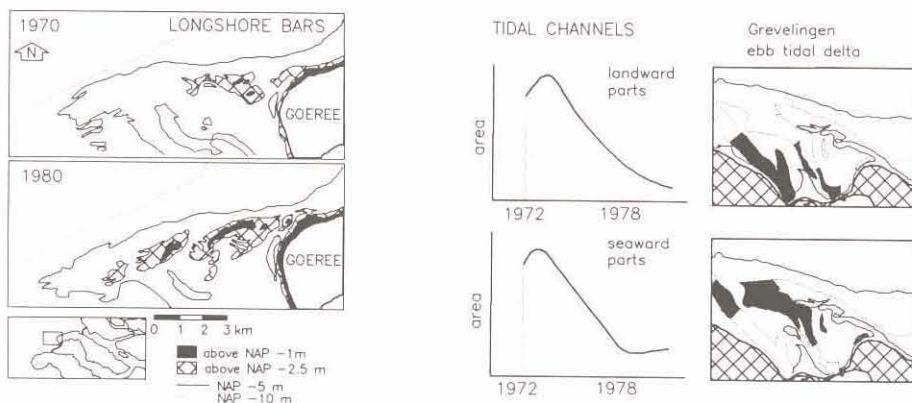


Figure 9 Development of longshore bars and tidal channels on the Grevelingen ebb tidal delta 1970-1980 (Kohsiek and Mulder, 1989)

3.4 Oosterschelde

The Oosterschelde basin was directly influenced by the construction works in other estuaries. Due to the building of the Grevelingen Dam (1965) and Volkerak Dam (1969), the tidal prism of the Oosterschelde increased circa 6 - 8% over the period 1960 - 1983 (Van den Berg, 1986). A considerable erosion and widening of the channels has been observed over this period (Van den Berg, 1986), which is in accordance with the expected geomorphological reaction (conform Fig. 4A).

Construction of the storm surge barrier (1986) and of the landward dams (Oesterdam, 1986, and Philipsdam, 1987) has disturbed these tendencies. Since 1986 the tidal volume of the Oosterschelde has decreased by 30%; tidal current velocities have diminished by a similar percentage and the tidal range by some 12%. This reduction in tidal influence, most probably has initiated a process of channel sedimentation and shoal erosion (conform Fig. 4B). However, no geomorphological observations are available yet to confirm this.

It has been estimated that the sedimentation process of the channels in order to establish a new equilibrium will involve some 500 millions m^3 of sediment over the next centuries. The total erosive effect over the next 30 years has been calculated as a loss of shoal- and mudflat area amounting to circa 1500 hectares i.e. 10 - 15% of the present total area (Kohsiek, et al, 1987).

The total area of salt marshes very drastically has been reduced after completion of the Delta Project. Since 1987 only 24% of the originally total area of salt marshes in the Haringvliet, Grevelingen, Volkerak and Oosterschelde is remaining in the Oosterschelde. It is estimated that these salt marshes are subject to an increased rate of erosion. Vegetation and erosion resistance most probably have been weakened considerably as a result of a prolonged period of extreme tidal reduction during the final construction phase of the Oosterschelde works.

The Oosterschelde's ebb tidal delta has shown a continuing expansion over the period 1960 - 1983 as a result of the tidal volume increase and resulting basin erosion over this period. Van den Berg (1986) has calculated a net sedimentation over these years of ca. 58 millions m^3 . This is in accordance with the expected trend as stated in Section 2.2. The decrease of tidal volume after 1987 indicates an opposite geomorphological trend for the future. It is expected that the deltafront will erode, the tidal channels will silt up and longshore sandbars will develop at the edges (Kohsiek and Mulder, 1989). No geomorphological data are available yet to confirm this.

3.5 Westerschelde

Tidal and geomorphological changes of the Westerschelde basin over the last 30 years are mainly due to large scale dredging. Because of it's importance for shipping traffic to the harbours of Antwerp, no closure dam has been defined for the Westerschelde. Within the framework of the Delta Project security against flooding around this estuary has been obtained by strengthening of the dykes. The intensified shipping

traffic, however, has induced a distinct increase of large scale dredging activities from about 1970 (Fig. 10).

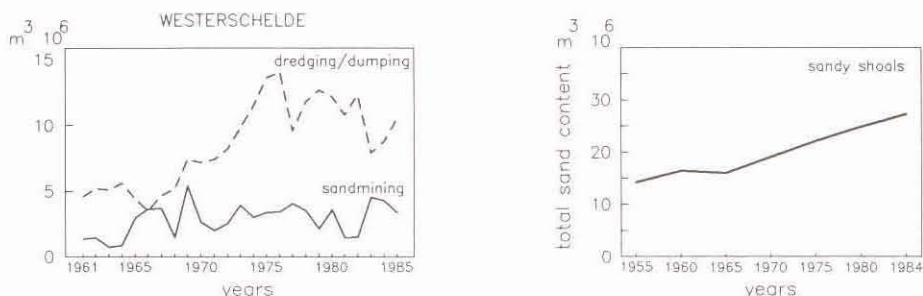


Figure 10 Impact of dredging and dumping in the Westerschelde on the development of sandy shoals (WWW, 1989)

The artificial deepening of the channels by dredging has contributed to an increase of tidal volume in the basin of 5 - 7% over the period 1970 - 1985 (Van den Berg, 1987). Theoretically (Fig. 4A) these hydraulic and geomorphological changes should invoke an expansion of the sandy shoals. Observations over the period 1955 - 1987 largely confirm this (Fig. 10). Future developments of the tidal landscape will depend mainly on the actual policy of dredging and dumping.

Westerschelde's ebb tidal delta should have shown an expanding tendency over the period 1970 - 1975 in response to an increasing tidal volume (conform Section 2.2). A morphological development in this sense, however, has been hard to observe over the past years. The tidal landscape seems to have been determined to a greater extent by dredging and dumping activities on the ebb tidal delta itself. Deepening of shipping channels and expansion of Zeebrugge harbour initiated the dredging and dumping of some 400 million m³ sediment on the Westerschelde ebb tidal delta between 1970 and 1984 (Van den Berg, 1987). These activities will continue to determine future developments.

Implementation of the Delta Project has initiated a process of large scale changes in the tidal landscape. Generally these changes may be described in relation to the specific changes in tidal volume of the basins. The dimensions and rate of the changes only partly have been foreseen at the outset of the Project. Detailed process studies over the last years have provided more insight. As a result of these studies adequate management measures have been defined to stop erosion of shoals and mudflats in the tideless basins. A policy plan incorporating the developments of the ebb tidal deltas - the Voordelta - is in preparation. The definition of adequate measurements to manage developments of the tidal landscape in the Ooster- and Westerschelde is subject of study.

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ECOLOGICAL DEVELOPMENT OF SALT MARSHES AND FORMER TIDAL FLATS IN THE
SOUTH-WEST NETHERLANDS

A.M.M. van Haperen

ABSTRACT

Both in the remaining and in the embanked estuaries of the South-West Netherlands there are good possibilities for conservation and development of (semi-)terrestrial ecosystems. In the Oosterschelde and the Westerschelde conservation of the estuarine salt marshes has highest priority. They are characterized by cyclic dynamic processes that largely depend on the tidal water system.

On former tidal flats and salt marshes that are no longer inundated emphasis lies on the development of new ecosystems. Already in the first years after embankment rare and threatened bird and plant species colonized the new habitats. Environment was, however, dominated by non-cyclic adaptative processes (e.g. desalination, physical and chemical ripening of the soil, etc.) causing a rapid change of flora and fauna. Probably it will take more than a hundred years before the new ecosystems will be stabilized.

Management of water and land is of great importance for the type of nature that will result ultimately. When making a management plan it is important to get a good idea of the abiotic potentialities of the different habitats. Together with the value of the different types of nature for nature conservation it is the main criterion to come to the decision what type of nature should be developed on the new land.

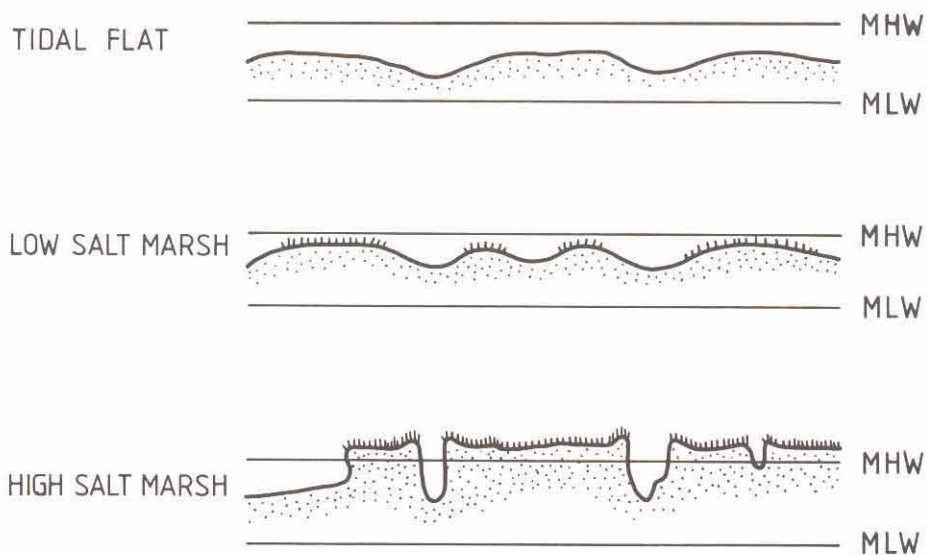


Figure 1 Geomorphological differentiation of tidal flats and salt marshes in the estuaries of the South-West Netherlands.
MHW: Mean High Water, MLW: Mean Low Water

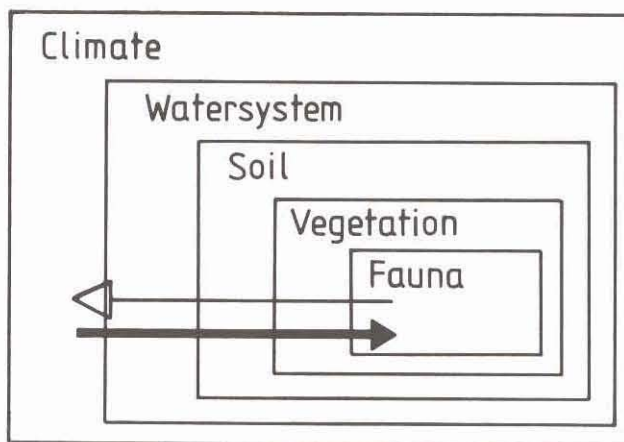


Figure 2 Hierarchical model of the estuarine ecosystems in the South-West Netherlands

In tidal water systems sedimentation and erosion of sediment continue above mean low waterlevel (MLW) and even mean high waterlevel (MHW). The lowest parts of the tidal zone have no vegetation except algae and some water plants (Zostera spec.). These tidal flats are an important feeding habitat for birds (Meire, et al, 1989). Some decimetres below MHW the first semi-terrestrial vegetation starts to grow (Salicornia spec., Spartina spec.). This vegetation is usually inundated twice a day. When accretion continues to above MHW, vegetation develops to a variety of plant communities. Geomorphology and vegetation of these higher salt marshes are much more differentiated than on the mud flats and the lower salt marshes.

The above-mentioned pattern of succession (see also Fig. 1) represents the situation in the saline tidal areas of the South-West Netherlands. In the fresh and brackish tidal water systems this pattern is not essentially different, but there is a difference in vegetation types of the marshes (reed, rushes and willows).

The construction of the Delta Works resulted in an enormous change of the estuarine environment. In most areas a more or less fixed waterlevel was realized somewhat around NAP (Dutch Ordnance Level). The consequence was that the lower parts of the tidal land were permanently inundated, while the higher parts were hardly influenced by the flooding water. Large parts of the latter could develop as (semi-) natural ecosystems. This development and its future perspectives for nature conservation are the subjects of this paper.

