THE WADDEN SEA IN THE FUTURE - WHY AND HOW TO REACH

N. Dankers, K.S. Dijkema, P.J.H. Reijnders & C.J. Smit

RIN Contributions to Research on Management of Natural Resources 1991-1

Research Institute for Nature Management
P.O. Box 59
NL-1790 AB Den Burg, Texel
The Netherlands

1991

Foto voorkant A. Meijboom

CONTENTS

FOREWORD

The Wadden Sea is our largest and most natural nature reserve. The 'Wadden Sea Key Physical Planning Act' (hereafter also referred to as PKB) specifically established for the management of the Wadden Sea in 1981, has a duration of 10 years and must be revised in 1991. The Research Institute For Nature Management has been asked via The Department of Nature, Environment and Fauna Management of the Ministry of Agriculture, Conservation and Fisheries, to indicate on the basis of available knowledge, how the Wadden Sea might look in the future. Also asked for, is an indication of which measures must be taken for the stimulating of developments in the direction of this reference.

This report indicates on the basis of the natural processes active in the Wadden Sea, what the future Wadden Sea could look like. This reference situation will, if possible, be described quantitatively. It is emphatically stated that it must not be attempted to approach the reference quantitatively at the cost of the natural quality.

The management

SURVEY OF THE PUBLICATIONS mentioned in the following report and its appendices, with complete title, name of the publishers, place and date (they are not mentioned separately in the bibliography).

Algemene Beheersvisie - general management objective on the wadden area. Coördinatiecollege Waddengebied. Leeuwarden 1985.

Beheersplan Natuur Ministerie van Landbouw en Visserij Directie Natuur-, Milieu- en Faunabeheer. Den Haag 1988.

3e Nota Waterhuishouding - Ministerie van Verkeer en Waterstaat. Den Haag 1989.

Ecoprofielen - Ecological profiles of plant and animal species from our salt waters (part 1-5). Rijkswaterstaat, Dienst Getijdewateren. Den Haag 1990.

Indicatief Meerjaren Programma Milieubeheer 1987-1991 - Tweede Kamer der Staten-Generaal. Year 1986-1987, 19 707 nr. 2.

Interprovinciale Structuurschets voor het Waddengebied - Part 4: De Structuurschets. Provinciale Besturen van Friesland, Groningen en Noord-Holland. Leeuwarden 1981.

Nationaal Milieubeleidsplan - choosing or loosing. Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer. Den Haag 1989.

Natuurbeleidsplan - Ministerie van Landbouw en Visserij. Den Haag 1989.

Planologische Kernbeslissing Waddenzee - De Waddenzee. Part e: text of PKB composed after parliamentary discussion. Ministerie van Volkshuisvesting en Ruimtelijke Ordening. Den Haag 1981.

4e Nota Ruimtelijke Ordening - on the way to 2050. Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer. Den Haag 1988.

Waddenactieplan - Nota GWWS-90.062. Rijkswaterstaat, Dienst Getijdewateren. Den Haag 1990.

SUMMARY

This report has as its aim, the formulation of a reference for the Wadden Sea and, to indicate which measures could be taken in order to stimulate developments in the direction of this reference. Reference situation is understood to mean: 'a hypothetical picture of a Wadden Sea under near natural circumstances within a number of fixed and accepted limiting conditions, such as the existence of the Afsluitdijk, the rising of the sea level etc.'. It is to be emphasized that a so-called target objective is not developed in this report. The establishing of a target objective is a political decision in which many matters of interest need to be considered. Insight into possible reference situations is of essential importance in determining these target objectives. From a nature conservation point of view, the reference situation may be seen as a target objective.

There are three distinct trends in the views on nature management and nature conservation. The most important basic views are:

- the classical nature-view;
- the functional nature-view;
- the natural development view.

This report is written from a natural development point of view. According to this view, natural processes are not interfered with and human use is only possible if the effects thereof are lost in the 'background noise' of the dynamics of nature, or when in exceptional cases, extremely important biota threaten to disappear as a result of human influences. This corresponds to the idea behind the present Wadden Sea Key Physical Planning Act (*Planologische Kernbeslissing Waddenzee -PKB*) as established in the General Management Policy. This approach matches the character and the dimension of the Wadden Sea, and is in keeping with the natural development idea from the Nature Policy Plan.

A reference is developed on the basis of the natural development view. Taking into account the developments until now, the present situation and the expected developments, a prediction is made as to what the future picture may look like. The developments expected can be determined in the following three ways : 1) A similar system can be studied on geographical grounds or, 2) an undisturbed area within the Wadden Sea can count as a reference for disturbed but otherwise similar areas. 3) Another method includes theoretical considerations with which, on the basis of ecological knowledge, it is determined what a system could look like. All three methods are used in the development of a reference situation.

References can be formed on the basis of very different parameters. Each choice has specific advantages and disadvantages. The parameters used most frequently are :

- the value of a number of abiotical parameters or the degree of human interference;
- the number of individuals of, or the space taken by, one or more selected species;
- the degree of action of several abiotical and biotical processes.

A reference focused on species will usually choose the number of a species as its parameter. The advantage is that policy and management then have a relatively easy to measure parameter with which developments can be followed. The disadvantage, however, is that natural dynamics and shifts between species can scarcely be accounted for.

The reference can also be based upon biotical and abiotical processes. A system in which the most important processes are able to develop and behave in a natural manner, may be seen as a reference value. These processes are identified on the basis of available ecological knowledge. Subsequently, it is attempted to indicatively show what species in which numbers will be present there, so that in an evaluation of the management pursued, quantified standards are nevertheless available. The reference situation can therefore clearly deviate from an historical situation if limiting conditions have been altered in the system or surrounding systems. In this case, for technical policy and management reasons, a distinction must be made between (1) natural, (2) irreversible and (3) reversible changes caused by human actions.

A reference based on abiotical parameters will usually use parameters such as current speeds, nutrient levels, concentrations of micropollution, oxygen levels, the degree of disturbance, or fishing activities as a reference value. Supporters of this way of thinking, point out to the fact that a policy aimed at approaching the most natural values possible within these parameters, automatically leads to a system that resembles the natural situation as closely as possible. The historical values of most of these parameters are known, or are calculable by assuming a system under a minimum of human influence. This is then a very practicable concept for policy and management. Causal relationships between abiotical parameters and the system's condition are however quantified to a limited degree only. That is why it is not possible to indicate to what extent a system that looks natural can be approached, if the abiotical parameters are only partly influenced (or could only be partly influenced) by management measures.

Ten Brink et al. (1990), point out that the use of processes as a parameter in the determination of a reference situation has a great number of disadvantages. Processes have little social appeal and are harder to define and measure than parameters of species. Of course, processes and knowledge of the relationship between process and parameter certainly are extremely important to nature managers. Once the relationship between processes and the number of a species is known, the effects of an intervention into the numbers of a species can be taken into consideration by the management policy, and moreover, by steering a process, it can be possible to influence the development of the species. A disadvantage is that the cause and effect networks and the processes connected to these, are mostly unknown. That is why it will not always be clear why numbers deviate from a reference norm. There is a risk that management measures geared to the achieving of a reference situation are taken by intervening in a process not responsible for the deviation in the level of reference. Those management measures then take on the characteristics of symptom treatment.

In this report, a reference situation is described on the basis of processes. An indication is given where possible, of the numbers that can be expected under these conditions. This prevents the management from focussing on an attempt to achieve, via technical measures, a target objective derived from the reference situation.

The Wadden Sea is one of the most natural areas in The Netherlands, in which natural processes have lead to a highly esteemed ecosystem. In the General Management Policy, the formulated management aim, for primarily the preservation, the restoration and the undisturbed progress of natural processes may be seen as a target objective. This target objective is based upon processes. That is also a reason for basing the reference situation upon processes. It is assumed that all structures, plant and animal species which belong to the Wadden Sea by nature, can maintain, develop and restore themselves there if the basic conditions for their development are present and if the quality thereof is optimized.

The most important processes

The geomorphological development of the Wadden Sea is mainly determined by physical processes. The geomorphological structure shows powerful dynamics through which sand banks disappear and originate elsewhere, channels reposition themselves and dunes are formed and eroded again. This goes together with a certain degree of turbidity caused by the repeated swirling up of sediment. In the future, changes will occur in some places but taking the Wadden Sea as a whole, it must be assumed that the future situation will be comparable to the present one.

The biological processes in the Wadden Sea are mainly influenced by the quantity of nutrients supplied from outside (The North Sea, the IJsselmeer). At the same time, toxic materials also have an influence. Since the policy is aimed at reducing loads, it must be assumed that primary production (algae) will decrease in the future. It is not quite clear what effect this will have on the density of benthic animals but the biomass will probably decrease slightly also.

It is assumed that the policy concerning the management of complete ecosystems will only be geared to protect species in exceptional situations. A policy geared to insure that (sub)systems function well, creates the conditions needed for the survival of individual species. In the description of the expected developments of the most important subsystems or groups of species, a choice has been made for tidal flats and their biota, seagrass fields, salt marshes, waders and sea mammals.

Tidal flats and salt marshes

A decrease in eutrophication will cause shifts in the domination of different species in the biota on the tidal flats. The number of species will remain approximately the same but the biomass will probably decrease somewhat. The annual fluctuations will remain large for the individual species due to the many factors that influence the spat fall and survival. The occurrence or non-occurrence of structured mussel and cockle beds, largely depends on the policy pursued in relation to fishery.

The major eelgrass (*Zostera marina*) that until 1932 was found in extensive fields (15,000 ha) beneath the low-water mark, has disappeared since then. The species was found together with the minor seagrass (*Zostera noltii*) in the tidal areas but since 1965, the area covered by these species has been greatly reduced. At the moment research is being done in order to see if seagrasses will be able to further develop in the future.

The salt-marsh surface areas have greatly been reduced in the last few centuries because reclamations occurred faster than new salt-marsh growth. Because the tidal-flat surface area lies relatively low for the salt marshes, and because a sharp rise of the average high-water mark (0,44 cm per year) occurs, in addition to the average sea-level rise, the mainland salt marshes will for a large part disappear unless technical measures are taken, or the summer polders are again placed under the direct influence of the sea. The survival of the island salt marshes depends on the extent of the rise of the sea level, and the management of the sand dikes and dunes which must supply part of the required sediment.

Birds

In the description of the development of birds in the Wadden Sea, a distinction is made between breeding birds and the staging or the overwintering migratory birds. The development of the breeding birds is, besides the availability of food and climatological factors, mainly determined by the presence of suitable nesting sites and no disturbance on the island nesting grounds or in the high tide roosts outside of the dikes. The numbers of staging migratory birds are not only determined by the situation in the Wadden Sea but also by the conditions in the overwintering grounds (Africa, amongst others) and the nesting grounds (the Arctic area).

The expansion of protection measures in the Wadden area and a decrease in eutrophication will probably result in an increase in the number of breeding eider ducks, oystercatchers, kentish plovers, ringed plovers and terns. The reduction of eutrophication and an artificially high quantity of food (eg. in the form of rubbish dumps) will probably result in lower numbers of herring and black-headed gulls. Prognoses on the development of the staging and overwintering waders and water birds in the Wadden Sea are, for the time being, impossible.

Sea mammals

Of the sea mammals, the common seal (*Phoca vitulina*), the grey seal (*Halichoerus grypus*), the porpoise (*Phocoena*) and the bottle nose dolphin (*Tursiops truncatus*) can be considered the indigenous species. The porpoise and the bottle nose dolphin have practically disappeared. The return of the porpoise seems to be dependent on population development in the North Sea. Before the construction of the Afsluitdijk, the bottle nose dolphin foraged mainly on Zuyder Zee herring. The return of the bottle nose dolphin must not be considered realistic as these fish populations no longer exist since the enclosure of the Zuyder Zee.

The grey seal disappeared many centuries ago from the Wadden Sea, probably as a result of hunting. During the last few years, a few dozen specimens of this species have been sighted again due to migration from waters surrounding Great Britain. Pups have been born in a colony that has settled on the sand flats between Terschelling and Vlieland.

The common seal has sharply declined in number since the beginning of this century. It is assumed that there were more than 7500 animals present then. Hunting and pollution have caused such a sharp decline in number so that, between 1975 and 1980, less than 500 animals were present. A hunting prohibition in Germany and Denmark has resulted in an increase, to more than 1000 animals in 1987. The virus epidemic of 1988 has resulted in a population of just over than 500 animals in 1989 and 1990.

The future expects an increase in the grey seal population up to several hundred individuals if enough rest areas are available. The population size of the common seal depends on the breaking-out of the virus disease or not. If the virus keeps coming up cyclically, then the population might reach a maximum size of approximately 1500 animals.

A reference situation for the Wadden Sea

On the basis of the descriptions of the present situation and the expected developments, a number of reference are being developed for the most important physical and biological processes, as well as for the described ecosystem types and groups of species. Although these are based upon natural processes, it is often possible, on the basis of knowledge of the system to give an indication of the surface of a biotope or the number of organisms of a species. Wherever possible, a rough indication is given of the numbers that occur in a reference situation. It is emphasized that these numbers have at the very most a value as a standard and should only have a limited function in the determination of policy and management plans for achieving a target objective. As for the hydraulics, it is assumed that this is a natural process. Hydraulic processes result in a certain geomorphological structure. The present situation can therefore be regarded as a reference. A substantially different situation can develop only in the very long term. If this new situation is the result of natural processes, then the development towards that new situation must be seen as the reference. Since the turbidity caused by silt is largely a result of the natural hydraulic processes and the geomorphological structure, the present turbidity can be considered to be the reference.

The most important biological process, the primary production, is especially dependent on the amount of available light and the amount of nutrients. Due to the increased nutrient levels and consequently the increased algae biomass, the amount of available light in the present situation is less than that in the reference situation. Therefore, a higher reference value must be used for the transparency of the water than the value now measured. A reference value that is lower than the present situation must be used for the primary production because the amount of nutrients is much larger than the natural concentration.

The present situation can continue to be used as reference for the distribution of the flora and fauna on the tidal flats and beach plains. As a result of eutrophication the density and production is however, at the moment, higher than the reference value. It may be assumed that the reference value will automatically be arrived at, once the eutrophication decreases. It is indicated that the reference value for wild mussel beds can be set at 3200 ha. The amount of mussels in these beds can however fluctuate between several million to 200 million kg. Fishing activities are partly the cause of a relatively small mussel biomass during certain years. It is difficult to give a good reference value in relation to seagrass. The reference value is dependent on the background view on nature management. If a once-only planting of seagrass is regarded as being acceptable, then it can be indicated where the seagrass fields will be able to develop and survive beneath the low-water mark. Without planting, spontaneous development will probably not occur. It should also be possible to develop a quantified reference value for seagrass fields on tidal flats. Further research is necessary however, for the determination of this reference value.

If a natural development is assumed, then most of the mainland salt marshes will disappear. An inventory of the present situation shows that virtually all the salt marshes have disappeared due to embankment. On the rest of the islands, there are at the moment more salt marshes present than in the reference situation as result of the presence of sand dikes. Along the mainlands of Friesland and Groningen, less than half the number of the salt marshes mentioned in the reference situation remain. Assuming that the amount of salt marshes present in the Wadden Sea, where dikes and salt marsh growth are balanced, is comparable to the percentage of salt marsh covered areas in the 17th and 18th centuries, one can take 5-10% of the surface area of the Wadden Sea as a reference value.