2 ECOLOGICAL DYNAMICS IN VARIOUS WATERS

The processes influencing the development of animal and plant communities can be ordered in an hierarchical model (Fig. 2, derived from Bakker, et al, 1981). In this model the outer compartments dominate the inner ones. Though there is some influence in the opposite direction, this is of minor importance because of its lower

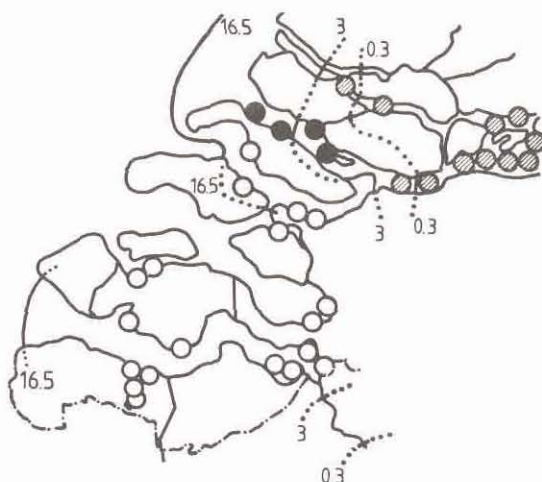


Figure 3 Distribution of some estuarine marshland types in relation to average chlorinity ($^0/00 \text{ Cl}^-$). Open circles: salt marshes; black circles: brackish marshes with reed and rushes; hatched circles: fresh marshes with reed, rushes and willow coppices. This figure gives the situation before the construction of the Delta Works

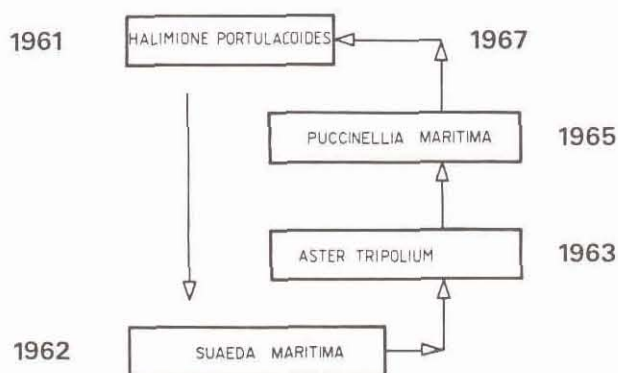


Figure 4 Cyclic vegetation dynamics in a salt marsh after severe waterlogged conditions (after Beeftink, 1979)

hierarchical position. In the estuarine situation the water regime is one of the most essential factors determining processes in soil, vegetation and fauna. The relation between the average salt concentration and the distribution of some vegetation types is a good example of this dominance (Fig. 3).

As soon as great changes occur in the outer compartments of the model (by human interference or other), this has important consequences for the hierarchically lower parts. Changes in the lower compartments have less consequences on the system as a whole. Figure 4 (derived from Beeftink, 1979) gives a good example of such a situation. In the wet autumn of 1961 severe waterlogged conditions occurred on a higher salt marsh in the Grevelingen estuary. This was the primary cause for a die-back of the vegetation of Halimione portulacoides on that marsh. In the long run there was, however, no change of the saltmarsh ecosystem as a whole and after some years the original vegetation could recover. The erosion of a tidal flat or a salt marsh and the development of new ones elsewhere in the same tidal system are an example of the same cyclic dynamics on a larger scale of space and time.

The construction of the Delta Works resulted in quite different types of ecological dynamics. The water system as a whole changed totally and resulted in a complete new and irreversible development of water and land (Beeftink, 1987). After the finishing of the dams many of the estuarine plants and animals died and new species had to colonize the disturbed ecosystems. In the beginning the dominating species in the vegetation changed from year to year. Later on changes took place much more gradually. There were also marked differences between habitats. The vegetation of the lower salt marshes died totally within two or three years. The higher salt marshes were well adapted to less frequent inundations and vegetation changed gradually after the disappearance of the tides. In the reed marshes and willow woodlands of the brackish and fresh estuaries the same pattern occurred. These vegetations actually did not die, but during some 5 to 10 years after damming their species composition and structure changed very much.

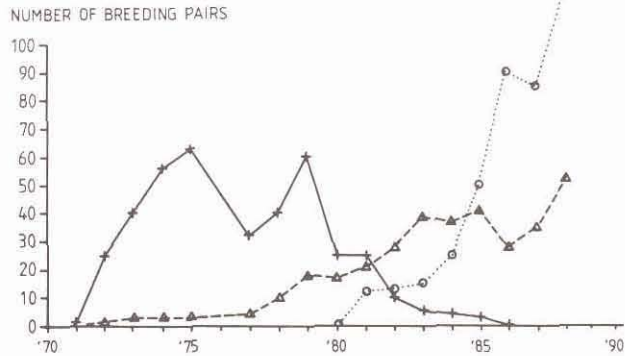


Figure 5 Development of three breeding bird populations on the Hompeloet, a newly created island in Lake Grevelingen. Crosses: Kentish Plover (*Charadrius alexandrinus*); triangles: Redshank (*Tringa totanus*); circles: Willow Warbler (*Phylloscopus trochilus*). Data kindly submitted by G.J. Slob, National Forest Service in the Netherlands, Goes.

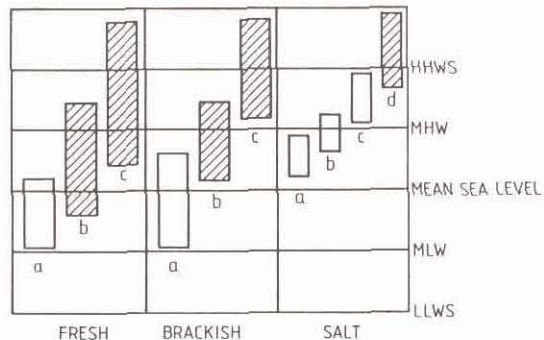


Figure 6 Distribution of some vegetation types in relation to height and tidal flooding before the construction of the Delta Works. The following vegetation types are indicated (Westhoff and Den Held, 1969):

- Fresh: a. *Scirpus*, b. *Phragmites*, c. *Salicion albae*;
 Brackish: a. *Scirpus*, b. *Phragmites*, c. grassland (*Lolio-Potentillion*);
 Salt: a. *Salicornion*, b. *Spartinion*, c. *Puccinellion*, d. *Armerion*

Of course, the environmental changes have not only influenced the vegetation but also the fauna. Figure 5 gives an idea of the dynamics of the breeding bird populations on one of the newly emerged islands in Lake Grevelingen. After the construction of the dam in the Brouwershavense Gat some 400 hectares of tidal flats and a small salt marsh were exposed to the air and wind. Especially the species of sandy beaches and pebble coasts (like the Kentish Plover) began to breed on the new land. The population of Redshank, also a coastal bird, did not increase before some vegetation was existing, mainly because the birds needed this vegetation to hide their nests. At that time the species of bare beaches were already declining. The first breeding birds of shrubs have colonized the island only recently and a common species like the Willow Warbler is still increasing. Woodland species do not breed on the island, because vegetation structure has not yet been differentiated enough and there are no nesting sites for these birds. It will take at least some 50-100 years before the bird communities begin to stabilize.

3 FACTORS INFLUENCING ECOSYSTEM DEVELOPMENT

Generally speaking the following factors influence the development of vegetation and animal wildlife on the former salt marshes and tidal flats:

- * the initial ecosystem present at the moment of dam construction;
- * processes of adaption to the newly created situation;
- * management of water and land by man.

3.1 Initial ecosystems

The newly developed ecosystems have their starting point in the old estuarine waters. These initial ecosystems are strongly influenced by the original waterregime. This is illustrated by the distribution of the vegetation series of Figure 1 in relation to height and tidal flooding (see Fig. 6). The vegetation types indicated by an open rectangle died within two or three years after embankment was finished

and this resulted in an almost complete bare soil. The hatched vegetation types changed much more gradually, without dying off totally. After the enclosure in most areas the water was permanently fixed more or less at mean sea-level (MSL). The following differences occurred. In the fresh and brackish tidal areas the original marsh vegetation came at a much lower level (on certain places even below MLW) than in the saline systems. Consequently a larger area of bare soils emerged after the completion of the dams in the saltwater systems in comparison to the upstream tidal waters. This difference is enlarged by the dying off of the lower saltmarsh species in the first years after the enclosure. Vegetation development on the former salt marshes and tidal flats was dominated by colonisation of the new habitats by annual pionier species. On the contrary, in the fresh and brackish areas the new species (that had to invade existing vegetations) were mainly tall perennial herbs and grasses, shrubs and trees.

3.2 Processes in abiotic environment

After the enclosure of an estuary a number of processes started changing abiotic environment of the new terrestrial environments (e.g.

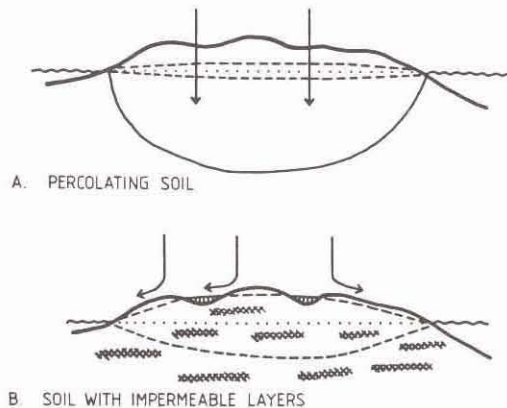


Figure 7 Two main groundwater regimes on the newly emerged land in the former estuaries (after Drost and Visser, 1981)

wind erosion, desalination, aeration, physical and chemical ripening and decalcification). The time scale of these processes differs from some months or years (wind erosion) to tens or hundreds of years (decalcification). In the beginning the effects of these individual processes are quite clear. When the new ecosystems grow older it is getting more and more difficult to separate them from each other and from the internal dynamics of the developing ecosystems themselves. Figure 7 (according to Drost and Visser, 1981) gives a good idea how the abiotic environment of different soil types behaves in relation to desalination. On well percolating soils desalination goes very fast. After some years there is already a rather large freshwater body in the soil. Glycophylous herbs and grasses can soon colonize the bare soil and natural shrub and then woodland development follows. Clay layers in the soil profile stagnate desalination and then this process can take tens of years. In autumn and winter the soil is saturated fast and most of the rain water will stagnate and run off superficially. Here only the upper soil layers will have a freshwater body and this will evaporate completely in summer. In this type of habitat halophylous plant species dominate in the primary vegetation development. Trees and shrubs can hardly colonize the vegetation giving it the character of open grassland for a long time.

3.3 Management of water and land

Water management is especially important on flat shores, where smaller or larger areas can be inundated during some time. This is of great importance for the survival and germination opportunities of certain plant species. A good example how this can influence the fauna is found in Lake Grevelingen. Here the bird species of scarcely vegetated shell shores and beaches are declining (e.g. Kentish Plover, see Fig. 5), because of continuing vegetation development. Maybe there is a possibility to maintain a larger area of this type of breeding habitat by raising the waterlevel of the lake in autumn or winter time during several weeks. Then a larger part of the shore is inundated by saline water, slowing down further vegetation development.

In the terrestrial habitats it is of great importance how the nutrient cycles of the ecosystem and the structure of the vegetation are influenced. The nutrient cycles determine growing and feeding conditions for plant and animal species, while vegetation structure is of great importance for their survival. Roughly speaking we can distinguish three ways of nature management: spontaneous development, mowing and grazing. Each of these management types has its own results and (financial) costs. Spontaneous development will lead to woodland ultimately, while mowing keeps areas open and rich in herbs. Grazing is in between these two types and the result depends on grazing intensity. It is an attractive type of management to create a habitat with a varied structure of grassland and shrubs in a semi-natural way. Grazing animals (indigenous herbivorous herds as well as domestic cattle) use large areas in traditional patterns. Some parts of the area are (year after year) more intensively grazed than others. In this way grazing can enlarge the differentiation of the abiotic environment creating additional stimuli for more diversity in developing ecosystems. In the long run it will not only result in grassland. Even for natural woodland development grazing (of course in very low densities) can be a good type of management.

4 BALANCE OF ECOSYSTEM DEVELOPMENT UP TO NOW

The first embankment of a large estuary in the South-West Netherlands took place some 30 years ago (Lake Veere, 1961). Since that time several other areas followed, with different abiotic environments and different types of water systems. As indicated above ecosystem development is still going on and even in the oldest areas it will take tens or even hundreds of years before the new terrestrial habitats will be stabilized. Notwithstanding these facts we will try to make up some balance from a point of view of nature conservation and management.