The fact that the number of birds present in the Wadden Sea is partly influenced by circumstances outside of the area, means that it is not quite possible to give a quantified reference value. Assuming that via good management sufficient food is available, then policy cannot strive for a management that will insure an increase in the number of migratory birds but, such a development may occur under the influence of a decrease in the hunting pressure outside of The Netherlands, or less disturbance due to stricter rules. It is possible to give a quantified reference value for different species of breeding birds. The numbers are mainly dependent undisturbed nesting grounds, the availability of food and in a few cases, the level of toxic materials in the food.

If enough elevated sand flats arise in the Wadden Sea, where little disruption occurs in autumn and winter, a reference value of several hundred grey seals can be counted upon. A population of more than 7500 common seals can be counted upon, assuming that these have a normal hormone regulation, a minor degree of disruption so that weaned pups have a good chance of survival and are prevented from drowning in fyke nets.

Measures for approaching the reference situation

Measures that can be taken in order to stimulate developments in the direction of the reference situation, must be separated into direct, mostly technical measures and indirect measures, such as the reduction of human influence (including disturbance, fishing pressure, reduction of dumping etc.), by means of regulations. Within the main aims of the Wadden area's management, indirect measures meet with no objections. The application of direct measures must be tested against the principle that natural processes should run their own courses.

As long as the breaking-down and building-up of ecosystems over the whole Wadden Sea area are in balance with each other, there is no reason for interfering. Reasons for taking technical measures do exist for the management of mainland salt marshes, the re-establishment of seagrass fields beneath the low-water mark and oyster beds, and the temporary stimulation of the seal population growth.

Since the geomorphological structure in a sea-level rise depends on a sufficient supply of sand, the areas from where that sand comes must be placed under the scope of the Key Physical Planning Act. Moreover, activities that increase the need for sand (sand extraction, gas extraction) must be prohibited.

The smooth progress of biological processes requires a balanced population growth. This is only achieved if eutrophication and contamination are decreased. Structured communities such as mussel, oyster, and cockle beds can only develop if fishing activities are stopped or zoned. Seagrass fields beneath the low-water mark can be developed by planting seagrass in well selected areas. The decreasing of eutrophication will improve the transparency of the water which in spring will cause the seagrass to grow in such a manner that the leafs will reach the surface.

In order to maintain a reasonable surface area of salt marshes, radical measures are necessary. Losses can only be compensated by gaining ownership of summerpolders and again exposing these to the influence of the tides. In areas where sufficient sedimentation occurs, the decline of the mainland salt marshes can be prevented by a better application of land reclamation techniques. Island salt marshes can only be maintained in the long term by a flexible management of sand dikes. That is to say, it should be possible for some of the sand dikes to disappear so that new dunes and quiet sedimentary areas can develop in favourable places. In the fight against coastal erosion, beach nourishment is preferable to attempts at holding down sediment.

The absence of disturbance in the colonies is the most important factor for breeding birds. This can only be achieved through effective guarding. The guarded areas need to be expanded by several beach plains that are momentarily under a great deal of military and recreational pressure. Such areas and several elevated sand flats must also be guarded against disturbances in the period 15 November to 15 May, in order to give the grey seals an opportunity to give birth to and to be able to rear pups. In order to regain a normal seal population, the decreasing of the PCB load is a first priority. Moreover, the so-called article 17 areas must also be excluded from fishing, air traffic and inspection craft disturbances. Fyke nets and other nets must be constructed in such a way that drowning is prevented. Until the population has reached an adequate level, the release of rehabilitated or bred animals is considered acceptable.

1 INTRODUCTION

The current Wadden Sea Key Physical Planning Act is valid until March 1st 1991. Before then, the government must inform the Lower House (*De Tweede Kamer*) of the proposed content of the adjusted or not adjusted Wadden Sea Key Physical Planning Act. The Ministries of Housing, Regional Development and Environment; Agriculture, Nature Management and Fisheries (until 1989 Ministry of Agriculture and Fisheries); Transport and Public Works; Economic Affairs; and Defence are responsible for the contents of the Key Physical Planning Act. The secretariat of the Wadden Sea Interdepartmental Workgroup (The State Planological Department) has asked the departments involved, to make known their wishes regarding possible changes with respect to the content of the Key Physical Planning Act. The Minister of Agriculture, Nature Management and Fisheries has charged the Department of Nature, Environment and Fauna Management with the coordination of the research into the desired changes form a 'nature' point of view.

This project is executed by the Research Institute for Nature Management, under the direct supervision of the Department of Nature, Environment and Fauna Management. In addition, this project was supervised by a group of representatives from the Ministries of Agriculture, Nature Management and Fisheries (The Department of Nature, Environment and Fauna Management, the Department of Fisheries, Outdoor Recreation), Transport and Public Works (Department of Public Works), Housing, Regional Development and Environment (The State Planological Department) and Economic Affairs. These representatives are not responsible for the contents of the report, nor for the statements made therein. The project may be regarded as a partial filling-in of the Nature Management Plan formulated 'Project 20'. During the execution of this project, it is assumed that the here presented ideas and conclusions are drawn into discussion by the Department of Nature, Environment and Fauna Management, on the alteration to the Wadden Sea Key Physical Planning Act. These discussions will in the first place be held by the Wadden Sea Interdepartmental Workgroup and the Wadden Sea Interdepartmental Commission. There, the ideas of other parties concerned will also be brought forward. - The Wadden Sea Action Plan; the policy view of the *Landelijke Vereniging tot Behoud van de Waddenzee* (National Association for the Conservation of the Wadden Sea), and the views of the remaining users such as the Department of Fisheries, The Ministry of Economic Affairs, Ministry of Defence etc.

An attempt has been made in the present report, to avoid, as much as possible, an overlap with other recently published reports. That is why this report cannot be regarded as being a complete survey of the developments in the Wadden Sea.

The still-to-be-held consultation should lead to the choice of a concrete target objective on the basis of which a general management plan can be drawn up. The measures to be taken suggested in this report can be of service in the drawing up of this plan.

1.1 The aim of this report

This report has two (clearly) distinct aims: the formulation of a reference and the indication of measures to be taken in order to stimulate developments in the direction of the reference situation. In accordance with the first aim, a reference for the Wadden Sea will be formulated on the basis of existing scientific knowledge. In the second place, it will be indicated which measures need to be taken in order to stimulate the developments in the direction of the reference situation or, if the present situation is taken as a reference for a particular characteristic, which measures need to be taken in order to maintain the present situation. The reference is a hypothetical picture of a Wadden Sea under near natural circumstances within a number of fixed and accepted limiting conditions such as the existence of the Afsluitdijk, the sea-level rise etc. This reference situation could strived for by nature management. However, since it is clear that all sorts of social interests are opposed to striving for the reference, an attainable target objective must be made. The establishing of a concrete target objective is a political decision in which many matters of interest need to be considered. A reference and not a target objective is developed in this report. It is assumed that the description of a reference is necessary in order to be able to develop a target objective within the scope of the Wadden Sea Interdepartmental Commission.

1.2 The report plan

The report is built up in stages in order to achieve the aims of this report and moreover, to explain why a certain choice is made. The following parts can be distinguished:

A. A stock-taking of views concerning nature conservation and management in the Wadden Sea and possibly, any target objectives developed on the basis of those views. Here a distinction is made between the national and local governments' views and the views of the nature conservation organizations and nature users.

B. On the basis of the stock-taking under A, conclusions are drawn resulting in a view with which the target objective must comply.

C. A conclusion based on scientific information concerning the previous development, the present situation and the expected developments of a number of Wadden Sea aspects important to the management. Those to be treated separately are:

- the most important physical aspects of processes (hydraulics, morphology, erosion and sedimentation, turbidity);
- the most important biological processes (primary production, grazing, predation) and the organisms influenced by those (algae, seagrasses, benthic organisms);
- ecological aspects (numbers, distribution etc.) of the most important subsystems (salt marshes, flats, channels, mussel beds) and species groups (birds, fish, sea mammals).

D. The construction of a qualitatative and if possible quantitative reference situation. The reference situation is designed on the basis of knowledge of the past situation, the situation in similar areas elsewhere or on the basis of understanding the important processes.

E. The indication of circumstances needed, in order to make developments in the direction of reference situation possible or circumstances needed for the preservation of an already existing reference situation.

Three Ministries, Housing Regional Development and the Environment; Transport and Public Works; and Agriculture, Nature Management and Fisheries, are responsible for the quality of the natural environment. This report mainly deals with those parts that are important in regard to developments directed towards the reference situation and which are able to be guided or partly guided by the policy of the Department of Nature, Environment and Fauna Management, of the Ministry of Agriculture, Nature Management and Fisheries. The water quality and the landscape quality are also of great importance, but they are the policy responsibility of other departments (Traffic and Public Works, and Housing, Regional Development and Environment). These responsibilities cannot be regarded as being separate from each other. The policy of one ministry is usually a necessary prerequisite for the policy of another ministry.

2 VIEWS CONCERNING NATURE CONSERVATION, NATURE MANAGEMENT, AND TARGET OBJECTIVES FOR THE WADDEN SEA

2.1 Introduction

It is an absolute necessity for it to be clear which background view nature conservation and nature development is approached from, in the determination of a policy for the Wadden Sea, the establishing of references and target objectives as well as the in drawing up of management plans. In appendix 2, a summary is given of the most important views existing in the Netherlands and suggested policies based on those views of different groups.

Three trends are distinguished whose main point lies in:

- a nature that is as functional as possible for mankind;
- a fully self-regulating nature;
- a technical development, provided it is harmless for man and the environment.

The most important basic views derived from these trends are:

1. The classical nature view. Supporters of this view strive for the protection, preservation and restoration of natural and scenic values. Human activities can play a positive and essential role. This view is particularly applied in the development of valuable man-made landscapes.

2. The natural development view. Nature is regarded as being a self-regulating ecosystem with natural processes and an entirety of biotic communities. There is practically no room for human interference. (The term nature development is defined quite differently in the *Raad voor Milieu- en Natuuronderzoek* (The Council of Nature and Environmental Research) view than in policy documents published at a later date, in which nature development is virtually equal to nature conservation).

3. The functional nature view. Nature serves man who accepts the dynamics and who shows flexibility in land use and land development.

The Wadden Sea is in the classical view (1), a nature reserve in which a number of other functions are tolerated if these do not obstruct the natural function. Intensive management is necessary in order to protect landscape elements such as salt marshes, sand dikes, elevated sand flats etc., so that in this way a varied system is maintained.

In the natural development view (2), natural processes are not interfered with and human use is only possible if the effects thereof are lost in the 'background noise' of the natural dynamics of nature.

In the functional nature view human influence is far greater, and the area is developed in order to optimally cater for a large number of functions important to man (fishing, mineral extraction etc.), but in such a manner that the ecological processes of the system can occur. By means of conservation, a greater diversity of biotopes and species can be achieved.

The various basic views are able to be recognized in the current practice of the Wadden Sea management. The various views seem to be in agreement that the natural development view is preferable for this relatively uninfluenced area. From a sectorial point of view, however, the functional view is usually adhered to, that is; an optimal use of the area for the benefit of one's own sector, taking into account the nature function as said in the classical view.

The national government's views are recorded in a number of policy documents such as the National Environment Policy Plan, the Nature Policy Plan, and the 3rd Document Water Management. On the basis of these views, implicit and/or quantified target objectives are sometimes developed. These target objectives assure a reference (also more or less quantified) but take into account a number of sectorial interests such as limiting conditions. The policy concerning the management of the Wadden Sea is recorded in the Wadden Sea Key Physical Planning Act. This Planning Act may be seen as an area-orientated result of the national plans. The main aim of the policy is 'the protection, the conservation and where necessary, the restoration of the Wadden Sea as a nature reserve'. A number of limiting conditions such as coastal protection, fishing activities, shipping etc. will have to be taken into account.

The main objectives of the Wadden Sea Key Physical Planning Act are concretely worked out in the General Management Objective. The General Management Objective has a coordinating function and gives general preconditions for the various activities. The possible effects of the sectorial activities are tested against the main aims. That occurs separately for each sector and not for a combination of activities.

The Wadden Sea Key Physical Planning Act shows a clear view on the policy and management of the Wadden Sea area. However, this view is so general that a quantified target objection cannot be deduced from it. A number of target objectives (particularly qualitative ones) are weighed against each other in the General Management Objective. On the basis of thorough reasoning, it is chosen to strive for a most natural situation possible, in which, rarely, corrective action will be taken in cases where characteristic Wadden Sea processes or organism species are threatened (by human activities). Within the framework of the General Management Objective, a quantified target objective for the Wadden Sea is not developed. In both the National Environmental Policy Plan and the Nature Policy Plan, quantified target objectives are not developed either. On the other hand, in the 3rd Document Water Management a general, mainly qualitative target object is developed. That general target objective is translated into testable aims for the management in the Wadden Sea Action Plan. For the development of the target objective, a reference has been assumed for which the situation of the Wadden Sea in 1930 serves largely as a model.

Independent of how a target objective is defined, the development of concrete quality demands (limiting values and target values) for the ecological and regional quality and the quality of water and sediment is necessary for the achieving of such a target objective.

2.2 Reference situation and target objective in this report

In this report both the terms reference situation and target objective are used. The term reference situation indicates what the Wadden Sea could look like under more or less natural circumstances. By means of a target objective, it is shown what kind of a Wadden Sea is attempted to be achieved by applying management measures. The target objective is politically determined and may possibly be equal to the reference. As a result of sectorial policy and the acceptance of the preconditions demanded by several sectors, the determined target objective can nevertheless strongly deviate from the reference. It must also be taken into account that even under the most extreme protection measures, the reference for a number of aspects will never again be attainable. In that case, the target objective will not be equal to the reference.

The views presented in appendix 1 have as a similarity that they are all extremely general and are susceptible to several explanations, so that it is not possible to derive from them, a collective, unambiguous and concrete target objective. There is a general point of departure that recognizes that the Wadden Sea for a large part owes its great value to the fact that most of the natural processes can occur, hardly influenced at all by people and, that that is the reason why the area is characterized by a great degree of natural dynamics.

The main aims of the Wadden Sea Key Physical Planning Act ('the protection, conservation and where necessary, the restoration of the Wadden Sea as a nature reserve') remain fully effective in all policy plans. A target objective to be formulated on the basis of the main aims, is greatly dependent on the view on nature conservation and management. Supporters of the classical nature view will strive for the preservation of the present values and the restoration of lost values, even if large technical interventions are thereby involved. Supporters of the functional nature view will strive for a Wadden Sea optimally used by man as long as the main characteristics of the ecosystem are preserved. The supporters of the natural development view will strive for a Wadden Sea influenced as little as possible by man, of which the effects remain within the natural fluctuations. Only in exceptional circumstances will a positive human influence be accepted.

A quantified target objective in accordance with the classical nature view can therefore be determined by taking the situation of a certain year (or for different parameters, different years) as a reference. It can then be attempted via a specific management to approach this reference.

A quantified target objective can also be developed in accordance with the functional nature view by using all human application functions and by quantifying on the basis of intervention and effect relationships, all influences separately, collectively and mutually. After mutual tuning, the preservation of the ecosystem's main characteristics can then be taken care of.