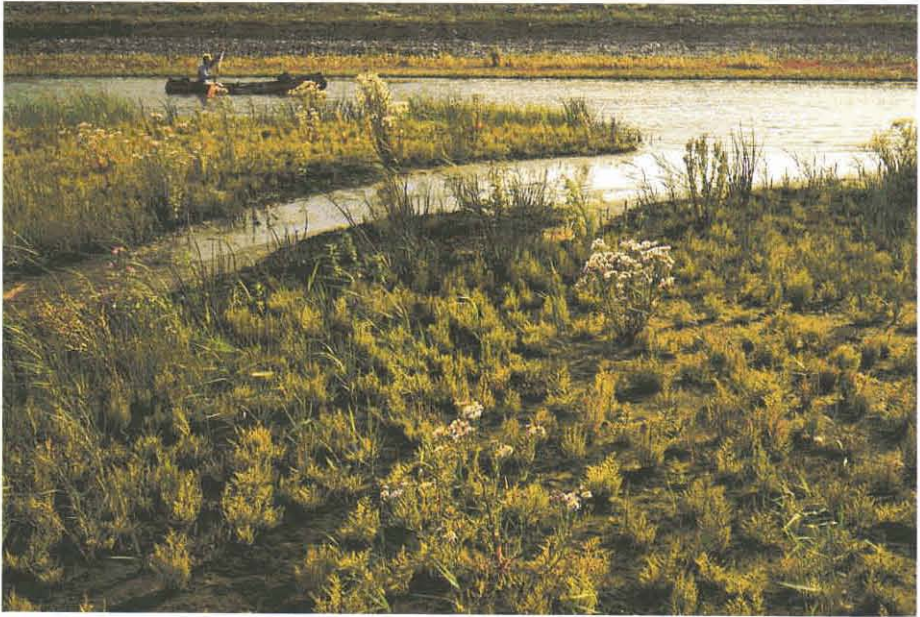
Firstly we must notice that there is a great loss of valuable (semi-) terrestrial habitats in the estuaries of the South-West Netherlands as a consequence of the Delta Works. (The loss of aquatic ecosystems and tidal flats is left out of consideration.) After the enclosure of the



Former tidal flats with saltmarsh vegetation



Grazed former tidal flat with dense grassland vegetation and small shrubs



Former tidal flats with changing vegetation



Grazing as a tool for vegetation management

Grevelingen, Lake Veere and Krammer-Volkerak, the area of salt marshes in the South-West Netherlands has been diminished and is at the moment no more than ca. 30% of that in 1950. If we look at the area of higher salt marshes this decline is even more dramatical. Especially these higher salt marshes are a valuable and rare type of ecosystem, with a number of endangered animal and plant species. For this reason high priority must be given to conserve the remaining salt marshes in the Oosterschelde and Westerschelde. In the Oosterschelde the sediment balance indicates that there are hardly any perspectives for the development of large new salt marshes. On the other hand the largest part of the remaining saltmarsh area is found in the eastern part of the Westerschelde (ca. 80%). Environment is under great pressure here because of chemical pollution of water and soil (Bijlsma and Kuipers, 1989) and the predicted erosion as a consequence of the proposed enlargement of the shipway to Antwerp.

However, there are also a lot of positive effects as a consequence of the works. In the first years after the completion of the dams, in the new habitats important populations of breeding birds have been established, including several rare species. Many of these were formerly quite common in our country on shores, in marshes or extensively used agricultural land. They have declined in recent years because of drainage or more intensive human use of their original habitats. For some species of terns and waders (e.g. Sandwich Tern, Little Tern, Kentish Plover, Avocet) the Delta area is now one of the most important breeding grounds in the Netherlands or even in Western Europe.

For wintering birds the situation is quite similar. Large numbers of herbivorous waterfowl like geese and ducks forage now on the grassland of the former tidal flats and salt marshes. The West-European population of the Barnacle Goose winters almost completely in the Netherlands and this species visits the grasslands along the Haringvliet since long. However, its original habitats strongly diminished here because of the public water works and the change of agricultural grassland in arable fields. Thanks to a nature management,

that changed former reed marshes and tidal flats into wet grasslands, the numbers of these wintering geese could stabilize and even rise.

In the new areas also important botanical values arised. The most striking example is the development of a wet dune-slack vegetation with rare species like Parnassia palustris, Blackstonia perfoliata and several species of orchids. This type of habitat originally occurred in the lower parts of the coastal dunes. There it disappeared, however, almost totally because of the lowering of the groundwater level. Especially on sandy soils with a stable groundwater regime in the Lakes Veere and Grevelingen hundreds of hectares of this particular vegetation type could develop and in the future probably also in the Krammer-Volkerak.

However, the new areas are still in a dynamic state and the above-mentioned values may be temporary. The decline of shore birds in the Grevelingen (Fig. 5) is a good example of this. We also see that shrubs and trees begin to colonize the dune-slack habitats and displace the characteristic herbs. In a later phase parts of the actual dune-slack environment will probably change because of decalcification. In certain cases it is possible to stop or slow down natural succession by grazing or mowing, thus conserving certain development stages by appropriate management methods. However, we have to realize that it is not possible to keep the former estuarine landscape in a young stage, because there are no cyclic dynamic processes to renew abiotic environment. In the long run the ecosystems will grow to a more mature stage and this will inevitably lead to a decline of certain species and the appearance of others. At the moment it will be possible to keep certain species by grazing or mowing for a certain time. However, in the longer run they will disappear.

Anyhow, it is quite clear that a grazing management will lead to ecosystems totally different from those of spontaneous development or a mowing regime. And from that point of view the decision lies with the ecologists and the nature management: what type of nature do we want on the new emerged land?

As mentioned above an important question is what type of nature we want to develop. Do we want open easy grassy areas where geese can forage and waders can breed, or vast marshy woods with breeding colonies of rare and threatened birds like the Spoonbill and the Nightheron? Or maybe we prefer a more patchy landscape with grassland vegetation alternating with shrubs and woodlands, inhabited by threatened invertebrates, amphibia and reptiles. All these types are possible in large parts of the new land. What will be realized depends on the choice how to manage nature. To make such choices the following criteria can be used.

Firstly there are the potentialities of the area that may determine the choice. It is good to point out several elements of this criterion, like:

- * The abiotic environmental conditions, that may differ from place to place. On a salty soil, for instance, it is rather easy to develop a grassland vegetation, but a woodland will not grow there before the soil is desalinated to a depth of several metres.
- * New plant and animal species will have to colonize the new areas. Therefore the proportion of the area, its position to the actual distribution of the species aimed at and the presence of suitable migrating zones are very important.
- * Ecosystems must not only be realisable. They must also be maintainable, especially on the long run.

Another important criterion to formulate the goal for ecosystem development is the significance of the new type of nature for nature conservation. It will be clear that the highest priority must be given to species and communities that are threatened on an international scale.

A final criterion is the technical and financial ability to realize the management that is required.

If we translate the things mentioned above spatially the following pattern results (Fig. 8).

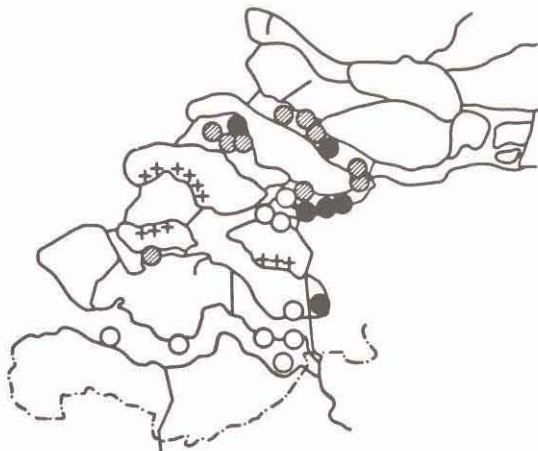


Figure 8 Priorities for futural ecosystem development in the (former) estuaries of the South-West Netherlands. Open circles: salt marshes; hatched circles: former marshes and tidal flats to develop as open landscapes; black circles: the same, but to develop as woody landscapes; crosses: agricultural areas that can be set aside for ecosystem development

Firstly there is a strong reduction of the saltmarsh area. On the one hand the greater part of the remaining salt marshes in the Westerschelde are under great environmental pressure and on the other there are hardly any perspectives to develop new marshes in the relatively clean Oosterschelde. This loss can partially be counterbalanced by setting aside parts of some wet agriculture areas in the polders along the Oosterschelde. In those areas, with a lot of saltwater seepage, there are very good conditions to create inland salt marshes and brackish grasslands or even to abandon polderland to tidal influence. Especially the plants and animals of the higher salt marshes can find a habitat here.

A second important perspective for ecosystem development is lying outside the new dams in the North Sea, the so called "Voordelta". Here are on several places good possibilities to develop dune areas with gradients of fresh dune slacks to salt marshes and breeding places for shore birds.

Finally there are the new terrestrial habitats on the former tidal flats and salt marshes in the closed estuaries. In the estuaries closed first, like Lake Veere, Lake Grevelingen and Haringvliet, large grasslands are the dominating type of ecosystem. From an international point of view spontaneous woodlands and patchy environments with shrubs can also contribute very much to the conservation of endangered species and communities. For this reason it is necessary to make room for shrub and woodland development in the more recently closed estuaries like the Markiezaatsmeer and the Krammer-Volkerak.

7 MANAGEMENT

In conclusion I would like to stress the differences between the developing ecosystems of the former salt marshes and tidal flats and the nature reserves on the "old land".

Firstly there is a great difference in size. Most nature reserves of the old land are, in general, much smaller than the areas in the former estuaries. In the Netherlands there are very few nature reserves with a size of 500 to 1500 hectares with undisturbed gradients in height and a natural groundwater regime. This gives special perspectives in the former estuaries for those species and ecosystems which depend on large-scale processes and lack of disturbance. For this reason splitting up of the new areas must be prevented and nature management must try to consolidate their large-scale character.

Secondly we must realize that in the former estuaries we are developing new values, while on the old land we are conserving existing ones. Because of the non-cyclic dynamics of the ecosystems on the former tidal flats and salt marshes, conservation of the actual flora and

fauna often is the wrong policy, whatever rare the species may be. It is more important to get a good idea of the (abiotic) processes in and the ecological potentialities of the area. On the basis of this knowledge we must formulate a management plan with a goal for ecosystem development on the long run. The long-term goal must be used to evaluate what short-term measurements can be taken. For instance, with the long-term goal to stimulate woodland and shrub development it will be difficult to accept short-term mowing to conserve breeding habitats for rare shore birds. When the long-term goal is the development of grassland ecosystems a mowing regime during some years may be quite acceptable, particularly when endangered species are involved. Even in the last case, however, it is possible that the breeding habitat gets more and more unattractive.

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A CHANGING DELTA: EFFECTS OF LARGE COASTAL ENGINEERING WORKS ON FEEDING
ECOLOGICAL RELATIONSHIPS AS ILLUSTRATED BY WATERBIRDS

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ABSTRACT

In the Delta area of the South-West Netherlands the majority of estuarine ecosystems has disappeared due to large coastal engineering works, creating new artificial saline and freshwater lakes. These hydrodynamical changes had enormous consequences for plants and animals. In this paper the changes in the avifauna are described.

The Voordelta is characterized by a large number of diving ducks and gulls. In comparison with the tidal basins, where the benthivorous species (mainly waders) dominate, numbers of herbivores and piscivores increased substantially in the new lakes, while waders nearly disappeared. Herbivores dominate the avifauna of the lakes. This differentiation is even more obvious in the distribution of individual species, since some species prefer fresh over saline conditions and vice versa. In order to understand the observed distribution patterns, the densities of different bird groups were compared with estimates of the available food. In the tidal areas and the saline lakes a clear relation between piscivore bird density and Gobiid density (their main prey species) was observed. Also wader densities in the tidal basins were clearly related to their food supply. Densities of herbivores are comparable between various basins. Their food source is very variable and hence impossible to estimate. The distribution of diving ducks, feeding mainly on macrobenthos, is very puzzling and seems not at all related to food supply. This indicates factors other than food supply

are determining the distribution of birds in the Delta as well. Next to ecological factors such as population size, migration pattern and diet selection, human activities affect birds, often negatively, in a variety of ways. Disturbance, pollution and habitat loss are immediate threats. Several management options are available and discussed in order to improve the ecological conditions.

1 INTRODUCTION

Over the last two decades the so-called Delta area in the southwestern part of the Netherlands has changed profoundly. In this area the rivers Rijn, Maas and Schelde flew into the sea through a complex system of estuaries. In response to the disastrous storm flood of 1953, in which about 1800 people were killed, an ambitious plan of damming up all but one estuaries was developed. In 1987 the execution of this plan, although adapted in the course of the years, was completed. This resulted in profound changes in the ecological relations, as large tidal areas disappeared and new habitats, such as stagnant saline and brackish lakes, were created. Since describing all these ecological changes is impossible, in this paper we shall restrict ourselves to describe how the occurrence and distribution of birds over the different basins changed and to indicate relations with food supply and other factors. Indeed, the area is very important for birds (Baptist, et al, 1988; Saeijs and Baptist, 1977) and, as the general public is sensitive to birds, they have played a relatively important role in decision-making (e.g. in the discussion about an open or closed Oosterschelde; during the closures of the Philips- and Oesterdam; in the current discussion about the limits to be set on recreation in the Oosterschelde etc.).

In the first part of this paper the major habitats in the Delta area and the observed changes in the occurrence of waterbirds are described. In the second part some factors influencing this observed distribution, being food availability and many other factors as migration patterns, population size and human interference are analyzed.

The present knowledge of birds in the Delta area and the data presented in this paper result from the work of many people. Much is due to Rijkswaterstaat, Tidal Waters Division (the former Delta Department) which sponsored a project in which Rijkswaterstaat (Henk Baptist, Eric Martejn and Peter Meininger) carried out the monthly counts and breeding bird surveys, the Delta Institute for Hydrobiological Research, Yerseke (Rob Lambeck and colleagues) which started a ringing programme in co-operation with Rijkswaterstaat, and the University of Gent which studied some aspects of the feeding ecology of waders (Patrick Meire, Jan Seys, Johan Stuart, Fred Twisk and Tom Ysebaert).