The development of a good quantified target objective on the basis of the natural development view is not as easy. A prediction must be made of what the future situation could be like on the basis of the developments up to now, the present situation and the developments expected. It still remains a political decision whether that situation must be strived for or approached. As mentioned before, the reference situation is an ideal one. The target objective in a natural development, cannot be anything more than being 'as far as possible in the direction of the reference'. Thus not so much 'What do we want to achieve?' but 'What can we achieve?' It should therefore be about the creation of good limiting conditions while the rest ought to be left up to the natural processes. With regard to the latter, the target objective for seals will therefore not be '3000 seals in the Dutch Wadden Sea' but 'seals with a normal hormone regulation and sufficient peace in the nursery area so that weaned pups have a realistic chance of survival'. Depending on the natural limiting conditions such as available food, territorial behaviour etc., there is then room for a specific number of animals in the Dutch Wadden Sea. Only as monitor parameters in order to give an indication whether one may talk about a 'healthy' situation, is a comparison with an undisturbed situation useful.

In the first place, a prognosis on the basis of natural development will be given in this report, of the developments to be expected in the future. This will be done for a number of important ecosystem types or species groups. On the grounds of that information, it is indicated what a Wadden Sea could look like in the future. Also, it will be indicated on the basis of the information, what can be considered as a reference. Subsequently, it will be indicated whether 'improvements' (meaning 'going in the direction of the reference or the preservation of the values introduced by man') are possible or necessary.

Policy must decide to what extent the target objective must lie on another level than that of the reference since several sectorial interests must be complied with. As a result of political choices, a number of human activities will remain possible. These will have an influence on the target objective that is to be strived for. In the description of the reference, the present and future 'natural' situation is assumed in which the Afsluitdijk and the tidal range and currents, that go with it, the sea-level rise and the subsequent delivery of contaminants are regarded as being 'natural' parameters.

In order to be accepted socially and politically, the measures to be taken (technical as well as those in accordance with policy, and juridical) and the target objective developed on the basis of the reference, will have to comply with the following demands:

- They have to fit in with the government policy as established in the 4th Document Regional Development, the 3rd Document Water Management, the National Environmental Policy Plan and the Nature Policy Plan.
- The target objective must be realistic, that is to say; it must be based upon the current knowledge of processes and developments of the Wadden ecosystem, taking into account the fixed limiting conditions (in the medium term) such as the existence of the Afsluitdijk, the delayed discharge of contaminants from the silt and a certain degree of human influence (recreation, fishing activities, eutrophication, dredging activities etc.).
- They must agree with the nature conservation and nature management views of the most important nature conservation groups (The Wadden Sea Association, The World Wildlife Fund etc.) and of the representatives of social groupings in the Wadden Sea area (The Wadden Advisory Body).

3 DEVELOPMENTS IN THE WADDEN SEA

3.1 The most important physical aspects and processes

Much literature exists on the genesis of the Wadden Sea, the hydraulics, morphology, erosion, sedimentation and turbidity. Up to now however, no attempt has been made in sketching a picture of the relationship between these processes and the expected developments. In appendix 2, an attempt has been made to do this. From this appendix the following conclusions may be drawn.

Silt management. Silt in the North Sea shows a shorewards transport. A turbidity minimum is therefore created, several tens of kilometers from the coast. Directly alongside the coast, a lot of matter is found in suspension. It moves with the residual current along the coast of Holland to the north and a great part flows at high tide into the Wadden Sea. The source of the silt is therefore known. There are a number of described mechanisms which ensure that the suspended matter (that is to say, silt and organic matter and also at high current velocities, sand) is transported increasingly further into the Wadden Sea. These processes occur until a state of balance between erosion and sedimentation has been reached. Whether this state of balance lies in the present geomorphological situation or in a Wadden Sea largely turned into land, is not known.

Fine material generally sinks down along the edges of the Wadden Sea or sinks into old channels which have lost their water-transport function. The silt is, however, swirled up every once in a while in many sedimentary areas. Depending on the area, this happens every tide, spring tide, storm, change in the wind direction or with human activities such as dredging or the maintenance of mussel culture lots.

Wave erosion is the most important process responsible for the dominating turbidity in the shallow areas of the Wadden Sea. The chlorophyll levels in the Wadden Sea are low in comparison to those in fresh water. It could be concluded on the basis of that, that algae contribute little to turbidity. If however, a blooming of the colony-forming algae *Phaeocystis pouchetii* occurs, colonies are formed with a great amount of mucus through which the transparency of the water can nevertheless be limited at relatively low concentrations of chlorophyll.

Silt concentrations show large fluctuations, both in space and time. During a single tidal period, the concentration can vary between 15 and 900 mg/ℓ. It is concluded, on the grounds of measurements taken in several places spread throughout the year, that in 1980, the yearly average in the western Wadden Sea was 60 mg/ℓ and in the eastern Wadden Sea 100 mg/ℓ.

Hydraulical and morphological changes. The Wadden Sea was created in the 12th century by great floods in a peat and swamp area. Since then, the area has again been decreased in size by accretion and embankment. From a hydraulical point of view, the original Wadden Sea and the Zuyder Zee were clearly separate systems between which, under normal circumstances, there was hardly any exchange of water. But there was a gradual change from fresh water to salt water and for many species then, the combination Zuyder Zee - Wadden Sea was of great importance.

Large changes have occurred in the hydraulics of the western Wadden Sea due to the construction of the Afsluitdijk. The tidal range increased: 15 cm in Den Helder, 56 cm near Harlingen and more than twice as much near the Afsluitdijk - 70 cm to 160 cm. The storm surges also increased. A strong sedimentation occurred in the no longer used Zuyder Zee supply channels, while other channels such as Doove Balg grew much larger. Most of these adaptations to the new hydraulical conditions, occurred very quickly. At the moment, a new development towards a new state of balance only occurs at a slow rate, but along the Afsluitdijk, there is still a great need for sand and it will take a couple of hundred years before a new balance is created.

The erosion and sedimentation patterns measured on the tidal flats and in shallow sublittoral areas during the last twenty to thirty years, must be regarded as being natural processes which are amongst others, connected to cyclic phenomena and long term changes in the average sea level and high water mark. The occurrence of sedimentation or erosion, probably has a great influence on the average turbidity in a specific area or period.

Elevated flats, beaches and beach plains. A dynamic area, special because of its geomorphological structure, is formed by elevated flats, beaches and beach plains. Beaches and elevated sand flats are formed in places where sand is deposited by currents, waves or wind. Elevated sand flats are found in and around tidal inlets. The most important elevated sand flats within the tidal inlets are Hengst, Richel, Engelmansplaat and Simonszand. Those outside of the tidal inlets are Noorderhaaks, Engelschhoek and Bornrif. The Engelschhoek has been very strongly eroded during the last few years.

Beaches are formed by waves. During the summer, sand is transported onto beaches from the area beneath the low water mark to the foot of the dune. The beach is then relatively steep. During the winter, erosion of the foot of the dune occurs and sand is removed from beneath the low water mark. The beach then becomes flatter.

Sand flats are formed by currents in the tidal inlets. In the tidal inlets, the tidal flow moves along the islands' heads inside and continues on inside as a straight, and not as a diverging current. The ebb channels run within the estuary along the islands' heads and continue virtually straight into the sea. The seaward side of the islands is also eroded by the tidal flow, and the Wadden Sea side by the ebb current. Sand banks are created between the ebb and flood channels. Along our Wadden Sea coast, the sand movement shows a residual transport from west to east. Consequently erosion generally occurs along the west heads of the islands and sedimentation occurs at the east points. These processes also occur on the flats. The channels shift themselves in a clock-wise direction. On the bare sand plains, dune formation caused by wind, can sometimes occur in the form of parabolic dunes. Usually, the first onset will however be stimulated by plants such as *Cakile maritima* and saltwort, which grow in the tide mark. The sand-catching function of these annual plants is later taken over by *Elymus farctus* and *Elymus pycnanthus*. At that moment, one can already speak of little, but real dunes. Once these small dunes are so high that the vegetation is mainly under the influence of fresh water, then marram grass takes over the function of sand catcher.

If this process continues, a stable dune can be formed. However on most of the beaches and elevated sand flats, the dynamical influence of wind and water is so great that any vegetation succession cannot occur. Dune formation on the sand flats of the islands has been stimulated in the past, so that sand dikes have formed. If silt sinks in the shelter thereof, salt marshes may be formed. Most of the salt marshes formed in that way on Texel and Ameland, were later embanked.

3.1.1 *Prognosis on the development of hydraulics, geomorphological structures and turbidity*

Hydraulics. As can be expected in a dynamic system such as the Wadden Sea, channels and flats will shift themselves. In parts of the system, cyclic processes occur in a period of several decades to hundreds of years. As a result of these changes, current patterns will change through which, both local current velocities and tidal ranges can change. However, for the Wadden Sea as a whole, the general hydraulical situation will remain the same. As for the hydraulics, some aftereffects can be expected as a result of the enclosure of the Zuyder Zee and the Lauwers Sea. These changes will continue until a stable morphological situation has been reached.

The effects of the sea-level rise are not yet clear. If the sedimentation is large enough to keep up with the average increase, the hydraulics will not essentially change. During the last few years, however, the high tide has risen faster than the low tide. The tidal range therefore increases a bit, which has as a result, an increase in current velocities in the channels.

Morphology. As a result of the hydraulical changes after the enclosure of the Zuyder Zee and the Lauwers Sea, morphological adaptations still occur. The situation in the Lauwers Lake (the former Lauwers Sea) is reasonably stabilized but it can be expected that the Schiermonnikoog tidal divide will again slightly shift back in a westerly direction.

Due to the expansion of the tidal basin of Texel's tidal inlet in an easterly direction, the sedimentation along the Frisian coast has increased. This area will also continue to lie in the future, at the back of the tidal basin so that it must be assumed, just as in the last decade, that strong sedimentation will occur there. Also in the area along the Afsluitdijk, a great deal of sedimentation must still take place before a state of balance is reached. Thijsse (1950) estimates this amount to be at approximately 1 billion m^3. It will take at least two hundred years before a state of balance has been reached.

If the increase in the tidal amplitude as observed in the last few years continues, the morphological character of the Wadden Sea will change somewhat. A system of higher elevated flats and deeper channels goes by nature with a larger tidal range. The sedimentation along the borders of the system as well as the elevation of flats and the deepening of the channels is shown by the comparison of bathymetric charts during a long period of time. It can be expected that this development will continue.

The Wadden Sea has been able to keep up with the natural sea-level rise by means of sedimentation during the last centuries. The Wadden Sea has, according to Dronkers (1984) the typical form of a sediment importation system. As the rivers do not deposit sand, the sand in the Wadden Sea must come from the North Sea. Approximately 200-300 m of the coast between Den Helder and Ameland has been washed away during the last hundred years (Veenstra 1971). According to Eysink (1979), this is enough sand for the Wadden Sea to be able to keep up with the sea-level rise. It must be assumed that with a sea-level rise (35-38 cm per century) that is expected as a result of the greenhouse effect, a need for sand that still exists in the vicinity of the Afsluitdijk and a drop in the sea-floor level due to gas extraction, the sand transportation to the Wadden Sea will double. One must assume that it is impossible to prevent erosion of the coast. Sand is then taken from the beaches and dunes along the North Sea coast. The sedimentation in the Wadden Sea does occur at the cost of erosion of the islands unless, by means of beach nourishment, sand is supplied from the deeper parts of the North Sea.

It can therefore be concluded that the morphological structure of the Wadden Sea will change locally but that a characteristic system of channels and tidal flats, where natural dynamics rule, will continue to exist. Only in areas where sand is extracted on a large scale, is there an indication that erosion in the area is increasing. That is why flats are becoming smaller and channels deeper. This report however, in the description of a prognosis, does not deal with regulating human activities, and in occurring cases, in the description the reference derived thereof.

In the morphology of the Wadden Sea and especially in the outer deltas, cyclic processes occur with a frequency of tens to hundreds of years. Very characteristic and valuable geomorphological structures such as elevated flats and islands, disappear in one place and arise in another. As long as islands or elevated flats lie in the sand supply route, they will continue to exist. If they lie outside, they will disappear. In the Dutch Wadden Sea, elevated flats and sand banks in the outer deltas and in the Eems, and the islands Rottumerplaat and Rottumeroog are good examples. Bartholdy & Pejrup (1990) even assume that attempts to protect the islands by stabilizing dunes eventually stimulates sediment losses. Erosion takes place anyway during storms, whereas the dune could have lain in a more natural and stable position via sand drifts.

Turbidity. It is hardly possible to give a well-founded view on the expected development of turbidity in the Wadden Sea since very little is known about the dynamics of silt transport. As mentioned before, the turbidity is dependent on hydraulics, morphology and supply and transport. As for hydraulics, one must think of current velocities, tidal amplitude and waves. Possible changes in the large channel current velocities will hardly have an effect on the turbidity because those channel floors are made of sand. An exception must be made here for channels that have recently lost their current transportation function (for instance, through the enclosure of the Zuyder Zee and the Lauwers Sea). These channels are often filled with relatively fine matter due to a relative shortage of sand. If high current velocities occur as a result of storm, silt will then be swirled up in these channels. In the long term, these channels will also be filled with sand or a layer of sand will cover the silt. Only channels and flats along the edges of the Wadden Sea where the supply of silt is greater than or equal to sedimentation plus transportation, will be a permanent source of turbidity.

Morphological changes can have an influence on the turbidity because silt is 'produced' in an area of erosion. On the other hand, silt in an area of sedimentation, is 'extracted' from the system. Also flats can come to be positioned in such a way that they alternately (for example spring and neap tide cycles, different wind directions etc.) show erosion or sedimentation.

Silt is mainly supplied from the North Sea. The turbidity will remain high as long as the supply is greater than or equal to the permanent sedimentation plus transportation. In the basin of Texel's inlet, there is about 2900 x $10^6 m^3$ water present at half-tide. If there is an average of 60 mg/ℓ silt present, then there is 177,000 tons of silt in suspension. There is in this figure, no account taken of the silt in the layer of water found just above the bottom (fluid mud), that can be most important locally. The water mass shuttles back and forth and if the silt were able to sink somewhere, then the water mass would become clear. In the coastal area of the North Sea however, there is enough present annually for the sedimented amount to be replenished (table 1).

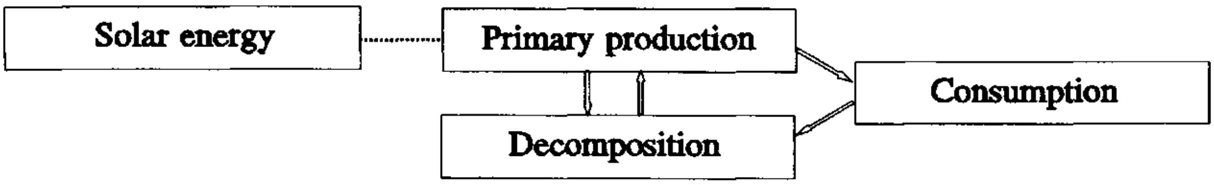
Table 1. The amounts of silt available per annum in the Dutch coastal area (according to McCave (1981) and Postma (1982)).

Source	Source amount per annum in tons x 10^6
Schelde	0.7-1
Vlaamse banken	1-3
Rhine, Waal, Maas	3.8
Rotterdam dredge spoil (marine slib)	4
IJsselmeer	0.2
Eems	0.16

3.2 The most important biological processes

3.2.1 *Introduction*

The ecosystem of the Wadden Sea is controlled to an important degree, by processes that are mutually connected. This can be schematically shown as follows:



The arrows indicate that an exchange of matter occurs. In principle, an ecosystem can function as a closed system to which only energy is supplied from outside. The bringing in of matter is not necessary. Since most of the ecosystems are openly connected to systems in the near vicinity, import and export probably occurs. This is also the case in the Wadden Sea. If the import of organic matter and/or nutrients is greater than the export, one can then speak of eutrophication. From both the North Sea and the IJsselmeer, great amounts of organic matter and nutrients are transported to the Wadden Sea. The dissolved nutrients are immediately available, the nutrients from the organic matter are only available after decomposition.

Because biological processes are mutually connected, an increase in nutrients has an effect on the whole ecosystem. To concretely predict what the effects will be is, however, far more difficult than the subsequent giving of an explanation of the effects observed.

Eutrophication causes an increase in the primary production. This increase can, however, manifest itself in an increase of small benthic algae (fytobenthos), macro algae (sea lettuce) or phytoplanktons by which a distinction must be made again between the edible forms such as diatoms and flagellates, and for most of the organisms inedible species such as the colony-forming or non colony-forming micro flagellates (eg. *Phaeocystis*). The form in which the primary production manifests itself, depends, amongst others, on factors such as turbidity, the availability of nutrients not affected by human activities, such as silicic acid, the development of zooplanktons or filtering shellfish etc.

An increase in algae will mean an increase in oxygen consumption at night and after dying off. Apparently problems can be caused (locally) by this. In principle, an increase in algae means a greater availability of food for zooplankton and benthic organisms. However, in practice, it seems that a great deal of the increased algae biomass caused by eutrophication, is comprised of inedible species for suspension feeders. These sink to the bottom and after first being partly decomposed by bacteria, are consumed there by sediment feeders (usually worms and the balthic tellin) and therefore cannot or, can hardly benefit the filterers (mussel, cockle etc.).

3.2.2 *Developments until now*

The transportation of nutrients from the Rhine to the coastal water of the North Sea has increased greatly since 1950. Phosphate increased with a factor of 5-7 and nitrogen compounds with a factor of 2-4. An increase in the primary production has occurred in the North Sea, causing an increase in the importation of organic matter to the Wadden Sea.

Some of the Rhine water flows directly to the Wadden Sea via the IJsselmeer. The buffering effect of the IJsselmeer caused the nutrients from the Rhine water to be held in the IJsselmeer for a long period of time. Until the early seventies, there hardly was a question of an increase in nutrient level via the drainage sluices of Den Oever and Kornwerd. Only since 1975, has there been an obvious increase in nutrient level from the IJsselmeer. The eutrophication of the western Wadden Sea is at the moment caused by the high nutrient load from the IJsselmeer and to a lesser degree, by import from the North Sea.

In relation to the period between 1950 and 1960, the nitrogen compounds contents of the Wadden Sea doubled in the first quarter of the year. During the course of the season, they are absorbed by the algae and in the third quarter, the nitrogen concentrations are comparable to those in 1960. The nitrogen is therefore stored in living organisms or in detritus. The ortho phosphate concentrations have become three to four times higher in the period 1950-1985, but this is the case for both the first and the third quarters. The fact that with an increase in chlorophyll concentration, ortho phosphate remains the same and nitrogen decreases between the first and third quarter, indicates that phosphate is excessively present. The low nitrogen concentrations in the summer indicate that nitrogen is still restrictive for the primary production, that is to say, changes in the nitrogen pressure has a direct effect on the primary production.

It is difficult to get a good picture of the effects that eutrophication has on primary and secondary production. The primary production is in the winter 20-30 mg C/m^2/day. During the spring peak, the value rises in a short time to 700 mg C/m^2/day, only to then decrease again. A rise occurs again in the summer, up to 800 - 1000 mg C/m^2/day. Only by taking very regular measurements, could a possible trend over a number of years be made visible.

Different species during different seasons account for the primary production. During the spring peak, mainly diatoms develop, for which they also need, besides nitrogen and phosphate, silicon. As soon as the silicon has been consumed, the diatom number decreases and the number of flagellates increases.

The eutrophication in the Wadden Sea seems to mainly have an effect on the duration of the bloom of the colony-forming micro flagellate *Phaeocystis pouchetii*. During the dying off of the colonies, a vigorous formation of foam can occur. At the beginning of the seventies, the bloom lasted for 10-20 days while nowadays, it is usual for it to last 100-150 days. Between 1971 and 1989 also the number of days with a high density of diatoms (> 1000 mℓ^{-1}) gradually increased from 20 to 150.

However these algae also occurred in high densities for more than 100 days in 1969 and 1970 (Cadée 1986a, 1986b). It is notable that the average chlorophyll concentrations in summer, winter and autumn between 1950 and 1983 have not increased (Cadée 1984). It is not clear whether this is a result of increased grazing. There was certainly an increase in the spring. It can be concluded that on an average of one year, the chlorophyll concentration and the primary production have increased. This increase manifests itself mainly as an increase in *Phaeocystis*. Moreover, these are indications that eutrophication in the summer stimulates the development of poisonous algae.

There is a great amount of data available on the density and production of benthic organisms since 1970. The biomass of the benthic organisms has approximately doubled during the last twenty years (Beukema & Cadée 1986). Of the 27 frequently occurring species, 12 species increased significantly and 13 species showed such fluctuations that no conclusions concerning changes can be drawn. The density of these last species during one period, is determined by the success or not of the spat fall. The degree of the spat fall depends on 'coincidental' factors such as the winter temperature, the presence of predators etc.

The increase in the biomass is mainly caused by the increase of short-life species, but these species are also responsible for the large fluctuations in different years; for example, in 1980 approximately 7 g/m^2 and in 1981 approximately 30 g/m^2 (Beukema 1989).

It is notable that the biomass increase is mainly due to an increase in the number of organisms per m^2 and not because of a greater individual growth speed. Only in regard to the balthic tellin (*Macoma balthica*), it is shown that the production per animal in the period 1979-1984 has doubled with respect to 1970-1978. The growth of the balthic tellin is mainly determined by the food situation during a very short period of time in the spring, when the temperature is suitable for growth. If the potential growth period and the availability of algae (especially diatoms) are not tuned together, a bad year for growth occurs. That is why responsible statistical conclusions can only be drawn after a great number of measuring years. The biomass of the cockle is since 1970 approximately constant, with the exception of several extremely high peaks, due to good spat falls.

The fact that organisms at a greater density still grow as before at a lower density, indicates that a comparable amount of food per individual is available. The food availability in the period of establishment can also be an influence on the success or not of the spat fall but more factors probably play a role also.

It may be concluded that the increase in eutrophication makes a greater algae biomass and a greater primary production possible. The secondary production has also increased in the same period. It is however, impossible on the basis of current knowledge, to predict which species will undergo changes if the eutrophication were to increase or decrease. There are indications that shell fish especially benefit from an increase in diatoms and that eutrophication mainly has an effect on the algae *Phaeocystis*, which mainly sediment feeders use as food.

It is not clear in how far eutrophication has directly or indirectly influenced the occurrence of macro algae (*Ulva* etc.) or seagrasses. Research into this, is being done at the moment. If there was an influence, then possibly an increase of micro algae and the local lack of oxygen connected to this, as well as a decrease in the seagrass population, could be explained by this.

3.2.3 *A prognosis for the most important biological processes*

The policy is aimed at strongly reducing the pressure on surface-water nutrients. This will not be directly noticeable in the Wadden Sea, due to a subsequent supply from the IJsselmeer. Nitrogen compounds disappear from the ecosystem by denitrification processes. Phosphorous compounds are possibly exported, to a certain extent, into the North Sea and are partly stored in sedimentary areas. One can assume however, that an excess of ortho phosphate will be present for a long time to come, or possibly for ever. Since nitrogen is a limiting factor for the growth of algae, a decrease in nitrogen compounds will result in a decrease in primary production. Generally speaking, that would mean a shortening of the *Phaeocystis* blooming season. This is at the expense of the production of sediment feeders and possibly in the second instance, at the expense of juvenile fish and shrimps. The turbidity especially caused by *Phaeocystis*, will decrease in the spring time.

There are indications that in certain years, a great autumn peak of phytoplankton (not *Phaecocystis*) occurs. During those years, shell fish (amongst others, mussels on culture lots) show an extremely good growth and quality. At a decrease in eutrophication, those extremely good years will not occur again, if the amount of mussels on the culture lots remains at the present level.

Possible negative effects of eutrophication (such as an increase in macro algae, a reduction of seagrass, the occurrence of an oxygen lack etc.) will disappear with the reduction of eutrophication.

3.3 Ecological aspects of the most important subsystems of species groups

3.3.1 *Introduction*

Different choices can be made for a description of the ecological aspects of the Wadden Sea. An extensive survey of the Wadden Sea ecology is given in 'The Ecology of the Wadden Sea' (Wolff 1983). In 1990, the Dienst Getijdewateren (Department of Tidal Waters) of the Department of Public Works, has written so-called 'ecoprofiles' for a great number of species. The species is the central point of these 'ecoprofiles' (except for the part on salt marshes) and the situation of a reference year (1930), the development, the processes and interferences that have an effect on that development, are described. With these and other reports, the policy has at its disposal a wealth of background information.

The numbers of certain species can be a good graduator for the condition of the environment but in the management of complete ecosystems, policy should only be geared to the protection of species in exceptional situations. Therefore, the system or a group of species is the central point in the following chapter. With this, it is assumed that a policy aimed at the well functioning of (sub)systems, creates the conditions needed for the survival of individual species.

A choice has been made for tidal flats and their biota, seagrass fields, salt marshes, the group waders and the sea mammals. Fish will not be dealt with, due to a lack of time and the fact that another Ministry of Agriculture, Nature Management and Fisheries' institute has a great deal of expertise at its disposal. The sea mammals have not been chosen because they are an indicator for the condition of the environment, but because they are important in the species' policy of the Ministry of Agriculture, Nature Management and Fisheries and possibly measures within the scope of the Nature Conservation Law, will be necessary for the stimulation of population growth.

3.3.2 *Tidal flats and their biota*

The area west of the tidal divide of Terschelling consists for 50% of tidal flats; east of the tidal divide, 80% consists of tidal flats. Dijkema (1940) has described and mapped the different types of tidal flats. There is a clear relationship between the physical, geomorphological and sedimentological aspects and the density of different groups of organisms. Beukema (1976) and Dankers & Beukema (1981) have shown that the greatest biomasses and the greatest number of species per surface unit occur in areas with an average time of submergence and an average sediment composition. Filterers such as the mussel, the cockle and the *Mya arenaria* only occur in great densities (up to more than 1000 g fresh weight per m^2) at a height which places them for at least 50% of the time under water. Above that, the time of submergence is too short for optimum growth. The sediment feeders such as the lug worm, the *Corophium*, *Scoloplos*, the *Macoma balthica*, the *Heteromastus*, the *Pygospio* and the *Scrobicularia* occur more regularly throughout the whole intertidal area.

The highest parts of the intertidal area (more than 67% time of emergence) are important for the juveniles of a number of species, probably because there, the predation pressure of fish, shrimps etc. is strongly reduced. The highest density of benthic organisms occurs in areas that are clear of the water for 25% and 60% of the time (Beukema 1976, 1981).

The type of sediment is probably not of direct importance to most of the organisms (Wolff 1973, Reise 1979, Dankers & Beukema 1981). Since the sediment type is a reflection however, of a great number of factors such as current velocity, wave energy and the food supply connected to these, it is possible to find good correlations between the density of a number of species and the type of sediment.

Large fluctuations occur in the biota of the tidal flats due to the dynamical character of the Wadden Sea. Fluctuations are partly determined by natural processes, but human influences can also have great effects. The off and on occurrence of high density mussel beds, cockle beds, *Lanice* fields and *Mya arenaria* has natural causes. Also the disappearance of these organisms can have natural causes, such as age or weather conditions. In a few cases, such as the almost total disappearance of old, structured mussel beds and old cockle beds, must the cause be searched for in human activities. Developments until now. Due to the lack of quantitive information on the period before 1979, it is not possible to describe the development of the different species of benthic fauna in the Dutch Wadden Sea before 1970. It seems, from German research, that the number of species has remained the same over a period of sixty years, but a shift has occurred from shell fish to worms. Of the shell fish, only the mussels seemed to have increased. The changes have mostly been caused by human activities. Quantitive information concerning the macro fauna of the tidal flats in the Dutch Wadden Sea is available since 1970. This information indicates that the density of the maco fauna has increased since then. Chapter 3.2.2 has already dealt with this. However, there are indications that the density on the flats was relatively low around 1970 (Van der Veer 1989).

Because tidal mussel beds can be seen clearly, estimates concerning the amounts, are available over a longer period of time. The large fluctuations are shown in table 2. The table shows that the mussel density on the tidal flats has fluctuated between 6 and 200 million kg. Natural causes are partly responsible for this but a great deal of the fluctuations is caused by fishing.

Table 2. Mussel biomasses on tidal flats in the Wadden Sea (from Dankers & Koelemaij 1989).

Year	The western Wadden Sea x 10^6 kg	The eastern Wadden Sea x 10^6 kg
1949	16	
1955		45
1961		180
1971	7	142
1977	24	
1978	17	50
1987	1	5.5

Although mussel beds repeatedly arise and disappear again, it is clear that they usually come to lie again in the same place (fig. 1). If seed mussels fall on the remains of old beds, relatively stable beds are formed that are able to withstand storms. In the years with a good spat fall, mussel beds also form on sandy bottoms. As these mussels come to lie on a layer of fine silt after a while, they are very susceptible to storms. Nevertheless, a small part of these beds, grows into structured old beds with mussels of different age classes.