2 DESCRIPTION OF THE AREA

As the ecological conditions are so different between the basins and because they have changed considerably, a brief description of the Delta area (Fig. 1) is given. More details can be found elsewhere in

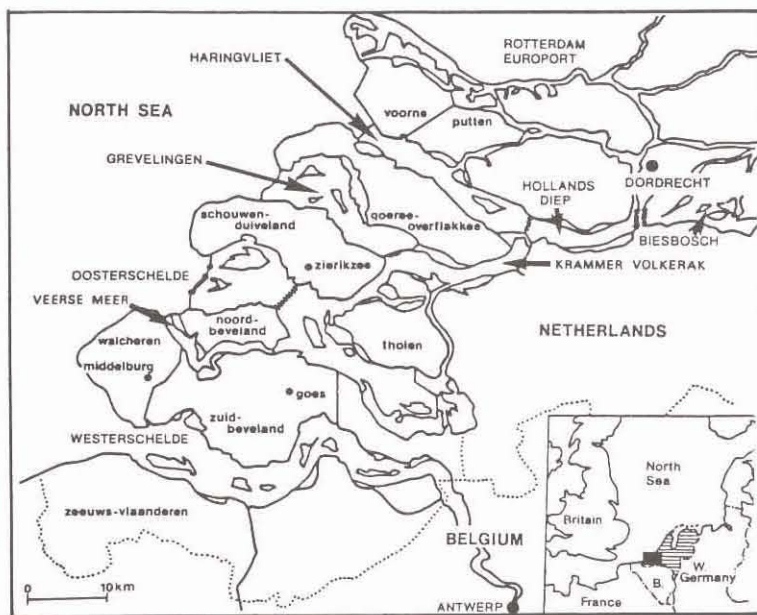


Figure 1 Map of the Delta area with the location of the different basins

this volume or in Duursma, et al, 1982. The situation is described up to 1984 since the data on birds presented in this paper are restricted to the period 1976-1984.

The major physical and chemical characteristics of the different basins are given in Table 1. For each of the tidal areas, the surface of salt marshes, tidal flats, tidal waters (the area permanently covered by water) and adjacent wetlands (creeks, "inlagen" and grasslands which are used by birds either as resting or as additional feeding sites) is given. For the lakes the surface of deep water (> 1.5 m), shallow water (< 1.5 m) and shores is given. Shores are the very shallow areas (< 0.2 m) of the lake of the majority of the areas permanently exposed after the formation of the lake and now used by waterbirds (agricultural land, nature reserve etc.) as well as the adjacent wetlands.

The Voordelta is that part of the North Sea just off the Delta area. It consists of a system of channels and shallow areas. Salinity and turbidity are high. The sandy beaches are subject to heavy wave action and suffer from a very high recreation pressure. More details of this area and the changes occurring here are described by Mulder, 1989. The Westerschelde is the only remaining true estuary in the Delta. The freshwater input from the river Schelde is small (on average $100 \text{ m}^3/\text{sec}$), hence the brackish part is limited to the area between Antwerpen and Hansweert. From the mouth towards Antwerpen a gradient of decreasing salinity, oxygen and transparency, and of increasing suspended matter and nutrients is found (Hummel, et al, 1988). Large mud- and sandflats occur all over the estuary. "Het Verdrongen Land van Saeftinghe", in the brackish part of the estuary, is the largest salt marsh (2250 ha) of the whole Delta area. The estuary is characterized by a large anthropogenic stress due to discharges of inorganic and organic contaminants, mainly by the river Schelde, but also from other effluents along the Westerschelde itself, and due to intensive dredging activities for shipping. In the Oosterschelde the input of fresh water is so small, that the area is better characterized as a sea arm than as an estuary. Salinity is high and constant; turbidity, concentrations of nutrients and pollutants are low. Before the construction of the

Table 1 Some important physical and chemical characteristics of the different basins in the Delta area. Voordelta (VD), Krammer-Volkerak (KV), Oosterschelde (OS), Westerschelde (WS), Grevelingen (GV), Veerse Meer (VM), Haringvliet (HV), Hollands Diep (HD), Biesbosch (BB). (^o VM tidal range is difference between winter and summer level.)

	VD	WS	OS	KV	GV	VM	HV	HD	BB
Tidal range	3.5	3.8-4.5	2.8-3.8	3.8	0	0.7 ^o	0.2-0.35	0.2-0.35	0.2-0.65
Chloride content (g Cl-/l)	17.4-18.7	0.3-18	15-17.5	4.3-14.5	13-17	6-16	0.1-0.4	0.1-0.3	0.04-0.2
Visibility (Secchi disc, m)	?	0.2-0.75	1-2.4	1.6-1.9	3-3.7	2.6-4.1	0.6-1.7	0.6-0.8	0.6-1
Suspended matter (mg/l)	5-41	31-98	6-37	5-16	1.5-35	1-?	3-14	6-23	?
N (mg/l)	0.2-0.4	0.6-7.1	0.92-1.14	2.85	0.5-0.9	2.4-?	0.9-1.9	0.9-2.2	?
Nitrate NO ₃ - (mg/l)	0.2-0.5	0.2-4.8	0.04-1.3	0.5-3.9	0.01-0.6	0.01-3.0	3-4.5	3.2-4.4	2.7-4.6
Ammonium NH ₄ - (mg/l)	0.04-0.1	0.1-5.3	0.02-0.2	0.03-1	0.01-0.2	0.03-0.4	0.2-1.7	0.2-1.9	0.2-1.8
P (mg/l)	0.06-0.1	0.1-1.6	0.1-0.2	0.1-0.2	0.1-?	0.3-0.7	0.3-0.5	0.4-0.5	0.65-?
Orthophosphate PO ₄ - (mg/l)	0.03-0.1	0.06-0.8	0.02-0.09	0.06-0.2	0.07-0.5	0.3-0.7	0.2-0.4	0.2-0.4	0.1-0.3
Total Surface	28500	31000	41698	6945	13600	3622	9850	4960	7300
Salt marshes	0	2775	1078	645	-	-	-	-	-
Tidal flats	3000	8240	14310	2570	-	-	-	-	-
Tidal water	25000	20135	23540	3230	-	-	-	-	-
Adjacent wetlands	500	1000	2770	500	-	-	-	-	-
Deep water	-	-	-	-	8302	1425	6820	3950	2800
Shallow water	-	-	-	-	2498	350	1150	450	900
Shores	-	-	-	-	2800	1847	1880	560	3600

Volkerak sluices, the Oosterschelde had a much more estuarine character. The relatively few and small salt marshes are restricted to the eastern part, whereas extensive tidal flats occur all over the estuary. The northeastern branch of the estuary (Keeten, Mastgat, Zijpe) continues as the Krammer-Volkerak. The freshwater input here was regulated by the Volkerak sluices at about 50 m³/s. In both Oosterschelde and Krammer-Volkerak there is a very intense mussel culture. Although most of the musselbeds occur sublittoral, the intertidal ones are extremely important for birds. The Grevelingen Meer was created in 1971 after the closure of the Brouwersdam and is a saline lake. Water exchange with the North Sea was re-established in 1978 when a sluice in the Brouwersdam became operational and an

artificial waterflow was created after the construction of a sluice in the Grevelingendam in 1983. This had profound effects on waterquality (Bannink, et al, 1984). Large musselbeds and extensive fields of Eelgrass (Zostera marina) occur in the lake. The Veerse Meer was created in 1961 after the closure of the Veerse Gat Dam and the Zandkreekdam. To improve water drainage from the surrounding polders the waterlevel is lowered about 70 cm in winter and raised again in spring with water from the Oosterschelde. This management resulted in a brackish, very eutrophic lake. As a consequence seaweeds, especially Ulva sp., are very common and in the deeper parts of the lake anoxic conditions prevail during most of the year (due to stratification). The Haringvliet, formerly a typical estuarine area, and the Hollands Diep and Biesbosch, formerly freshwater tidal areas, became freshwater lakes with a very small tidal influence (about 20 cm) after the construction of the Volkerakdam in 1970 and the Haringvlietdam in 1971. These basins are important for the discharge of the rivers Rijn and Maas. Fluctuations of the waterlevel are accordingly related to the river discharge. The reduction of current velocities after the closure resulted in a very high sedimentation rate of polluted mud, especially in the Biesbosch and Hollands Diep. More details on the Haringvliet, Hollands Diep and Biesbosch can be found in Bijlsma and Kuipers, 1989.

In the newly created lakes parts of the former tidal flats became permanently exposed. Here the vegetation could develop depending on the management of the site, and nowadays gradients from pastures to woodlands are present. Along the Haringvliet and Hollands Diep extensive rush and sedge vegetations occurred, which have now been replaced by reed and grass vegetations (Hermelink and Mes, 1987). The development of these areas is described by Van Haperen, 1989. In the lakes erosion of the shores, due to the wave action, became a widespread problem. Small dams, well in front of the existing banks, are now being built, creating a shallow area with calm water, which is very favoured by waterbirds.

The monthly bird-counts in the whole Delta area between 1976 and 1986 have been summarized in Meininger, et al, 1984, 1985; Meininger and Van Haperen, 1988, and Baptist and Meininger, 1989. The average number per species per month per basin was calculated and used in further analysis. The total number is the sum of these average monthly counts of each species in the period 1976-1984. It is the best measure of bird use of an area since it is not biased by seasonal patterns.

In winter up to 700 000 waterbirds can be present in the Delta area. Much smaller numbers occur in summer (Fig. 2). Approximately 80 species

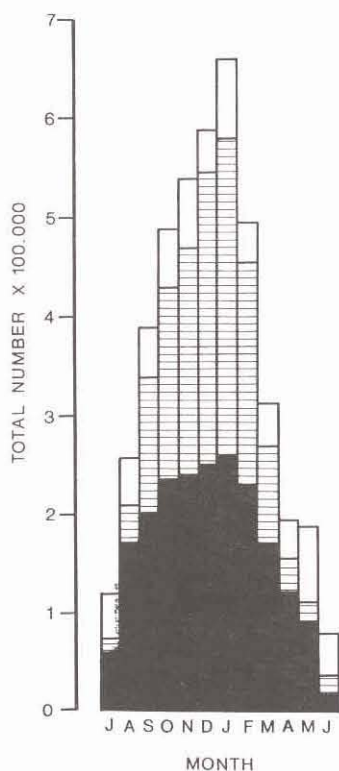


Figure 2 Pattern of occurrence of waterbirds in the Delta area. The average monthly totals of the period 1976-1984 are given. (Black, waders; hatched, ducks; white, other waterbirds)

of waterbirds occur regularly. The most important groups are ducks, waders, geese, gulls and terns; less abundant are grebes, cormorants etc. For all these bird species, occurring regularly, the Delta area has a very important function in several stages of their life cycles.

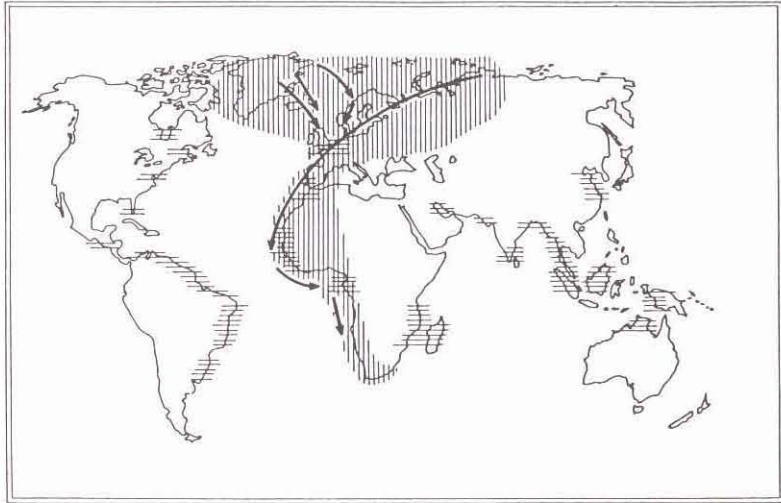


Figure 3 Map of the World, showing the major migration routes of birds occurring in the Delta area. (Horizontal hatching: major intertidal areas; vertical hatching: breeding and wintering range of birds using the Delta area)

Figure 3 summarizes the origins and destinations of birds occurring in the Delta. In summer important numbers of breeding birds of several species are present (Meininger, 1986). After the breeding season most of these birds migrate south, some to the west coasts of Africa, while other species are more or less resident. Birds breeding in the boreal, subarctic and arctic zone of Europe, Asia, Greenland and North America use the Delta either as a refuelling site on migration between the breeding areas and the wintering grounds (in spring and autumn), or as a wintering site. Many species also moult in the area. All these species have in common a large energy demand and are hence dependent on an abundant food supply and low levels of disturbance. Their occurrence show that the Delta area acts as a turntable in large scale movements

of birds and this immediately stresses the international importance of the Delta. Criteria have been agreed upon internationally to express the importance of a wetland area (Sziij, 1972): if more than 1% of a population (either 20 000 waders or 10 000 ducks) regularly occurs, the area is considered to be of international importance. In the Delta area the numbers of 41 species exceed these criteria.