Prognosis for the tidal flats and their biota. Since the occurrence of the different species of benthic fauna on the tidal flats is mostly determined by hydraulical, geomorphological processes and weather conditions, it is not possible to indicate for a certain year, how the populations of the different species will be built up. On the average of a number of years, one can assume that the number of species will be comparable to the situation in the past. The importance of individual species however, cannot be predicted. The total biomass is dependent on the degree of eutrophication.
Due to human influences (eutrophication) the biomass of a number of species (especially worms and the balthic tellin) is higher than it would be under natural circumstances. After a decrease in eutrophication, the biomass of those species will also decrease. Due to the large subsequent supply from the sediment and the IJsselmeer, the effect of measures can however not be measured in the short term. Large fluctuations in the amount of mussels will always occur, but the number and especially the structure of the tidal mussel and cockle beds, are, besides storms, also dependent on the

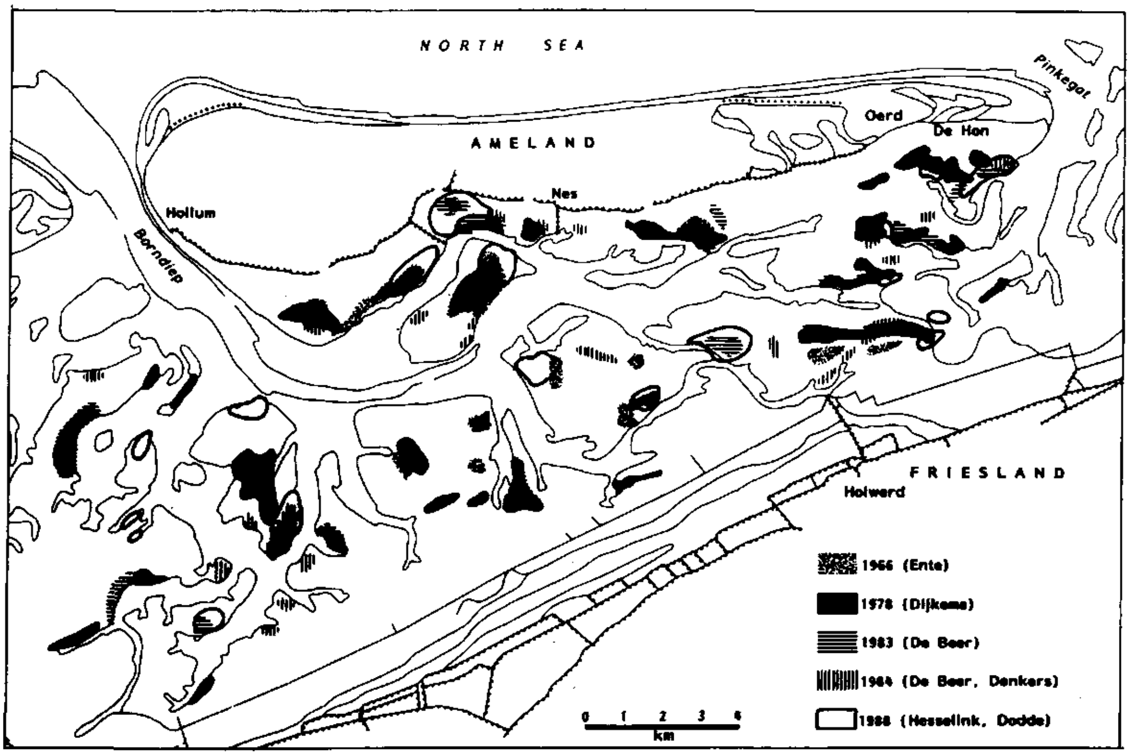


Figure 1. Mussel beds under Ameland between 1966 and 1988 (Dankers & Koelemaij 1989).

policy pursued in relation to mussel fishing. If the policy is not changed, then the old structured mussel or cockle beds will not, or hardly, occur. If areas for fishing, the digging of rag worms and large-scale collecting of mussels are closed, complex and richly structured mussel beds will develop again.

3.3.3 *Seagrass fields*

In the past, two species of seagrass occurred on an extensive scale in the western Wadden Sea. The eel grass (*Zostera marina*) covered more than 15,000 ha in the sublittoral. These very characteristic and densely overgrown fields provided a habitat for a number of rare species of fish but because of a disease, they completely disappeared in 1932. A small narrow-leafed form of the eel grass and another species, the minor seagrass (*Zostera noltii*), occurred on the tidal flats of the Wadden Sea. Since 1965, the surface area covered by these species has greatly decreased (Polderman & Den Hartog 1975).

Extensive literature on the decline and present status of the seagrass, is available. This has been summarized by De Jong & De Jonge (1989) in the ecoprofile 'seagrasses'. That is the reason why this report does not fully deal with seagrasses.

Prognosis for the sublittoral seagrass. It is not quite clear whether sublittoral colonies of eel grass will be able to return to the Wadden Sea. The present circumstances in the Wadden Sea are possibly no longer suitable for this species. This is a slightly controversial subject (Dankers 1989, De Jong & De

Jonge 1989). At the moment, research is being done to see if *Zostera marina* will grow under Wadden Sea conditions and if it can survive in the sublittoral.

Prognosis for the littoral seagrass. Research is also being done on the seagrass of the tidal flats. The Research Institute For Nature Management and the Agricultural University of Wageningen are making a description of the requirements for development in the whole Wadden Sea, after which, it should be possible to indicate the areas that would potentially be suitable for the establishment of seagrass. Further conclusions on this, can only be drawn once that research has been completed. It will then also be clear whether restrictive measures concerning the use of those flats, will be necessary.

3.3.4 *Salt marshes*

The development from 1600 to today. Considerable salt-marsh surface areas still occur in the Wadden Sea. These marshes however, are a modest remainder of an extensive landscape of salt and brackish marshes, peat areas and lakes, that until some two thousand years ago lay in the border region of pleistocene and marine deposits (Beeftink 1975, Behre 1979, Griede & Roeleveld 1982). After that period, our ancestors began with the embankment of inhabited areas. Soon after that, great sea invasions occurred. In the places of invasion and along the diked centres, new salt marshes (for example, in the Middel Sea, Lauwers Sea, Fivel and the Dollard) arose through the sedimentation of sand and silt. These invasions were diked in one by one. Only after 1600 did they succeed in the definite pushing-back of the sea and in the interaction between salt-marsh growth and diking, fewer and fewer salt marshes remained. The salt-marsh and Wadden area of the Lauwers Sea has even been embanked recently. However, the Balgzand, salt marshes and summer polders of the Frisian mainland, the north coast of Groningen and the Dollard have mostly been spared.

In order to determine the thoughts on the matter, the salt-marsh surface areas at this moment and the embankments of the last fifty years are summarized, for a number of areas, in table 3.

Table 3. Salt-marsh surface areas (including pioneer vegetation) and embanked salt marshes of the north-west European Wadden Sea and the south-west Netherlands (in km^2; * = including summer polders).

Region	Salt-marsh surface area in 1987	Embanked salt marshes in the past 50 years
The Netherlands	72 (85*)	22
Niedersachsen	85 (117*)	20
Schleswig-Holstein	51 (63*)	107
Denmark	81	8
South-west Netherlands	35	76

However, salt marshes can grow in size so that such a table says nothing about the changes in the salt-marsh area. That is why reconstructions of the salt-marsh area in a number of reference years, has been made for the Wadden Sea (Dijkema 1987a; here the methods and sources are also described). This is possible on the basis of the history of diking, which has been well described (amongst others, Verhoeven 1976). The embankments immediately after a reference year, are regarded as being salt marshes during that reference year. Furthermore, as many recognizable details as possible concerning the location of the salt marshes, have been transferred from historical maps to the present topographical one. Figure 2 is a simplified summary of the results.

The western Wadden Sea. In figure 3, the salt-marsh surface areas have been given for the years 1600, 1700, 1800, 1860, 1925 and 1987. The mainland salt marshes of the western Wadden Sea were hardly of any importance during these periods. On the other hand, during the 18th century, the island salt marshes grew to reach a considerable surface area of 88.5 km^2. That was possible in the shelter of the man-made sand dikes of Koegras (1610) and Eierland (1629). The total of all the dikes in these areas caused the salt-marsh numbers to decline to a minimum in 1817 and 1835 respectively (fig.3).

There are two circumstances that have made the (new) growth of salt marshes in the western Wadden Sea difficult up to now. Firstly, not only salt marshes but also large surface areas of flat had been diked here in previous centuries (66 km^2 in the 19th century: the Anna Paulownapolder, the Waard Nieuwland polder, the Prins Hendrikpolder and Het Noorden), a method only occasionally applied in the rest of the north-west European Wadden Sea in the last few decades. That is why hardly any elevated flats remain along the borders, on which new growth can occur. Secondly, the western Wadden Sea has, due to a slight tidal range, an almost microtidal character (Hayes 1979, Dijkema 1987b). To this belong, amongst other things, fewer tidal flats and salt marshes than in a mesotidal system such as the eastern Wadden Sea. This particularly applies to the mainland coast because tidal basins between the river deltas and the coast are not filled up with sediment as in the eastern Wadden Sea. The tidal range however, has increased considerably (Rietveld 1963) as a result of the enclosure of the Zuyder Zee through which, the western Wadden Sea has required a more mesotidal character. Consequently in the long term, one may expect an increase in the surface area of the tidal flats and more salt marshes.

For this to be done, 1 billion m^3 sediment is needed in the tidal basin of the Marsdiep, and this could take a hundred to two hundred years (Thijsse 1950). Forceful sedimentation occurs along the borders of the area. In spite of this, the prospects for salt marshes are not good. After the construction of the Afsluitdijk, the rising of the high water mark has led to the erosion of the (extremely small) existing salt marshes. The present rising of the high tide (Dijkema et al. 1988) and the predicted possible sea-level rise as a result of the greenhouse effect, could make this erosion problem worse.

Figure 2. Simplified map of embankments in the Dutch Wadden Sea after 1600 and salt marshes in 1985 (from Dijkema 1987a).

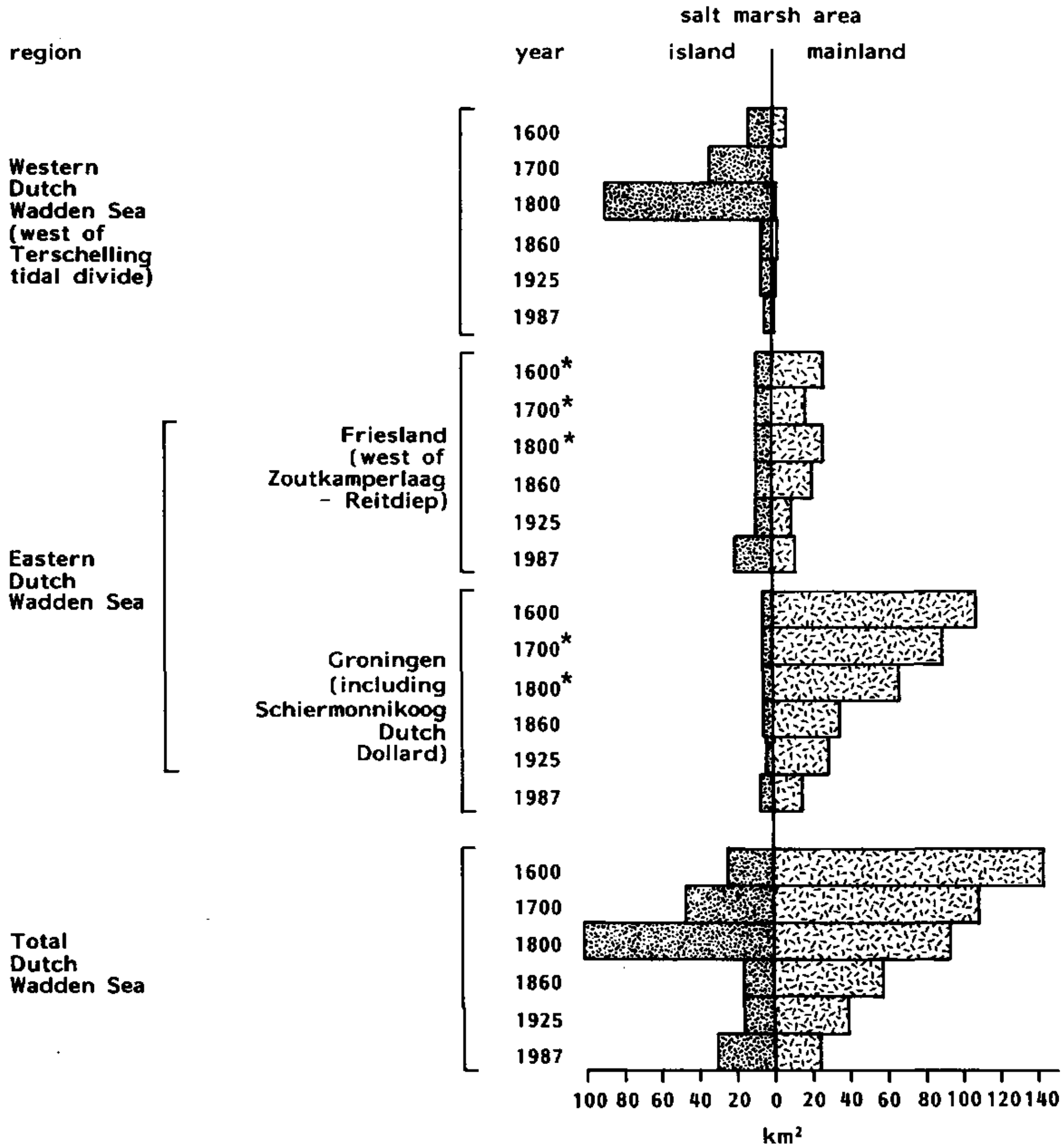


Figure 3. Salt-marsh surface area in the Dutch Wadden Sea after 1600, in km^2; including Huisduinen. Salt marshes in 1985, including the Slufter on Texel, but not including the summer polders and pioneer vegetation along the mainland. * = Ameland, Schiermonnikoog and Rottumeroog made equal to the situation in 1860 (from Dijkema 1987a).

The eastern Wadden Sea. Due to the mesotidal character and a lesser influence from wind waves, the conditions for salt-marsh growth are far more favourable in the eastern Wadden Sea, particularly along the mainland coast. This is clearly apparent in the larger salt-marsh surface area in Friesland and Groningen (fig. 3) and this is certainly clear if the relative small size of the eastern Wadden Sea is taken into account. Until 1800, Groningen scored considerably higher than Friesland (in 1600, 113 km^2 as apposed to 35 km^2). After a series of major embankments along the north coast of Groningen (amongst others de Noordpolder) at the beginning of the previous century, and after the construction of sand dikes on the Frisian Wadden islands, the proportion is now reversed in favour of Friesland (now resp. 22 and 32 km^2).

The diking in of salt marshes has occurred frequently along the mainland in both Friesland and Groningen, after which the growth again continued. Here the character of the landscape is determined by these traditional dikes. However, the size of the mainland salt marshes and therefore the possibility of embankment, has diminished further and further. That was the case on the north coast as well as in the bights (Lauwers Sea, Dollard). Consequently, the coastal farmers were gradually forced to actively encourage growth by digging drainage ditches and building small dams (Dijkema 1983). This was already started in the Dollard in 1740 (Stratingh & Venema 1855). This method had scarcely gained any results at the beginning of this century (situation of 1925 in figure 2). In 1935, the state began with large-scale reclamation works. Most of the present mainland salt marshes not only in the Dutch Wadden Sea but also in the German and Danish Wadden Sea are a result of these operations.

What is causing the decrease in size of the mainland salt marshes? The most obvious idea is, that the bights have become so small through rediking that the salt-marsh growth there, has been reduced to the normal values of the Wadden Sea. Details on the accretion speed in the Dollard, indicate this (De Smet & Wiggers 1960). That is why the embankments have practically been stopped. The accretion speed in the Wadden Sea's coastal strip has, however, hardly changed (Eysink 1979) while the decline of the salt marshes was just as great. It seems plausible that here, the speed of embanking was greater than the growth of new salt marshes. That is why the size of the salt marshes has gradually decreased and that is also why one has had to be satisfied with smaller and smaller polders. In addition to this, the new dikes, through better techniques and the already mentioned smaller polders, are placed closer to, or even further than, the edge of the salt marsh. This particularly occurred in Groningen. Placing the dikes closer (eg. 200 m) to the sea, means an extra salt-marsh loss of approximately 10 km^2 for the coast of Groningen. In places where the dikes are built far onto flats (Lauwers Sea, Eemshaven), the salt marshes will be out of the picture for an even longer period of time. Salt-marsh growth along the Frisian and Groninger coast has even come to a halt during the last twenty years, and now, mainly erosion occurs (Dijkema et al. 1988). The accretion that occurs in the overgrown area has not, however, decreased (Bouwsema et al. 1986). The erosion is attributed to the recent rise in the high water mark and to the insufficient functioning of the brushwood groynes (Dijkema et al. 1988).