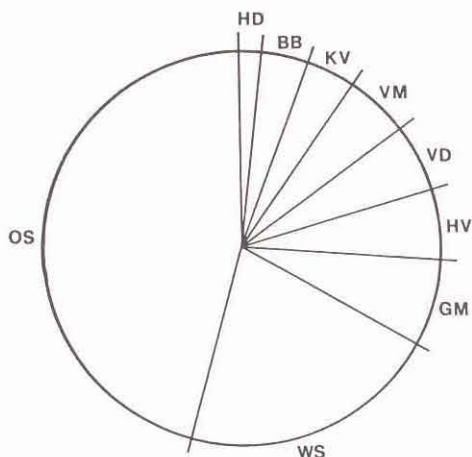


Figure 4 Proportion of the total number of waterbirds in the Delta occurring in each of the basins. (Voordelta (VD); Westerschelde (WS); Oosterschelde (OS); Krammer-Volkerak (KV); Grevelingen Meer (GM); Veerse Meer (VM); Haringvliet (HV); Hollands Diep (HD); Biesbosch (BB))

The birds are not evenly spread over the whole Delta area. In Figure 4 the relative importance of each basin is given (expressed as the percentage the total number of birds in each basin represents of the overall total number in the Delta). The outstanding importance of the Ooster- and Westerschelde is very clear. With less than 50% of the total wetland area they accommodate 67% of the birds of the whole Delta area. How this distribution is related to food supply will be analyzed in the following sections.

4 DISTRIBUTION OF WATERBIRDS OVER THE DIFFERENT BASINS AND RELATIONS WITH THE FOOD SUPPLY

Before relating the occurrence of birds to the distribution of their food it is necessary to describe the position of the birds in the estuarine or lake ecosystems. Therefore a simplified model of the energy fluxes in the different basins is given in Figure 5.

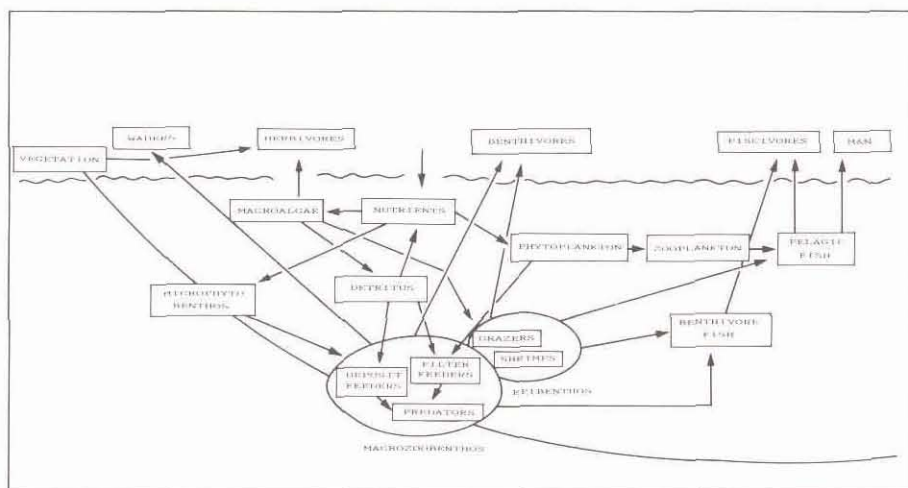


Figure 5 Schematic representation of the major links in the food web in the basins of the Delta area

Nutrients are used by phytoplankton, microphytobenthos and macroalgae. The latter, together with saltmarsh plants, their seeds or the vegetation along the banks and adjacent agricultural areas are the main food source for herbivores, being geese and most species of dabbling ducks. Microphytobenthos can be used as a food source by a few birds, especially Shelducks. The macrozoobenthos, large sized (> 1 mm) invertebrates living in the sediment, can be divided into filter-feeders, depositfeeders, scavengers and predators. Filterfeeders, mainly molluscs such as Cockles (*Cerastoderma edule*) and Mussels

(Mytilus edulis) in salt water, Cerastoderma glaucum and Mya arenaria in brackish water and the Zebra Mussel (Dreissena polymorpha), Pisidiidae and Anodontidae in fresh water, feed mainly on phytoplankton. Under normal conditions filterfeeders dominate the biomass. However, they are often the first species to decline or disappear under pollution stress. In salt and brackish water several polychaetes (e.g. the Lugworm Arenicola marina), molluscs (e.g. Macoma balthica) and crustaceans feed on detritus, others are scavengers or predators (e.g. the Shorecrab Carcinus maenas). Especially in the saline lakes the epibenthos must be very important although available data are scarce. It consists of shrimps (Crangon sp. and Mysidaceae) and many other species of Crustacea (Isopoda and Amphipoda). In fresh water Polychaeta are replaced by Oligochaeta and Chironomidae.

All these organisms form the prey of the different species of benthivores such as waders and diving ducks. Shrimps and mysids are also important prey for gulls (e.g. Black-headed Gull) and terns during the breeding season and for some species of grebes in winter. The diet of the Pochard, a diving duck, consists in the Delta mainly of the seeds of Eelgrass (Boudewijn and Mes, 1986) and this species is consequently included with the herbivores in our further calculations. Benthos and zooplankton also form the food source for many fish species, which in turn are eaten by the piscivores as Cormorant, mergansers and grebes. This basic food web is quite similar for the different basins, although - mainly depending on the salinity - different species are found and depending on the hydrodynamical conditions different links of this food web are more important.

The various functional groups of birds described above (benthivores, piscivores, herbivores) are used in further analysis and called bird groups. Benthivores were divided into waders and diving ducks as these groups differ so markedly in the habitat they use (tidal flats versus open water). Gulls are mainly omnivores and are also treated separately. Terns, typically piscivorous birds, are not included in the analysis, as this species is not very well covered in the counts. In addition their feeding areas are not well known. Since they are rather

small birds excluding them will not significantly change the conclusions.

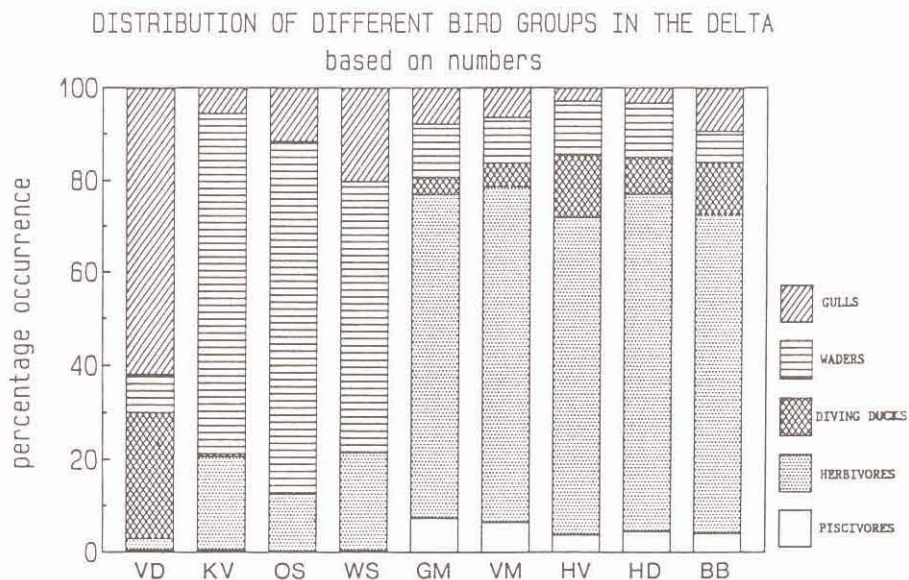


Figure 6 Occurrence of different bird groups in the different basins. For each group the percentage on the total number of birds is given. (For abbreviations see Figure 4; the bird groups are defined in the text and in the Appendix)

To gain insight into the distribution of waterbirds over the different basins the proportion of each bird group on the total number per basin is given in Figure 6. The Voordelta is clearly different from the other sites with a very high proportion of gulls, few waders and quite many diving ducks. The three estuaries, Krammer-Volkerak, Oosterschelde and Westerschelde, are very similar in having a very high proportion of waders and - to a lesser extent - herbivores and gulls. The relative importance of the different bird groups in the lakes is quite similar and characterized by a dominance of herbivores. Compared to the estuarine situation the importance of waders in the lakes decreased

substantially and that of piscivores and diving ducks increased. The distribution of individual species over the basins is even more pronounced than that of the bird groups. In Figure 7, as an example, the proportion of the total number in the Voordelta, the tidal areas (Krammer-Volkerak, Oosterschelde, Westerschelde), the saline (Grevelingen, Veerse Meer) and freshwater lakes (Haringvliet, Hollands Diep, Biesbosch) for some important duck species is given. Common Scoters are found almost exclusively in the Voordelta, Goldeneyes in the saline lakes and Tufted Ducks and Pochards in freshwater lakes. Wigeons and Pintails occur mainly in the tidal areas, Mallards are common everywhere with the exception of the Voordelta and Coots clearly prefer saline lakes. Similar preferences exist in the other species.

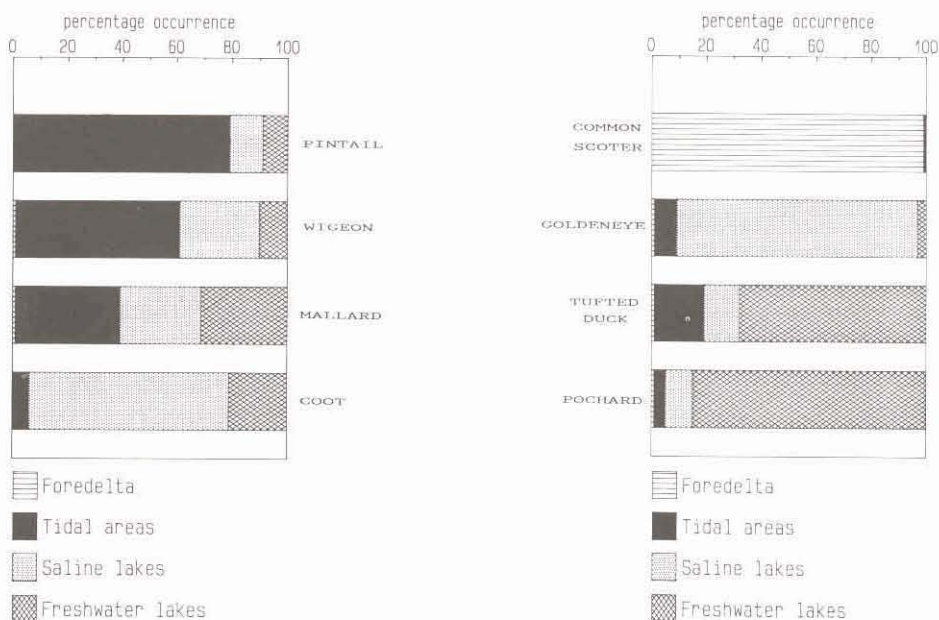


Figure 7 Distribution of some species over the basins (grouped in the Voordelta, the estuaries for tidal areas (Westerschelde, Oosterschelde, Krammer-Volkerak), saline lakes (Veerse Meer, Grevelingen Meer) and freshwater lakes (Haringvliet, Hollands Diep, Biesbosch). The percentage of the total number in each category is plotted.

In order to look for relationships between prey and bird abundance and to try to understand the distribution described above, the density of each bird group was calculated (the mean of the 12 average monthly counts of the period 1975/76 - 1983/84 was used). For each group the surfaces of the following habitats (for the tidal and stagnant basins respectively) were used to calculate the density: piscivores: tidal water and tidal areas or deep and shallow water; waders: tidal flats or shores; diving ducks: tidal water and tidal areas or deep and shallow water; herbivores: salt marshes and adjacent wetlands or shores and shallow water. Of course this is a very crude approximation but for such a large scale comparison no greater detail can be used.

Table 2 Winter density (N/1000 m²) of Gobiid fish and densities of Piscivores (N/100 ha) in the different aquatic systems of the Delta area. (Source of fish data: (1) Hamerlynck (pers. comm.) (2) Hamerlynck, et al, (in press) (3) Doornbos and Twisk, 1987 (4) Waardenburg and Meyer, 1988) (Voordelta (VD); Westerschelde (WS); Oosterschelde (OS); Krammer-Volkerak (KV); Grevelingen Meer (GM); Veerse Meer (VM); Haringvliet (HV); Hollands Diep (HD); Biesbosch (BB))

Basin	Fish	Source	Bird
	Density (N/1000 m ²)		Density (N/100 ha)
VD	0-12000	1	0.3
KV	?		1
OS	45	2	0.8
WS	27	2	0.9
GV	1592	3	15.4
VM	3500	4	61.6
HV	0		7.8
HD	0		5.6
BB	0		12.6

The main diet of piscivores in the saline waters consists of Gobiid fish (Pomatoschistus microps, P. minutus, P. lozani). In the Grevelingen Meer the diet of Great Crested Grebe consisted for more than 60% (by weight) of Gobiidae (Doornbos, 1984). Other important species were Herring (Clupea harengus) and Shrimps (Grangon crangon). The Three-spined Stickleback (Gasterosteus aculeatus) is very abundant in the Veerse Meer (Waardenburg and Meijer, 1988), but it is not known to what extent they are eaten by birds. As Gobiid fish forms the majority of the diet and more or less comparable data are available, the average winter density is given in Table 2 together with the densities of piscivores. Clearly the highest densities of both fish and birds are found in the Veerse Meer. In the Voordelta the Gobiid densities are very variable and probably transparency, which is very low, and wave action prevent birds from feeding here. In the tidal areas and the saline lakes a clear relation between piscivore densities and Gobiid densities is found. In the freshwater lakes rather high densities of piscivores are found. Perch (Perca fluviatilis), Roach (Rutilus rutilus) and other Cyprinidae as well as Gasterosteidae are important prey species in these lakes. However, no density estimations are available.