The area of the island salt marshes is assumed, on the basis of historical maps, to have been stable until the dikes were built (Schiermonnikoog 1860, Ameland 1915-1930). Of course, the old island salt marshes disappeared after the building of these dikes, but new growth occurred quickly in the shelter of the new sand dikes (for example, the Bosplaat 16 km^2 after 1931). As a result, the present area of the island salt marshes in Friesland have even become larger than that of the mainland salt marshes.

Prognosis for mainland salt marshes. Since most of the salt marshes have been created, and are maintained by human activities, the prognosis therefore takes these activities into consideration. As a result of propositions made for the further development of salt marshes by Minister Winsemius of the Ministry of Housing, Regional Development and Environment, during the symposium *De Waddenzee beheerst beheerd* (1985 in Leeuwarden), a prognosis for the development of mainland salt marshes is being worked on (Bouwsema et al. 1986). On the grounds of the accretion figures, the horizontal salt-marsh growth could be estimated at 6 m per year in Friesland (a total of 235 ha) and at 5 m per year in Groningen (a total of 270 ha). The reality shows however, that the horizontal salt-marsh growth does not keep up with the vertical accretion. At the moment, even erosion of the salt marshes is occurring. Since 1978, erosion of the largest part of the Frisian and Groninger coast measures between the 5 and 23 m per year (a total loss of 250 ha; Dijkema et al. 1988). This loss is attributed to a rise in the average high tide (0.44 cm/year), an inadequate system of brushwood groynes and resulting from these two things, an increase in wave energy. It is therefore difficult to determine what the expectation will be for the development of mainland salt marshes. This goes together with the uncertainty concerning a possible further increase in the sea-level rise, due tot the greenhouse effect. Despite this, for a number of alternative measures, a rough estimation will be made of the future salt-marsh area:

1. The stopping of reclamation works' maintenance. The 1250 ha of pioneer vegetation will quite soon disappear, which adds to the 1500 ha already disappeared since 1960. It may be expected in relation to salt marshes, that a cliff will arise on the border between pioneer vegetation and the salt marsh from which 6 m per year will be washed away. Because more elevated flat will come to lie before the salt marsh, in time, erosion could decrease. Once the older farm salt marshes have been reached, erosion would further be reduced to 0,5 m per year since these salt marshes are better rooted through. On the basis of this, on average, a duration of roughly thirty years is estimated for the entire coast before the whole 750 ha disappear (Since 1978, 250 ha have already disappeared). Then there is still the 750 ha farm salt marshes in Friesland, and the 250 ha in Groningen that are slowly washing away. The erosion will differ greatly from place to place.

2. The carrying out of a stabilizing maintenance in the reclamation works. Dijkema and others (1988) indicate that, in relation to the above said, a redistribution of the dam numbers is necessary. The wave energy in the pioneer zone needs to be reduced by a closer pattern of higher brushwood groynes while the outermost sediment fields can manage with fewer dams. Further, an adapted system

of ditches, that will rather be based upon natural processes is part of the stabilizing maintenance. It is expected, with this stabilizing maintenance, that areas of growth and erosion will keep themselves in balance. Without the redistribution of the dam numbers, the erosion mentioned under (1) will also occur along a large part of the mainland coast, although at a slower rate and depending on the rising of the high tide.

3. The expansion (or transfer) of the reclamation works. If one chooses to restore the mainland salt marshes that had disappeared in the past, the prospects for doing this lie on the west flank (near the Zwarte Haan in Friesland) and on the east flank (along the Emmapolder in Groningen).

The best sedimentary area of the Dutch Wadden Sea lies momentarily west of the Zwarte Haan. Expansive silt fields have risen by accretion to a height suitable for the development of pioneer vegetation. The high wave energy and a rising high water mark have, up to now, managed to prevent this from happening. If the sea level keeps on rising, natural growth cannot be expected here. Reclamation techniques would, however, be very successful and in the short term, 200 ha of salt-marsh growth may be expected from this. It could possibly be considered to transfer a bad reclamation area to this region.

Only in 1982 were the reclamation works along the Emmapolder abandoned. The altitude is adequate for hundreds of hectares of pioneer vegetation if these reclamation works are resumed. Reclamation techniques better adapted to natural processes could be used in the Zwarte Haan as well as along the Emmapolder since these are new areas.

4. The restoration of salt marshes from summer polders. Between the Zwarte Haan and Holwerd in Friesland 900 ha of summer polders lie between the reclamation salt marshes and the polders. Through the buying of these summer polders, the levelling of summer dikes and the development of a creek system, the regeneration of salt marshes is relatively easy here. The measure must be executed in stages, in order to be able to spot possible erosion of the present reclamation salt marshes in time.

In this prognosis on mainland salt marshes, little attention is paid to the expected rise in the sea level. Dijkema and others (1990) indicate that the mainland salt marshes are, through vertical sedimentation, able to withstand a rise in sea level of 1-2 cm per year, which is a lot more than was predicted. The rise in sea level does cause a lowering of the pioneer zone, situated in front of the salt marsh and therefore causes an intensified horizontal erosion of the outer-border of the salt marsh. The measures mentioned under (2) are aimed at the prevention of this.

Prognosis for the island salt marshes. Two other things determine the future development of the island salt marshes: the expected rise in sea level due to the greenhouse effect and the maintenance or not of the sand dikes. The present accretion of the island salt marshes is just sufficient enough to keep up with the rising of the high tide (0.44 cm/year) during the last decades (Dijkema et al. 1990). If the future rise in sea level due to the greenhouse effect, should reach values of 0.5-1.0 cm per year and this accretion speed does not increase, then nearly all island salt marshes will be lost. The expectation for the rise in sea level is in that range (35-80 cm in the coming century) and with that no account has been taken of the possible further rising of the high tide or of a drop in the sea-floor level caused by gas extraction.

The large influence that sand dikes have on the area of island salt marshes has already been discussed. In the western Wadden Sea all salt marshes that had grown behind sand dikes appear to have been diked in. All potential places for new salt-marsh growth have thus disappeared. Contrary to the past, there are more island salt marshes at the moment in the eastern Wadden Sea, due to a salt-marsh growth behind the sand dikes. With the help of sand dikes, the salt-marsh area in the eastern Wadden Sea can therefore be manipulated, where the present size must be seen as a maximum (2800 ha) and the situation in 1925, as a minimum (1200 ha - 750 ha, for the Amelander Polders = 450 ha). Further, horizontal erosion of the present island salt marshes also occurs, starting from the flat's edge; according to Ehlers (1988), an average of 0.5 m per year for the whole Wadden Sea. That means a decrease of approximately 10 ha per year in spite of sand-dike maintenance. On the other hand, there is natural growth in other places.

The alternative management activities and the results thereof are:

1. The stopping of all maintenance of the sand dikes. If the sand dikes disappear because of this, the salt-marsh area of the islands could decrease from 2800 ha to 450 ha. On the other hand, the dynamics is given a chance again, through which rare vegetation at a young development stage, is given a new chance by a sandy salt marsh (Westhoff 1987). Moreover, dynamic processes are the only way, by which a restoration of the salt-marsh area on the islands is possible, in the case of serious sea-level rise effects. The availability of silt seems to be too little for the application of reclamation techniques.

2. The continuation of all maintenance to the sand dikes. Local growth and erosion will occur. If the rise in sea level values reach between 0.5 and 1.0 cm per year, all island salt mashes could eventually disappear. In that case, the sand dikes will prevent new formation of elevated sand flats and consequently, salt marshes.

3. Different scenarios of partial abandonment of sand dikes in combination with expansive beach nourishments. This option must be worked out technically but seems, in the case of a serious rise in sea level, to be able to lead to the maintenance of between 450 ha and 2800 ha island salt marshes. Here is also room for the young development stages of the sandy salt marsh.

3.3.5 *Birds*

With the analysis of the developments of the ornithological meaning of the Wadden Sea, a distinction must be made between data on the dry parts, that is to say, the breeding birds from the tide roost areas outside the dikes and data on the wet part, in this case, the species which use the area as a feeding ground. This last group is comprised partly of breeding birds. Most of the birds belonging to this second group breed in arctic and subarctic regions far from the Netherlands and only use the tidal flats of the Wadden Sea as a staging place, moulting area or overwintering area.

Breeding birds. The following (potential) areas suitable for breeding birds, lie within the Wadden Sea Key Physical Planning Act area: Hors en Schorren (Texel); Vliehorst, 5e Kroonspolder en Posthuiskwelder (Vlieland); Richel; Noordvaarder en Bosplaat (Terschelling); Griend; Groene Strand; Nieuwlandsrijd en Hon (Ameland); Engelsmanplaat; Westpunt; Oosterkwelder en Balg (Schiermonnikoog); Simonszand; Rottumeroog; Rottumerplaat; Balgzandschorren; the salt marshes of the Frisian and Groninger mainland coast and the Dollard salt marshes. The Noorderhaaks and the Slufter (Texel) lie beyond the present Wadden Sea Key Physical Planning Act area but the landscape type is comparable to that of the previous areas. The same thing applies to the beaches on the North Sea side of the Wadden islands. A number of the areas that fall under the Wadden Sea Key Physical Planning Act have been allocated as protected nature reserves for years now. This protection on Griend dates back a long time. The area is the property of the *Dienst der Domeinen* and has been held in long lease since 1916, and is managed by the *Vereniging tot Behoud van Natuurmonumenten in Nederland* (the society for the protection of nature reserves in the Netherlands) (Abrahamse & Veenstra 1976, Natuurmonumenten 1985). Also the breeding-bird colonies of the Schorren in Texel, the first and second small dunes of the Bosplaat, the Oosterkwelder, Engelsmanplaat, Rottumerplaat and Rottumeroog, and the reef north of the Engelsmanplaat have all for many years been protected and guarded as nature reserve (Weijman 1980, Natuurmonumenten 1985, Mes et al. 1980). Moreover, since 1981, they have all been part of the *Staatsnatuurmonument Waddenzee* (State Nature Reserve Wadden Sea) and have been placed under the Nature Conservation Law (Dankelman 1983). The eastern tips of most of the Wadden islands and the North Sea beaches, do not for the large part, have protection. The Hors (Texel), Vliehors (Vlieland) and the Groene Strand of Ameland are also unprotected.

The proclamation of the Wadden Sea Key Physical Act and hence the allocation of a state nature reserve, have not led to essential changes in the protection of breeding birds in all the previously mentioned areas. This is partly the case for the Richel, a sand bank that has increased in height during the last few years, and since the mid-eighties, it has been used as a nesting ground by oyster-catchers and a colony of common terns and Arctic terns (J. van Dijk, pers. comm.). The Richel, however, is not permanently guarded. Simonszand also lies within the borders of the State Nature Reserve and is not guarded either. However, due to the altitude, this flat is not important for breeding birds (Smit 1981).

The salt marshes of the Frisian and Groninger coast are partly owned by private farmers and partly by the Department of Public Works. The management of the privately owned areas is mainly determined by the land owners and is not primarily geared to the preservation or maximization of natural elements typical for the Netherlands. Account is taken of the breeding birds in the natural, technical management of the areas owned by the Department of Public works. The Nieuwlandsrijd on Ameland is the property and under the management of Nieuwlandsrijd Ltd. In general, the same applies here, as applies to the privately managed areas of the Frisian Coast. Half of the salt marshes of Dollard are also owned by private persons. The same applies here, as applies to the salt marshes of the Frisian and Groninger mainland coast. Since 1981, 350 ha of the Dollard salt marshes have been owned and have been under the management of the *Stichting Het Groninger Landschap* (Natuurmonumenten 1985). This organization carries out a management geared to maximizing the natural elements typical for the Netherlands.

A comparison of the population developments of five bird species in four nature reserves in relation to their status or non-status of protected nature reserve and of being a part or not being a part of the Wadden Sea Key Physical Planning Act area (table 4), shows that there are very little clear differences recognizable in the development of the breeding-bird populations.

The oystercatcher population has increased in every one of these observed areas, probably under the influence of a national increase in this species' breeding-bird population (SOVON 1987). Only in the Slufter on Griend does it seem, in the period 1970-1990, that the possible densities have reached a maximum, through which no further increase can occur.

The ringed plover, not numerous in number, has increased in population on Texel during this century (several tens of pairs, of which 3-16 are in the Slufter), followed by a slight decrease during the fifties (Dijksen & Dijksen 1977). The Frisian coast does not offer a suitable breeding biotope for this species. Here, the ringed plover only occurs locally in small numbers, with no clear number development in time, being recognizable. The numbers on Griend are also too small (0-4 pairs) for making statement on the population development.

Redshanks seem to have increased in number along the Frisian coast, while in other areas no clear population changes have been observed. Because of the absence of a suitable breeding biotope, this species does not occur on the Amelander Hon.

Black-headed gulls do not occur as breeding birds on the Hon and in the Slufter. Following in the foot steps of the increase in the Dutch breeding-bird population, of the 25,000 in the thirties to 200,000 in 1978 (SOVON 1987), the species has also increased in number along the Frisian coast and on Griend. In both areas, the increase can be termed 'spectacular'. The Frisian coast saw an increase from 6000-7000 in 1974 to 25,100 in 1983 (Vijfhuizen & Haringsma 1984). On Griend, the black-headed gull bred for the first time in 1921. After the combatting of the species (egg collecting) had been stopped in 1965, the population grew to 10,000 pairs in the mid-eighties (Veen & Van de Kam 1988).

The increase in the herring gull population is to an important degree, related to the ceasing of combatting (egg collecting until 1969) and to the availability of artificial feeding grounds (amongst others, rubbish dumps) (SOVON 1987). As in many other places of West Burge, the population in the Netherlands has also strongly increased. Between 1968 and 1977, the Dutch population increased from 17,000 to more than 60,000 pairs. The decrease in population caused by egg collecting during the fifties and sixties, can be seen in the population levels of the Hon and the Slufter. The then following national increase of the herring-gull population is reflected in an increase in all the areas during 1970-1990 (table 4). The population increase on Griend is still restricted by combatting as a protection measure for the tern colonies.

Table 4. Development of the breeding bird population in four outerdike areas of the Wadden Sea, in relation with the fact whether these areas are under the Wadden Sea Key Physical Planning Act (hereafter mentioned as PKB) control or not. The categories indicated have the following status:

1) Mainly unprotected status, yet PKB area eg. Hon (Ameland) Source: Valk 1976
2) Mainly unprotected status, yet PKB area eg. Frisian coast. Source: Stichting Avifauna Friesland 1976, 1977; Vijfhuizen & Haringsma 1983.
3) Protected natural area, no PKB area: eg. Slufter (Texel) Source: Dijksen & Dijksen 1977; Dijksen, pers. comm.
4) Protected natural area, also PKB area: eg. Griend. Source: Veen 1988

The indications given have the following meaning:
-- strong decrease in the period mentioned
- decrease in the period mentioned
0 no obvious change in numbers
\+ increase in numbers in the period mentioned
++ strong increase in the period mentioned
not appl.= not applicable. This species has not bred in the area in the period concerned.