The biomass of macrozoobenthos and the densities of waders and diving ducks are given in Table 3. Waders occur mainly on intertidal areas where they feed on many different species of invertebrates. Some waders are very specialized, for instance Oystercatchers which feed mainly on Mussels and Cockles; others such as Dunlin feed on a variety of polychaete worms (Nereis sp.; Scoloplos armiger etc.) and small crustaceans (e.g. Corophium sp.) whereas Bar-tailed Godwits feed on both worms, crustaceans and molluscs. Sometimes the diet changes with the seasons. In autumn the diet of Curlew consists mainly of the Shorecrab whereas in winter, when the crabs move to deeper water, Curlews feed mainly on large worms (Lugworms and Nereis sp.). In the tidal basins an obvious relation between the densities of waders and the available biomass exists. A very high biomass and density is found in the Oosterschelde, much lower values in the Westerschelde and Krammer-Volkerak. The densities of waders in the other basins are much lower and as they are feeding there in a variety of habitats, the diet

Table 3 Biomass of macrozoobenthos and densities of waders and diving ducks in the different basins of the Delta area. The average autumn biomass (g ash free dry weight/m²) of the whole basin and of the intertidal area and the density of waders and ducks (birds/100 ha) are given. (Source of macrozoobenthos data: (1) Craeymeersch (pers. comm.) (2) Coosen and Van den Dool, 1983 (3) Coosen and Smaal, 1985 (4) Meire and Develter, 1988 (5) Lambeck, et al, 1985, 1986, 1987. (6) Seys and Meire, 1988 (7) Fortuin, 1985.) For abbreviations see Table 2.

Basin	biomass overall	biomass intertidal	source	waders	diving ducks
VD	20	?	1	44	17.5
KV	20.3	17.2	2	363	1.4
OS	62	45	3	761	1.5
WS	?	15.1	4	459	0.4
GV	28.7	-	5	70	8.3
VM	11.6	-	6	80	50
HV+HD	1.1	-	7	86	10.8
BB	?	-		21	18

is not known and hence it is not possible to calculate the available food supply. Diving ducks like Goldeneyes and Tufted Ducks feed mainly on molluscs (Zebra Mussels, Mussels, Cockles etc.) as well as on different species of worms and crustaceans. A relation between macrobenthic biomass and the density of diving ducks is not clear at all. The highest densities of diving ducks are found in the Veerse Meer, although the biomass is lower than in other areas. Additionally in the freshwater lakes high densities of diving ducks are found although the benthos biomass is very low. On the other hand in both the Oosterschelde and the Krammer-Volkerak a large benthos biomass is present but remarkably low densities of diving ducks are found. Clearly other factors must influence the distribution of these birds. This will be discussed later.

The herbivores form a rather heterogenous group of swans, geese and ducks. Some species like the Brent Geese feed mainly on Eelgrass and salt marshes, although in winter seminatural grasslands and cereal crops form an important part of the diet (Ebbinge, et al, 1987). Mute Swans are strongly attached to water for feeding, whereas other species like the Mallard feed mainly on adjacent wetlands and agricultural land and use the basins mainly for resting, drinking and preening. As the food source used by these birds is so variable (e.g. agricultural wastes and crops) it is impossible to estimate the available food supply. Therefore in Table 4 only the biomass of macroalgae (mainly Ulva sp. and Zostera sp.) and the density of herbivores are given. With the exception of the Voordelta the average density of herbivores is quite similar in the different basins, although somewhat higher in the

Table 4 Occurrence of macrophyta (tons ash free dry weight at maximum standing stock) and herbivores (birds/100 ha) in the different aquatic systems of the Delta area. (Source of macrophyta data: (1) Craeymeersch (pers. comm.) (2) De Jong (pers. comm.) (3) Nienhuis (pers. comm.) (4) Hannewijk, 1988.) For abbreviations see Table 3.

System	Total biomass macrohyta	<u>Zostera</u>	Green algae	Source	Density of herbivores
VD	small	0	small	1	87
KV	360	80	280	2	199
OS	1833	387	1457	3	334
WS	small	0	small	2	379
GV	?	1110-3300	?	3	302
VM	690	9.6	680	4	562
HV	small	0	0		415
HD	small	0	0		418
BB	small	0	0		190

freshwater basins. Clearly the presence of these macrophyta have no influence on the density of all herbivores as they form only a small part of the diet of only some species. Notwithstanding the huge differences in food supply it is remarkable no larger differences in densities exist.

Table 5 Comparison between the consumption (C) (kg ash free dry weight/100 ha) and density (D) (birds/100 ha) of different bird groups in the tidal areas, the saline and the freshwater lakes (for further explanation see text).

		TIDAL	SALINE	FRESH
Herbivores	C	8496	12150	12846
	D	300	430	340
Diving ducks	C	28	777	344
	D	1	30	13
Waders	C	6220	888	760
	D	530	75	75
Piscivores	C	28	935	312
	D	1	39	9

In Table 5 the data on densities are summarized together with estimates of the food consumption of the different bird groups. This was obtained by standard methods (see e.g. Nienhuis and Groenendijk, 1986). It is obvious that the densities of herbivores are high in comparison with those of other groups, their consumption even much higher. This is what we expect from primary consumers. Waders and diving ducks are secondary consumers and their densities as well as their consumption are much lower. The only exception are waders in the tidal areas. It is obvious

that the predation pressure here is very high. This is also confirmed by the review paper of Baird, et al, 1988, and the tidal flats form a very distinct ecosystem. Densities and consumptions of piscivores (tertiary consumers) are on average lower. Remarkable is the high density and consumption in the saline lakes. These results fit more or less in the concepts of ecological pyramids (Odum, 1972). From Figure 5, however, we see that a food web is a better description of the reality, hence explaining some deviations from the expected pyramid structure.

5 FACTORS COMPLICATING THE RELATION BETWEEN DISTRIBUTION AND FOOD SUPPLY

From the previous section it is obvious that relations between bird density and food supply are not always obvious. First of all the data of many species have been analyzed together. If wader densities in general are related to prey densities, it is very likely that this holds also for most of the abundant species. However, if no correlation is found for all birds of a bird group, this does not mean that the densities of individual species may not be closely linked to their food supply. It is clear, however, that not only food supply but many other variables may influence the distribution and density of birds. These factors may be purely ecological or resulting from human activities. We will try to briefly describe some of them in order to show the complexity of the whole system and the difficulties one encounters in predicting effects of impacts on the ecosystem. We hope this will make clear that in planning we should be very conservative and use very large margins concerning environmental matters.

5.1 Ecological factors

Migration, large-scale distribution patterns of a species and climatic conditions are very important in determining bird numbers. Indeed for several species the Delta area forms either the northern or the

southern boundary of the winter distribution (e.g. Lapwing, Avocet, Black-tailed Godwit and Barnacle Goose, Bewick's Swan respectively). In these cases the severity of the winter may strongly influence bird occurrence. In mild winters much larger numbers of some species, sensitive to frost, may be present; in severe winters large numbers of birds, normally wintering more to the north, are forced to migrate further southwards and peak numbers of some species can be counted. During a cold spell the presence of open water is extremely important and may attract birds from the large surroundings.

Furthermore bird numbers in an area are not only dependent on the food supply but also and on the quality of other areas. Indeed if, for whatever reason, the food supply at the beginning of the winter in an area is extremely high or low, many more or less birds may stay there, influencing the numbers in other basins, where nothing in the food supply might have changed.

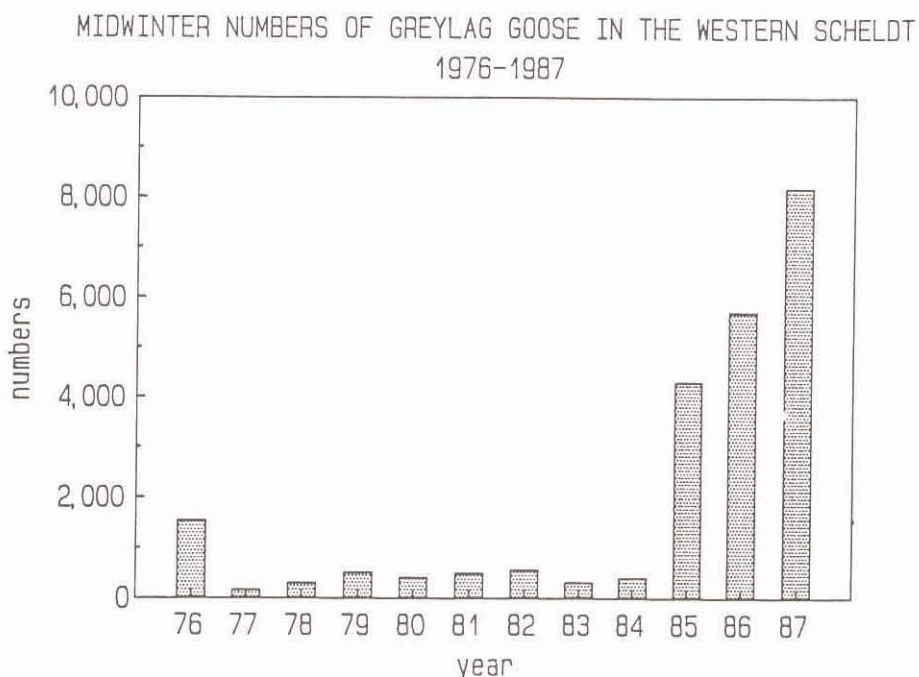


Figure 8 Evolution of the number of Greylag Geese in the Westerschelde

Overall population size is very important as well. Indeed in the last decades a few species, like the Greylag Goose (Fig. 8) and the Cormorant, increased in numbers in the Delta area. This is not due to any changes in the food supply but to an overall increase in the population. In Europe the Greylag population has increased from 30 000 to 130 000 between 1974 and 1984 (Madsen, 1987). The total population size of arctic breeding species can vary substantially between years due to the varying breeding success. Of other species (e.g. Dunlin) population size decreased during the last years, a decline which is obvious in the counts from the Delta area.

These were all factors acting on a large scale. In the Delta area itself, several aspects of prey selection may influence the distribution of a species. In the analysis presented all prey species were lumped into large categories. Some species are, however, very specialized feeders, whereas others feed on a large variety of prey species. This may affect the occurrence of birds quite substantially. In the Veerse Meer Ulva sp. forms a very important prey item for herbivores such as Coots and Brent Geese. Due to predation and the natural mortality of the plants the available amount of Ulva sp. declines rapidly during autumn and winter. During that time Brent Geese switch to other prey available in the area, mainly pastures and arable land, and their numbers remain stable until April-May (Fig. 9). Coots, however, do not change diet and numbers start to decline already in January, much earlier than in other parts of the Delta.

Even for birds feeding on one prey species, there might be factors complicating the relation prey abundance - bird density. The Oystercatcher is the most numerous wader species in the Oosterschelde and it almost exclusively feeds on Cockles and Mussels, with each individual only feeding on one of these species. The selection of mussels has been studied in detail (Meire and Ervynck, 1986; Meire, 1987) and it is found that there is not only selection for larger mussels but even for the thinner-shelled individuals within a length class. It has been shown that these selection patterns are caused by energetic constraints. While the cost for opening small mussels is not rewarding due to very small yield of flesh, the thick shelled mussels

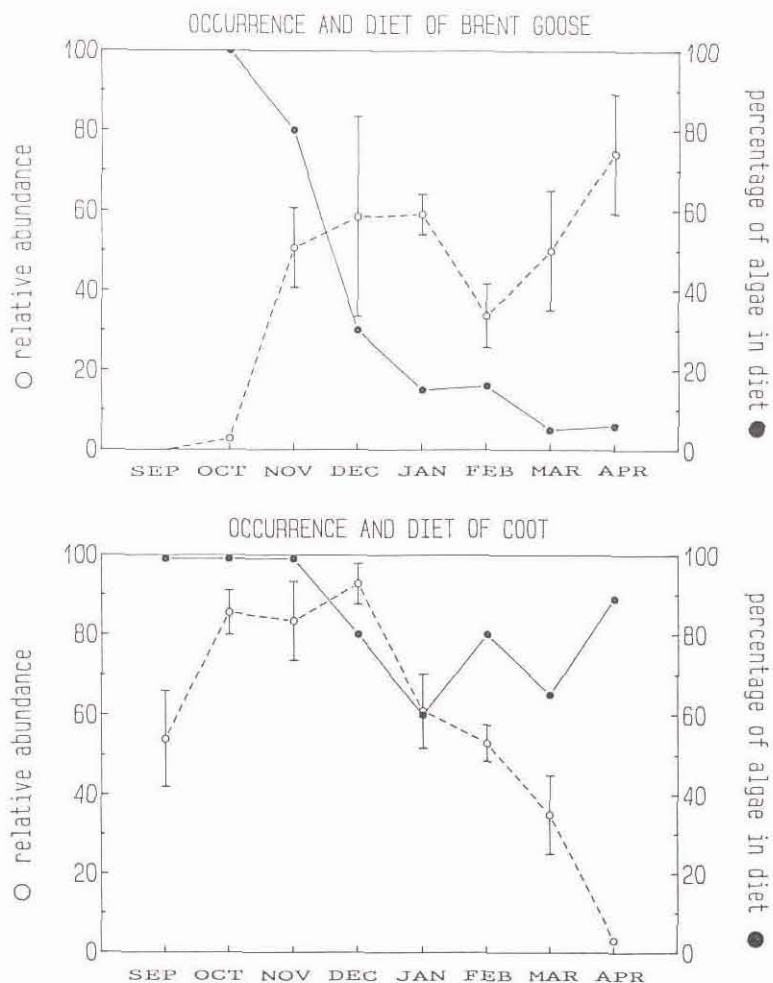


Figure 9 Occurrence and diet of Brent Goose and Coot in the Veerse Meer during the winter 1987/1988 (based on Stuart, 1989)

are too hard to open. This selection pattern implies that only a part of the prey population is really available to the birds, caused by the selection-behaviour of the birds themselves. However, prey availability is often influenced by the prey itself. In intertidal areas many macrobenthic species may be buried deep in the substrate, well beyond

reach of the birds' bill. Different age classes of burying bivalves, such as Scrobicularia plana and Macoma balthica, can be successively eaten by different species of waders depending on their bill length as the older individuals lie deeper in the substrate (Zwarts and Wanink, 1984). Similarly dabbling ducks can reach aquatic plants only within a small depth range. Mute Swans can reach down to 1.5 meter, Coots only to 0.5 meter. Benthic feeding ducks are also limited by the water depth as they can stay under water only for a certain time.

However, the availability of the prey population can also be dependent on its own activity. Corophium volutator, a small crustacean living in U-shaped burrows, is detected by its predators, e.g. Redshanks, when it is feeding on the mudsurface by quickly moving the antennae. After a Redshank passed, all C. volutator retreat in their burrow, due to the vibrations in the sediment caused by the walking bird, and become unavailable to the predators for nearly a quarter of an hour (Goss-Custard, 1970).

Another very important factor influencing bird distribution is salinity, not only by its effects on the prey populations, but by its influence on the osmoregulation of the predator. Birds feeding on marine prey organisms have to excrete the excess amount of salt intake, while feeding, through the nasal glands. If the salinity of the water where they are feeding is too high, they need to drink fresh water in order not to dehydrate (Nyström and Pehrsson, 1988). It is very well documented that the Pochard, which feeds on Eelgrass (Zostera marina) in the saline Grevelingenmeer, rest on the fresh Haringvliet (Boudewijn and Mes, 1986). Nyström and Pehrsson, 1988, linked both distribution and diet of several coastal waterfowl species to their uptake and ability to excrete salt. It is most probably that the very high densities, especially of diving ducks, in the Veerse Meer, in comparison to the Grevelingen Meer where the food supply is much higher, might be due to the much lower salinity in the Veerse Meer.

5.2 Human factors

Next to all factors intrinsic to animals and ecosystems the occurrence of birds is also strongly influenced by man in a great variety of ways. Disturbance, pollution and habitat loss are the major factors.

Disturbance by airplanes, boats, walking people, bait-digging, etc. causes birds to leave the feeding or resting areas for some time. For waders, disturbance distances have been measured. They differ greatly between species. Curlews are most sensitive and fly away at least 250 m from someone walking, Turnstones can be approached up to 100 meter (Van der Meer, 1985). Disturbance causes a reduction in feeding time and extra energy losses due to flying. This can cause the birds to leave suitable feeding sites. Not only disturbance at feeding sides but the availability of suitable rest sites can also determine the occurrence of some bird species. This certainly holds for breeding sites.

Pollution can affect birds in two distinct ways: through a deterioration of the food supply or through impairment of the physiological processes in the animal itself, possibly leading to death. It is known that pollution stress changes the structure of benthic populations and communities become dominated by a few small sized species (Gray, 1982). Although their densities can be very high, the biomass is on average quite low. Furthermore, few birds are able to exploit efficiently these very small prey items. When the pollution load increases and anoxic conditions occur, the macrobenthic fauna may nearly completely disappear, as is found in the eastern part of the Westerschelde (Develter, et al, 1988; Meire and Kuyken, 1988).

Obviously birds will disappear here as well. It has been shown that eutrophication can improve benthic productivity (Beukema and Cadée, 1986, 1987) and Van Impe (1985) associated the increase in bird numbers in the eastern part of the Westerschelde between the fifties and the seventies to the improved foraging conditions for these birds as a consequence of higher productivity due to eutrophication. As the benthic fauna has collapsed in this areas by now the positive effects of the eutrophication were only very shortlived (Develter, et al, 1988; Meire and Kuyken, 1988).



Little Tern (*Sterna albifrons*), characteristic and threatened bird of the Delta area



Young Little Tern (*Sterna albifrons*)



Bewick's Swans (*Cygnus columbarius*)



The Delta area is one of the most important wintering areas of the species

As birds are mainly top predators, they accumulate quite a lot of toxic substances. The dramatic effects of chlorinated hydrocarbons, insecticides and chlorinated biphenyls on many piscivores in general and especially on the Sandwich Terns in the sixties, decimating their populations are well known (Koeman and Van Genderen, 1972). The effects of accumulation of pollutants are, however, not always so obvious, nevertheless they may severely affect populations. Few data on concentrations of pollutants in birds in the Delta area are available. However, experiments with Tufted Ducks clearly demonstrated that when fed with Zebra Mussels from the Haringvliet their reproductive output was very much depressed (Marquenie, et al, 1986; Scholten and Foekema, 1988). Clearly pollution is a major factor affecting birds in the Delta area and, as its effects are very diverse and by now not very well understood, much more attention should be paid to this problem in the future.

Habitat loss is of course a very important factor influencing birds. The effects are obvious. In the remaining areas bird densities increase, causing a higher predation pressure and hence a smaller food supply. This together with an increased level of social interactions between individuals can reduce quite substantially the food intake leading to death. A detailed review of the effects of habitat loss on wader populations is given by Goss-Custard, 1985. It should be noted that habitat loss is not only caused by physical removal of an area but also by deterioration of the food supply e.g. due to changing environmental conditions. In the Westerschelde the increased dredging activities cause the intertidal flats to become more sandy since in the larger channels higher current speeds occur, influencing the sedimentation patterns. The benthic fauna and the numbers of waders are much smaller on sand- than on mudflats. This is especially in the Westerschelde a severe threat.

5.3 Management

Man's activities do not always have to affect ecosystems in general or birds in particular in a negative way. Indeed many management measures can be taken to improve the situation, measures which often are rather cheap but very effective. On the Hooge Platen, a large intertidal flat in the Westerschelde, a small part is flooded only at extreme high tides. The construction of a small dike by means of sandbags made the site very attractive for Little Terns. The population increased from 60 in 1979 to 170 in 1985 (Fig. 10), a threefold increase, compared with a

NUMBERS OF BREEDING PAIRS OF LITTLE TERN ON THE HOOGE PLATEN
1979-1988

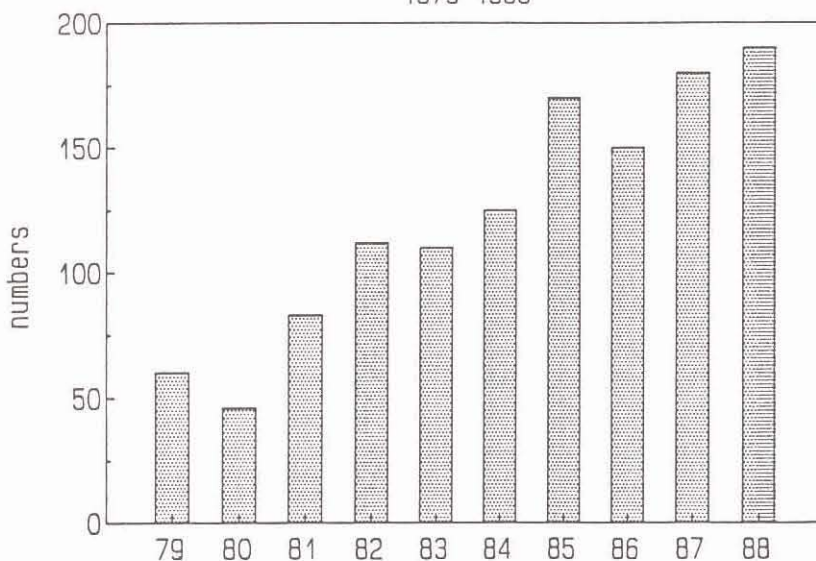


Figure 10 Evolution of the number of breeding Little Terns on the "Hooge Platen" in the Westerschelde (data from R. Beijersbergen, personal communication)

1.3-fold increase in the whole Delta during the same time (Meininger, 1986). On many of the artificial islands in the Oosterschelde, formerly used during the construction of dams, sluices etc., there are

possibilities to create potentially valuable breeding sites for characteristic coastal breeding birds. By means of changing the hydrology, e.g. by (partially) inundating small polders adjacent to the Oosterschelde and the Westerschelde, the importance for birds can be improved. In most places the ever increasing pressure by recreational activities (boating, wind-surfers, walking, bait-digging, fishing etc.) is a serious threat to the various functions for birds. In particular the intertidal areas are highly vulnerable to disturbance, and measures to reduce this disturbance are required. The same applies to some of the shallow parts of the Veerse Meer and Grevelingen Meer, which are increasingly visited by wind-surfers, not only in summer but also in winter! Simple measures (such as floating cables) can be taken to make at least some of these areas inaccessible.

6 CONCLUSION

The creation of new habitats by damming up estuaries has, beyond doubt, increased the diversity of bird life in the Delta. Of both breeding and non-breeding birds several species increased in numbers. Less is known, however, on the changes in population size of the species originally present, although there are indications their populations did not decrease markedly until 1984. Birds quickly reacted to the new habitats created, and the Voordelta, the estuaries, the saline and the fresh lakes each have now their more or less typical avifauna. The gradient in abiotic and biotic conditions is very well reflected by the distribution of the different bird groups as well as by the individual species. However, notwithstanding the attention paid to nature conservation in the newly created habitats, the estuarine areas still accommodate the largest numbers of birds. It should also be stressed that all estuarine ecosystems, and especially brackish and freshwater tidal habitats are on a global scale very rare habitats, which should now be completely protected. Their loss can not be compensated by the creation of new habitats.

For several bird species or groups it is shown that their distribution and abundance is closely linked to that of their food supply. Any

measure affecting food supply or available feeding area will reduce the population of these species (e.g. waders in the Oosterschelde). For other species the relation between density and food supply is less obvious and other variables confounding this relation are discussed. The influence of reduced food supply or available habitat on these species is less easy to predict, although the birds will certainly not benefit from these. Beyond doubt, disturbance has a negative effect on all species. If the international importance of the Delta area for waterbirds is to be preserved, this aspect should receive much attention from the manager. It is very important to inform the public about the importance of the area for birds and their need for rest. Canalizing people by means of hides or observation places might be one part of the solution. It reduces disturbance and the good observation possibilities may enhance a positive attitude towards the habitat and its inhabitants. Additionally the accessibility of certain sites should be restricted. Man's impact on the habitat, by means of dredging, pollution, etc., should be minimized so that naturally functioning ecosystems might be created or preserved.

These few examples imply that management of the Delta area should be based on a sound ecological knowledge, but in order to understand the ecology of a species much detailed research has to be done and a general pattern, as presented in this paper, is only a first step.