Area	Species	1900-1950	1950-1970	1970-1990
1	Oystercatcher	+	+	0
	Ringed Plover	0	0	0
	Redshank		not appl.	
	Black-headed gull		not appl.	
	Herring gull	+	-	+
	Common tern	-	0	0
2	Oystercatcher	+	+	+
	Ringed Plover	0	0	0
	Redshank	?	+	+
	Black-headed gull	?	+	++
	Herring gull	0	0	0
	Common tern	?	-	+
3	Oystercatcher	0	0	0
	Ringed Plover	+	-	0
	Redshank	-	0	0
	Black-headed gull		not appl.	
	Herring gull	+	-	+
	Common tern	-	0	0
4	Oystercatcher	+	+	0
	Ringed Plover	0	0	0
	Redshank	0	0	0
	Black-headed gull	+	+	++
	Herring gull	0	0	+
	Common tern	++	--	0

The population of the common terns breeding in the Netherlands has to a large extent, been influenced by number changes. During the fist part of this century, many tern feathers (and consequently terns) were collected in order to be used for ladies' hats. The population again increased after protection measures became effective in 1912 (Teixeira 1979) only to receive a new blow in the form of poisoning from chlorinated hydrocarbons discharged by the Rhine. In a few years time, the population on Griend decreased from 25,000 in 1954 to 1000 in 1963-1965 (Veen & Van de Kam 1988). The population on Griend and in the Slufter, as well as on the Schorren on Texel, (SOVON 1987) have not really recovered since then. This is however, the case along the Frisian coast where numbers increased from 275-325 pairs in 1974 to 945 pairs in 1983 (Vijfhuizen & Haringsma 1984).

Table 4 shows that the population developments on the Frisian coast (an unprotected area where a management is carried out that is only partly aimed at preserving the natural elements typical for the Netherlands, but is a part of the Wadden Sea Key Physical Planning Act area, compare relatively favourably with those in other areas. A number of causes for this can be indicated; amongst others, the fact that the Department of Public Work's natural technical management takes the breeding season into account, so that most of the working activities occur before or after that period. The Frisian coast may be regarded as a relatively peaceful nesting grounds where, besides a generally intensive grazing, not many other disruptive influences occur. It may be generally stated that sufficient peace and quiet, and protection from disturbance during the establishment phase and breeding season are certain guarantees that the area is or remains suitable as a nesting ground. In principle, this can be realized in agricultural areas and without taking further nature conservation measures.

Breeding birds on beach plains. Although it is not clear from table 4, the natural elements typical of the Dutch (mostly unprotected) beach plains on the inhabited Wadden islands and the North-Sea beaches generally fall short of the potential possibilities. Disturbance through recreation (and the effects of season expansion) is the most important cause of this. The characteristic breeding-bird species of this biotope are, the oystercatcher, the ringed plover, the kentish plover, the herring gull, the common tern, the arctic tern, the sandwich tern and the little tern. A number of species from this group have not fared well in the Wadden Sea during the last number of years. This is especially true for the kentish plover and the little tern. These species have decreased in number on every inhabited Dutch Wadden island during this century (Smit 1981).

Birds other than breeding birds. The tidal flats of the Wadden area form a rare habitat type, not only rare in the Netherlands and the surrounding countries but also elsewhere on this planet. Wolff (1989) estimates that in Europe, the total area of tidal flats at low tide, is 9300 km^2. This means that only 0.09% of the total surface area is taken in by intertidal areas. The group of birds that occur here, has to a high degree, adapted itself to the typical characteristics of the intertidal areas. These birds, termed in the Dutch language *wadvogels* meaning waders, consist of a number of species ducks, geese, gulls, terns and twenty-odd species of stilt-birds. The species that overwinter and stage along the coasts of Europe and West-Africa breed in North-west Europe, Scandinavia, the western part of Siberia, on Iceland, Greenland and the north-east part of Canada. The migratory routes of these birds show a set pattern, while also, in successive years, the staging areas along the way are visited at set times. Examples of such area loyalty has been observed of several species of bird, both the stilt-birds (Smit & Houghton 1984) and the barnacle goose (*Branta leucopsis*) (Ebbinge 1989). The predictability of the migratory behaviour of the wader species has led to the distinguishing of migratory routes (often indicated with the American term *flyways*). Through the combination of data from the whole range of distribution within a migratory route, much insight has been gained into the total size of populations of ducks, geese and swans (Monval & Pirot 1989) as well as stilt-birds (Smit & Piersma 1989). Besides this, a good picture has also been obtained of the distribution of these birds during the winter period.

The fact that a large connection exists between the Wadden Sea and other tidal areas elsewhere in Europe or West-Africa means that the sizes of in the Wadden Sea overwintering populations are determined both here and elsewhere. This can be the case in the nesting grounds as well as in tidal areas elsewhere along the migratory route. This makes it extremely difficult, if not impossible, to relate the advancement or decline of a specific species to nature conservation measures taken in one specific country or area.

During high tide, these birds concentrate themselves on so-called high tide roosts. By visiting all the areas where they occur and by taking counts there, a fairly dependable picture of the numbers present in the Wadden Sea can be developed for most of the species (Rappoldt et al. 1895). Unfortunately, it is only partly possible to compare the current numbers of birds present to the data from the past. The organization for the more or less frequent counting of waders, only started to function from the mid-sixties and unfortunately since then, organized counts have not always delivered sufficient, systematically gathered information. Besides a few fragmentary details dating from the twenties and thirties, the only other data known comes from a simultaneous count on all the islands, held in 1931 by aeroplane (Van Oordt 1932). The results hereof, offer few points of departure for a comparison with recently gathered data because only a limited part of the observed birds were able to be identified. During the fifties, counts were held on Vlieland (Rooth 1960) and on the Bosplaat (Mörzer Bruyns & Braaksma 1954). Of these, the counts held on Vlieland are not very useful for a comparison with recent data because only a part of the Vliehors was counted and the numbers present on the eastern part of the island were not counted at all. A problem in the interpretation of the counts held on the Bosplaat is that the data of 1951-1953 only consists of counts up to and including the third little dunes and that the numbers of the birds overtiding further east, were estimated. This could have led to a serious under-estimation of certain species. The gathered data of the sixties (Tanis 1966) concerns monthly maximums which include, besides the Bosplaat, counts of a part of the Terschellinger polder. Although hardly optimal in conception, a comparison of these old data to recently gathered material does produce useful results. Besides, it is still the only data that makes a comparison possible, of recent data, to data from the fifties. Figure 4 shows that the numbers of oystercatchers overwintering on the Bosplaat, have not clearly increased. This does seem to be the case for the numbers of gray plovers. The picture that the dunlin shows is fairly vague. Other data on this species shows that the population increased during the period 1950-1980, in the months July-December and decreased in the months January-May (Smit, in press). The knot shows a tendency to decline. A comparison of index values for the overwintering populations of these species in Great Britain shows, that there are similarities between the gray plover and the knot. This qualitatively better data can be used for a number of species, as a good indication of developments such as those that have already occurred in the Wadden Sea. Such a comparison is only possible for species or

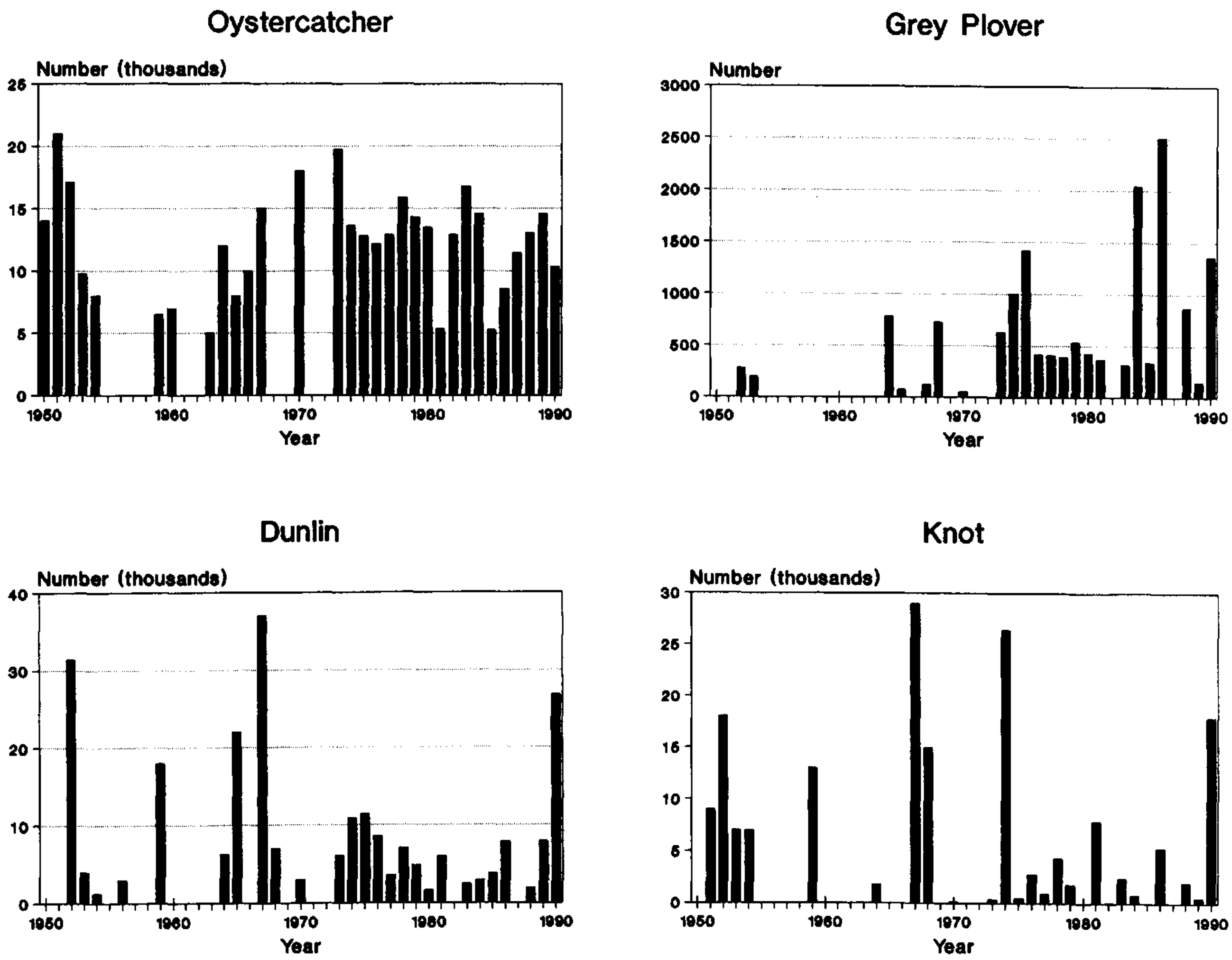


Figure 4. Maxima of numbers of oystercatchers, grey plovers, dunlins, and knots as counted on Bosplaat during the winters (November - January) of 1950 - 1990 (source: Biologisch Station Schellingerland; G.J.M. Visser, written inf. and birdcounts by RIN Texel).

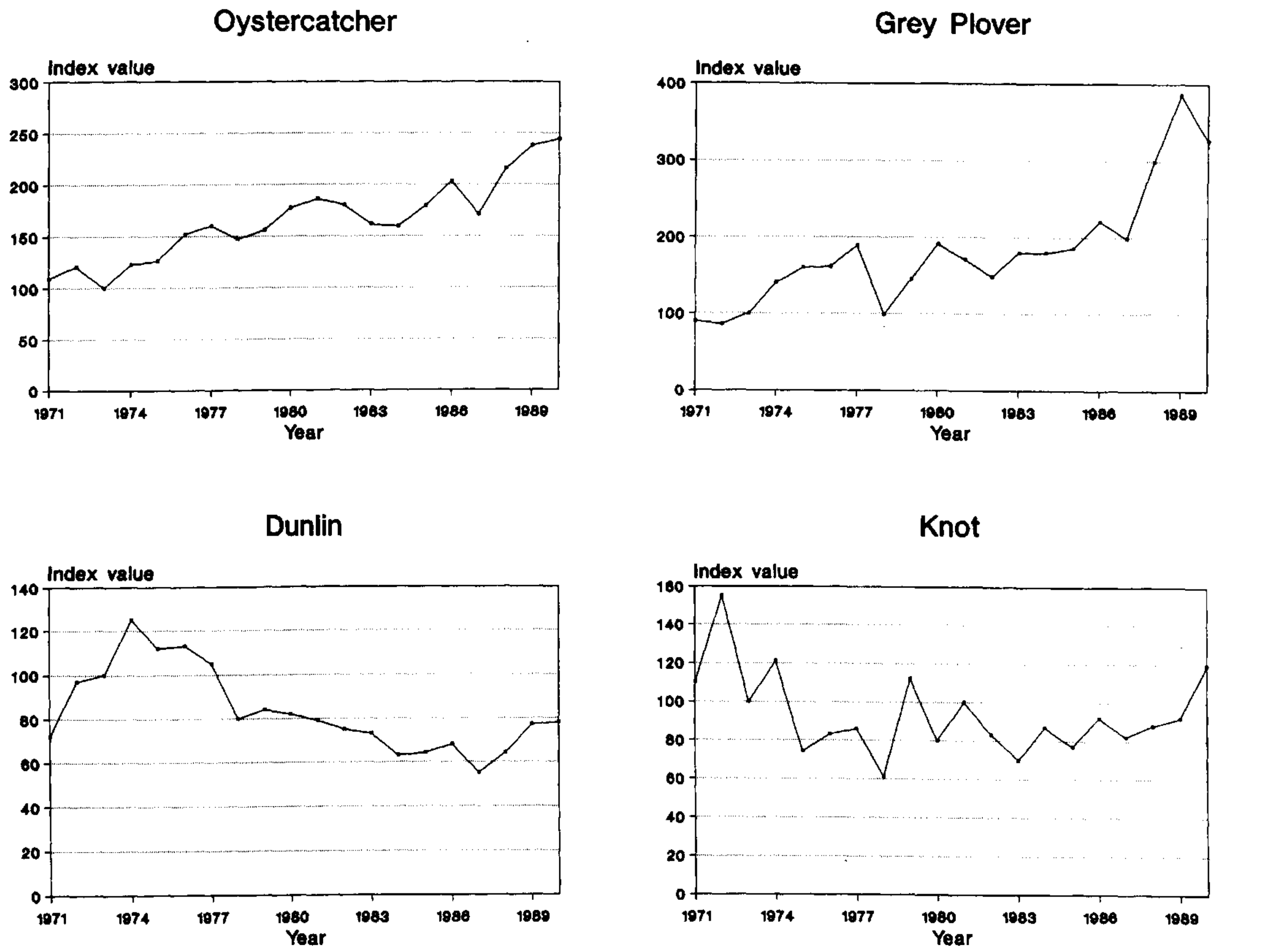


Figure 5. Index values for the numbers of oystercatchers, grey plovers, dunlins and knots overwintering in Great Britain (from Prys-Jones & Kirby 1987, 1989).

populations with a similar migratory pattern such as, the oystercatcher, the gray plover, the knot, and the bar-tailed godwit. Such a comparison is not really possible for the curlew, since there are indications that this concerns (or partly concerns?) birds from another nesting ground. Because of differences in migratory behaviour and the fact that populations from other nesting grounds, partly overwinter in Great Britain, a comparison with the Wadden Sea is not really possible for species such as the avocet, the ringed plover, the black-tailed godwit and the redshank.