ACKNOWLEDGEMENTS

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Appendix

PISCIVORES

Little Grebe	(<u>Tachybaptus ruficollis</u>)
Great Crested Grebe	(<u>Podiceps cristatus</u>)
Black-necked Grebe	(<u>Podiceps nigricollis</u>)
Cormorant	(<u>Phalacrocorax carbo</u>)
Grey Heron	(<u>Ardea cinerea</u>)
Smew	(<u>Mergus albellus</u>)
Red-breasted Merganser	(<u>Mergus serrator</u>)
Goosander	(<u>Mergus merganser</u>)

HERBIVORES

Mute Swan	(<u>Cygnus olor</u>)
Bewick's Swan	(<u>Cygnus columbarius</u>)
Bean Goose	(<u>Anser fabalis</u>)
White-fronted Goose	(<u>Anser albifrons</u>)
Greylag Goose	(<u>Anser anser</u>)
Barnacle Goose	(<u>Branta leucopsis</u>)
Brent Goose	(<u>Branta bernicla</u>)
Wigeon	(<u>Anas penelope</u>)
Teal	(<u>Anas crecca</u>)
Mallard	(<u>Anas platyrhynchos</u>)
Pintail	(<u>Anas acuta</u>)
Shoveler	(<u>Anas clypeata</u>)
Gadwall	(<u>Anas strepera</u>)
Coot	(<u>Fulica atra</u>)
Pochard	(<u>Aythya ferina</u>)

BENTHIVORES

(WADERS AND SHELDUCK)

Shelduck	(<u>Tadorna tadorna</u>)
Oystercatcher	(<u>Haematopus ostralegus</u>)
Avocet	(<u>Recurvirostra avosetta</u>)
Ringed Plover	(<u>Charadrius hiaticula</u>)
Kentish Plover	(<u>Charadrius alexandrinus</u>)
Golden Plover	(<u>Pluvialis apricaria</u>)
Grey Plover	(<u>Pluvialis squatarola</u>)
Lapwing	(<u>Vanellus vanellus</u>)
Knot	(<u>Calidris canutus</u>)
Sanderling	(<u>Calidris alba</u>)
Dunlin	(<u>Calidris alpina</u>)
Ruff	(<u>Philomachus pugnax</u>)
Bar-tailed Godwit	(<u>Limosa lapponica</u>)
Curlew	(<u>Numenius arquata</u>)
Spotted Redshank	(<u>Tringa erythropus</u>)
Redshank	(<u>Tringa totanus</u>)
Greenshank	(<u>Tringa nebularia</u>)
Turnstone	(<u>Arenaria interpres</u>)

(DIVING DUCKS)

Tufted Duck	(<u>Aythya fuligula</u>)
Common Scoter	(<u>Melnitta nigra</u>)
Goldeneye	(<u>Bucephala clangula</u>)

OMNIVORES (GULLS)

Black-headed Gull	(<u>Larus ridibundus</u>)
Common Gull	(<u>Larus canus</u>)
Herring Gull	(<u>Larus argentatus</u>)
Great Black-backed Gull	(<u>Larus marinus</u>)

HYDRO-ECOLOGICAL RELATIONS IN THE DELTA WATERS OF THE SOUTH-WEST
NETHERLANDS

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ABSTRACT

The Delta Project has taught us a great deal about the ecological relations between the individual waters of the Delta and between the waters of the Delta and the North Sea and the major rivers. In a number of instances the knowledge gained could directly be translated into terms of allocation and management measures. In other cases valuable lessons were learned for present or future management. In all cases it became clear that in the context of compartmentalization, allocation plans and management should primarily be geared to supervising the resulting processes of change. The object is to make optimal use of the potential of the individual systems as they relate to one another. This paper provides a brief summary of the lessons to be learned from previous studies.

1 INTRODUCTION

One of the most important lessons learned from the Delta Project, and one which has been learned elsewhere too, is that it is fatal to attempt to fight nature. Victories often turn out to be Pyrrhic. The battle against the waters must be waged, but in such a way that nature is on man's side. One should learn from nature, rather than try to teach nature a lesson. Examples can be found in the Delta region of how, in this way, an increase in safety can be combined with the

development of lasting and valuable systems. This should not be interpreted as a licence to compartmentalize estuaries and to create polders in coastal areas. If we have learned one thing, it is that estuarine systems are precious and irreplaceable, both in an ecological and an economic sense. Estuaries are by nature highly productive and dynamic systems. Adequate protection of these areas against pollution, over-exploitation and other detrimental influences can provide a lasting guarantee for such assets. The compartmentalization of the Delta had taught us that this is no matter of course in the case of the thus created waters. The developments, which this process triggered off, require close supervision if these newly-formed waters are to achieve their full potential, and these new Delta waters do indeed have the potential to develop into valuable systems.

The natural relations in the Delta have been upset. However, it has been replaced by new relations. In some cases this has happened on a fairly limited scale, whereas in others an entirely new natural basis has been created. Natural relations are no longer taken for granted. Instead it must be taken for granted that an attempt will be made wherever possible to manage the Delta in its present form as a single coherent whole. The lessons which have been learned up to now, and which have been dealt with extensively in previous chapters, can help to guide this process.

2 SEDIMENTATION AND ACCUMULATION

The build-up of silt and pollutants are processes with which the Netherlands, as a delta-country, is eminently familiar. This problem has also affected the Delta of the South-West Netherlands, and the following lessons have been learned:

- Upstream pollution results in the build-up of pollutants in downstream sedimentation areas with serious detrimental effects on ecological development and economic potential (e.g. pollution of eels). This process is being reinforced by damming up the downstream areas at one side. Therefore damming up cannot be seen

apart from upstream purification;

- In natural estuaries, areas of sedimentation - mud flats and salt marshes - are usually the most valuable areas. They are accordingly exceptionally susceptible to pollution, as in the case of 'Het Land van Saeftinghe'. Attempts to clean upstream should therefore at the very least be directed at safeguarding the natural riches of these sedimentation areas;
- Compartmentalization can be used to confine accumulation of pollutants to a restricted, manageable area. This protects other areas from pollution and accompanying problems. Without compartmentalization a considerable part of the severely contaminated silt, now present as sedimentation in the Hollands Diep and Haringvliet, would have entered the coastal waters and the Wadden Sea. So compartmentalization could also be applied especially for this purpose, however, as an interim measure in combination with efforts to clean up pollution.

3 DOWNSTREAM FRESH WATER EUTROPHICATION

Besides being exceptionally vulnerable to pollution, the semi-stagnant freshwater basins situated downstream are also increasingly susceptible to eutrophication. Heretoo, upstream purification is necessary for responsible compartmentalization. At the same time, however, the scope for management increases:

- A major factor affecting heightened susceptibility to eutrophication is the increase in the residence time of water. The organization of the watermanagement infrastructure, in such a way that the residence times can be reduced to a sufficient degree, is an important management aid;
- Eutrophication primarily results from an excess of nutrients. One of the factors affecting the way in which nutrients pass through an aquatic ecosystem is the latter's structure, and this creates scope for controlling such systems, particularly in the early stages of development, as in the case of the Zoommeer. Ecological parameters must be set for the establishment and development of rich, diverse biocoenoses characteristics of clear water rich in nutrients.

Crucial here is the presence of extensive, protected shallows. Manageability of fish stocks should be central to policy. Simply granting fishing rights to anglers and fishermen, frustrate attempts to combat eutrophication directly by means of active biological management. Success is conditional on the management of fish stocks being incorporated into water quality management.

4 SALTWATER EUTROPHICATION

Saltwater eutrophication is different from freshwater eutrophication, although closed, stagnant salt waters also have a greater susceptibility to eutrophication. One of the main differences is that in the case of salt water often nitrogen is the limiting factor and nitrification is the key process. In response to this the following management measures can be taken:

- Excessive levels of nutrients in stagnant, saline systems are chiefly regional in origin. In principle this provides scope for gearing nutrient levels to the individual capacity of a system. At its present level, the channelling of nutrient-rich polder water into the tidal systems does not lead to undesirable effects associated with eutrophication. The channelling to the Eastern Scheldt of the polder water currently released into the Veerse Meer, for example, is even expected to bring about a slight rise in productivity. The main objective, incidentally, continues to be the improvement of polder water quality, not in the least because of present pollution levels;
- Besides adapting nutrient levels to the system, it is necessary to create sufficient scope for intermingling with salt tidal waters if stagnant, saline systems are to develop. Besides the significance of salinity as such as an ecological determinant, this approach permits regulation of the nutrient balance. Surplus nutrients and organic matter can be drained off and the likelihood of stratification can be reduced. That this latter phenomenon is important is illustrated by the Veerse Meer, where stratification has been found to exacerbate the current problems of eutrophication;



Storm surge barrier Eastern Scheldt



Tidal flats in Eastern Scheldt



Recreation on Lake Veere



Shore protection Haringvliet

- In addition to existing management measures, there may well be *future scope for a creative response to the ways in which salt, stagnant lakes function*. Such steps might include increasing denitrification in order to remove nitrogen from the system. This might be achieved by influencing nitrification and denitrification processes in the bed by means of stratification. Another possibility would be to make use of the natural process, whereby organisms which inhabit the salt lake bed act as an essential filter in the regulation of nutrients. The possibility of using such organisms as an active policy instrument could be investigated.

5 MORPHOLOGICAL STRUCTURE AND DYNAMICS

The water in the Delta owes its major significance to the morphology of the basins. The hydraulic conditions of the tidal waters have given rise to a morphological structure and dynamics, which contribute to the productivity and diversity of these regions. Compartmentalization has sparked off a process of morphological change, which will lead to more unfavourable conditions in the closed compartments. On the other hand, the morphological changes along the coast - the creation of the Voordelta - should be regarded in a favourable light, because:

- The morphometry of estuaries provides an ideal starting point for maximizing the development potential of compartmentalized systems. *This applies particularly to the presence of large areas of shallows and their gradual transition to the banks*. It is essential to preserve the morphometry of such areas as much as possible if their potential is to be exploited. Considerable experience has been amassed in the Delta in the construction of outer bank defences;
- It is possible to create new and valuable areas through influencing processes of sedimentation and erosion. The Voordelta is a good, albeit unintentional, example of this. However, it should be possible, given present know-how and experience, consciously to create such areas by working in harmony with natural processes and establishing the right parameters. In line with this approach, ways are currently being investigated of influencing mud flat and salt

marsh development in the east of the Western Scheldt.

6 TERRESTRIAL NATURAL DEVELOPMENTS

Just as in the case of morphological developments, natural developments often take place on a time scale which far exceeds the term of the average government. This is particularly important in the case of natural developments, because opinions of the desired course of such developments are subject to change. However, this concerns not so much the ecological conditions, which have been dealt with earlier, but more the management and policy choices which affect natural development. This applies particularly to former intertidal areas.

To date natural developments in the Delta have sometimes faced us with unexpected situations. Although now more is known of the directions in which nature can develop, it is important to be aware that the future may still hold surprises in this respect. Since long-term developments are involved, it is important to guard against phasing the successive stages too rigidly and against trying to steer them too quickly in a certain direction.

Water management remains a key control element in natural development, especially in areas along the banks. It is crucial to maintain not only the quality, but particularly the level of the water. Despite this fact, in almost no Delta area waterlevel management is geared to natural development. This is due to other social interests having been taken into consideration. In the downstream freshwater areas of the Delta, the potential for natural development would be optimally furthered by waterlevel management, which reflected the natural rise and fall of waterlevels in downstream areas. In the case of the salt lakes of the Delta this is less clear-cut. The best approach is probably to maintain a standard level, with brief periods of flooding in winter. However, in the event of a review of or change in waterlevel management great weight should be attached to the natural development factor.

Nature is pliable. Relatively young and dynamic areas offer particular scope for positive influence of natural development. Such possibilities must, however, be recognized. Reference was made earlier to the creation of mud flats and salt marshes through the control of processes of sedimentation and erosion. Another possibility might lie in the hydrology of the areas within the dykes. The dyking in of mud flats and salt marshes has resulted in the loss of many saline areas. At the same time the construction of dykes strongly reduced the potential for the re-emergence of new saline areas. Without wishing to add new land to the list of "Het Verdrongen Land van" *), use could be made of the scope for promoting the establishment of new saline areas within the dykes, for example in polders which are now already marginal for agriculture.

7 FOOD ECOLOGY CONNECTIONS: BIRDS

The Delta is an important "filling station" for birds, and must remain so. In the context of nature conservation and the wise use of wetlands, this is one of our most important international responsibilities here in the Delta.

Besides supervising the changing ecological parameters, dealt with extensively earlier, management and policy should be geared to regulate the changing use of such areas by the general public as a result of greater accessibility. Particular attention will have to be given to restricting the disturbance caused by recreational activities. Other, related points will however also require consideration, such as limiting food competition resulting from fishing.

On the other hand, public support for certain measures will increase if people can see for themselves how valuable such areas are.

*) "the drowned Land of"

The best approach would seem to be to provide restricted but targeted admission, for example by building hides and providing effective public information.

Compartmentalization has sharply increased the diversity of habitats. As a result, the individual systems are characterised by different bird populations. Some systems are still in a state of transition. Sandwich terns, for example, still breed in the Grevelingenmeer area, whereas the type of bare ground required by these birds for nesting purposes is increasingly disappearing from the region through natural causes. Although the presence of this species may be extremely important to local nature conservationists, one must try and avoid making desperate efforts to try to keep certain species in areas which are actually no longer suited to them. A more sensible approach would be to try to reinforce the characteristics peculiar to each individual system.

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