Prognosis. The expansion of conservation measures in the Wadden area will lead to an increase in the eider duck population. The increase in the number of this species (up to 6000 pairs in 1960), set in motion just after the establishment in 1925 and abruptly halted by pollution caused by chlorinated hydrocarbons in the immediate years following, indicates that a breeding-bird population of 10,000 pairs is possible. The oystercatcher population also keeps on increasing in the Wadden Sea, although a stabilization in a number of areas (see table 4) indicates that the limits have been reached here. It is possible that the reduction of eutrophication could have a negative effect on the population growth. Kentish plovers and ringed plovers ought to be able to benefit from better protection measures and to regain their earlier population size, or to gain an even bigger one. Herring and possibly black-headed gulls will probably decrease in population due to a cut in food supply, caused by the closing of open rubbish dumps as well as the reduction of eutrophication. There are indications already for both species, that the numbers are stabilizing or decreasing locally (Spaans & Noordhuis 1989). All tern species ought to be able to benefit from a better protection and a reduction in pollution. The earlier population sizes at the end of the previous century and of the thirties until the fifties of this century (Rooth, in Teixeira 1979), could be reached again as new nesting grounds are becoming available or, former nesting grounds are again suitable. It is, for the time being, not clear how the shelduck, the redshank, and the avocet populations will develop. It is most probable that these species will maintain their present level, or will increase slightly under the influence of better protection.

It is not possible to give a good prognosis on the development of population sizes of non-breeding species. On the one hand, it can be expected that different populations could increase under the influence of better protection in the nesting and overwintering grounds, or by the reduction of hunting pressure (eg. in Denmark), on the other hand, the reduction of eutrophication may lead to a changed food supply of benthos. However, a less intensive fishing of cockles and mussels would compensate the decreased food supply caused by this. The number of variables is nevertheless large and the available knowledge on the capacity of estuaries (how many birds can be catered for per surface-area unit feeding ground?) is, at the moment, insufficient for the making of unequivocal statements on future developments.

3.3.6 *Sea mammals*

Introduction

A total of 25 species of sea mammals has been observed in the Wadden Sea, of which one is in a sub-fossilized form. Most of the species were and are visitors, and only the common seal (*Phoca vitulina*), the grey seal (*Halichoerus grypus*), the porpoise (*Phocoena phocoena*), and the bottle nose dolphin (*Tursiops truncatus*) may be regarded as indigenous species. The bottle nose dolphin and the porpoise almost completely disappeared from the Wadden Sea during the sixties (Reijnders & Wolff 1981). Worth mentioning is, the observation of three live porpoises in the Wadden Sea near the sluices of Den Helder at the beginning of March 1990 (P.J.H. Reijnders, unpublished). A possible restoration and the corresponding population developments of the porpoise and the bottle nose dolphin in the Wadden Sea, will firstly depend on population developments in the North Sea. As an instrument of management, the Wadden Sea Key Physical Planning Act will not have a great direct effect on this. If the dolphins occur in large numbers again in the North Sea, the food supply in the Wadden Sea must be sufficient enough for these animals to forage there. As this is not yet relevant in the medium term, only the common seal and the grey seal will be dealt with in further considerations.

Historical developments until 1960

The grey seal. In prehistoric times, the grey seal was the largest species in the Wadden Sea. Excavations show that in the Danish Wadden area between 6000 and 1000 B.C., only grey seal remains were found in more than fifty settlements. Fossil finds in the German Wadden area show that until the beginning of the Christian era, only grey seals occurred, and that during the Middle Ages, the number of common seals had evidently increased (Scheibel & Weidel 1988). Due to an increase in population, grey seals were hunted with increased intensity in the Wadden area and after 1500, virtually only common seals occur (Reijnders 1978; E. Drescher, pers. comm.). Until the mid-fifties, reports on grey seals sighted in the Wadden area are rare. After that, the number of reports increase but even though this species was seen every month of the year, groups or individuals were never seen to stay in one place for more than a few months. It would seem that the area was unsuitable for a re-establishment of the species (Van Haaften 1974, Reijnders 1978).

The common seal. Besides information gained from fossil remains concerning the occurrence of the common seal, not many quantative details are known. Brouwer (1928) and Havinga (1933) give estimations based on counts taken, but they themselves conclude that on the grounds of the registered shootings, the population must have been much larger. On the basis of several assumptions, Havinga gives a population of approx. 2700 seals in the Wadden area, around 1930. Not all the assumptions can be verified today. On the grounds of Havinga's data on the shootings and the just as difficult to verify data from Russian researchers on harp seals, Mohr (1952) calculates that the seal population in the Wadden Sea must have been one of almost 6000 animals. The uncertain factor in this calculation is mainly the lack of information on the age distribution of these populations. A simple calculation model for which this information is not necessary, is indicated by the formula:

$$N_{t+1} = N_t - K_t + R_t\,(N_t - FK_t)$$

The population size N in the year $t+1$ is calculated from the year t, plus the net recruitment in the year $R_t\,N_t$ and with the subtraction of the realized shootings K_t as well as the part of the pups born before the shooting of the mothers $R_t\,FK_t$. This model is a combination of the calculation method used in Harkönen (1987) and Reijnders (1976) to calculate the earlier population sizes, only three parameters are needed: the net recruitment ratio R_t which is regarded as being equal to the population-growth speed, the annual shootings K_t known from the hunting statistics and the population size at the moment the calculation is started. The first thing that is examined is, the effect of the different estimates on the recruitment R_t. The choices for this are a) 0.05 = the estimated value for a population that has been hunted (Harkönen 1987), b) 0.093 = the real seal populations of Niedersachsen and Schleswig-Holstein and c) 0.120 = the intrinsic growth speed, that is to say, a normal seal population cannot grow faster than 12% per year. On the basis of the shooting data, a F value of 0.046 has been introduced for that time. The different population trends have been plotted in figure 6. The starting point is a population size of 1250 animals in 1959, when Van Haaften (Research Institute For Nature Management) began doing counts in the Wadden Sea from the air. Depending on R_t, the population of 1900 was between more than 5,500 and 12,800. The introduced yearly shootings is of course, a minimum estimate. In reality, it was much higher since not all the recovered animals were registered and that some animals were shot but not recovered. On the grounds of experience elsewhere and the anecdotal information provided by old seal hunters in the Netherlands, the percentage of underestimation would have been a minimum of 25% The population trends belonging to the different R_t values are shown in figure 7. The estimation of population size in 1900 would come through those, within a range of 7,300 to 16,800. R_t is however, dependent on density. During the first decades, this would have been approximately 0.05 (cf. hunted population) and due to the increase in hunting pressure in the thirties, have increased by gliding to 0.093 (cf. The German population). The curve in figure 7b will probably come closest to the real population trend. The estimation of Mohr (1952) for 1930 corresponds with this.

Developments from 1960 to today

The grey seal. Through the stringent protection of the grey seals in Great Britain, the growing population there, has a definite influence on the number of young grey seals that migrate, amongst others, to the Wadden area. Many of the tagged animals found in the Dutch Wadden Sea, come from the Farne islands. However, it has only been since 1980 that one may talk about a colony of grey seals in the Wadden Sea. This colony can be found on a sand bank between Vlieland and Terschelling and

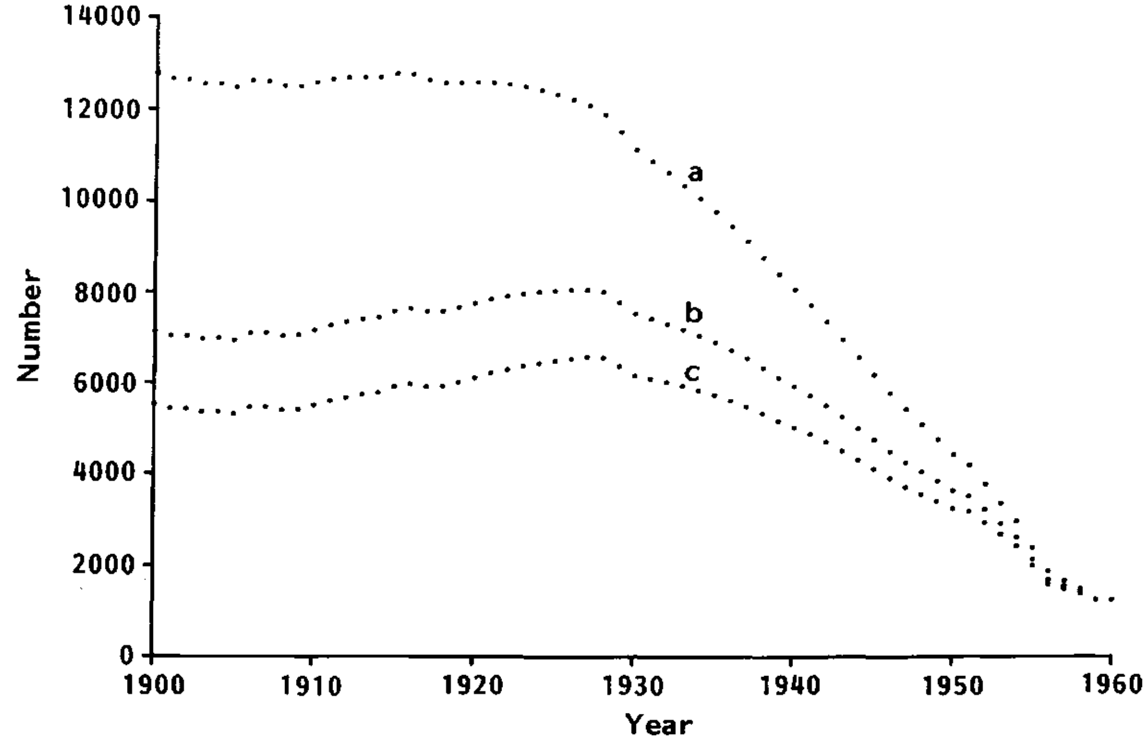


Figure 6. The historical population development of the common seal in the Dutch Wadden Sea; R_t-values: a = 0.05; b = 0.093 and c = 0.120.

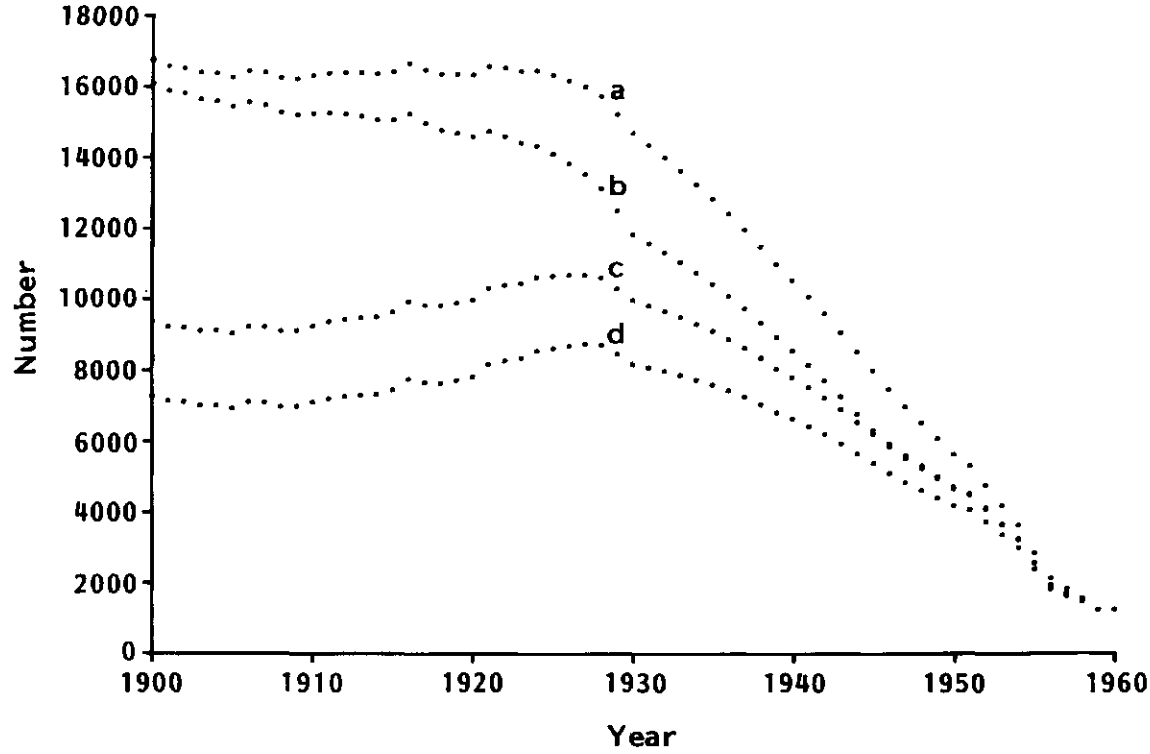


Figure 7. The historical population development of the common seal in the Dutch Wadden Sea with the correction of the underestimation (25%) of the shootings. R_t-values: a = 0,05; b: = gliding from 0,05 to 0,093; c: = 0,093; d: = 0,12.

in 1989, it counted 80 individuals. The population development of that colony and the one on Engelschhoek is shown in figure 8. The number of pups born, has fluctuated around five per year for the last five years, and the colony is further reinforced by the releasing of animals rehabilitated by the relief centres Pieterburen and Ecomare. Because death occurs and because some of the released animals and pups born in the colony leave, the population growth cannot be explained by birth and release alone. Immigration from other areas must therefore be assumed. Most of the animals are sighted during the moulting season in March and April. After that, the numbers decline. Some animals are later observed in other places in the Wadden Sea, but it is assumed that most of them will, except for those two months already mentioned, leave the Wadden Sea.

The common seal. After the number of shot seals sharply declined at the end of the fifties due to a decimated population, the ruling premium system was converted into a complete hunting prohibition in 1961. Initially, the numbers increased but decreased again after 1964 reaching a low point in 1976 with 480 individuals. For several years, the number remained approximately 500 and after 1980, began to increase again. In 1987, the Dutch population of common seals counted 1055 individuals but due to the breaking-out of a virus epidemic in 1988, and the high death rate as a result of this, only 535 animals were counted in 1989 (fig. 9). The causes of the population changes since 1960, have been reported on in detail earlier. Due to water pollution, mainly by PCBs, not enough pups were and are born in the Dutch Wadden Sea (Reijnders 1980, 1984, 1986). The pup death rate was high throughout the entire international Wadden Sea but was compensated by a normal birth percentage in Schleswig-Holstein. However, the high pup death rate is of importance to the Dutch situation. The cause of the high death rate is probably the combined effect of water pollution and disturbance (Reijnders 1981). Contaminants not only cause a decrease in the number of births but also a decrease in the weight at birth (P.J.H. Reijnders, unpublished.). Since a linear connection exists between the weight of birth and the weight at weaning, the animals born with a lighter weight, will on average, reach a lower weight at weaning. Disturbance causes a decrease in the growth rate of young seals and therefore, decreases the chance of survival. It is not clear which of the two factors plays the most significant role in relation to the high death rate of pups, but it is clear that they work synergetically. Besides the high death rate of young seals, death also occurs especially in the young age groups by drowning in fyke nets. It is not possible on the basis of the available figures, to give a reliable quantitive estimate of the magnitude of this (Reijnders 1985). Despite the small recruitment, the population has clearly increased since 1980. Two factors are responsible for this: immigration of young animals from other parts of the Wadden Sea since the prohibition of hunting there and the releasing of rehabilitated animals by relief stations. Both factors have begun to play an important part since the mid-seventies (Reijnders 1983, 1988a). In 1988, a virus epidemic broke out and because of the seal disease, the population dropped back down to the level of the mid-seventies (Reijnders 1988a, 1989).

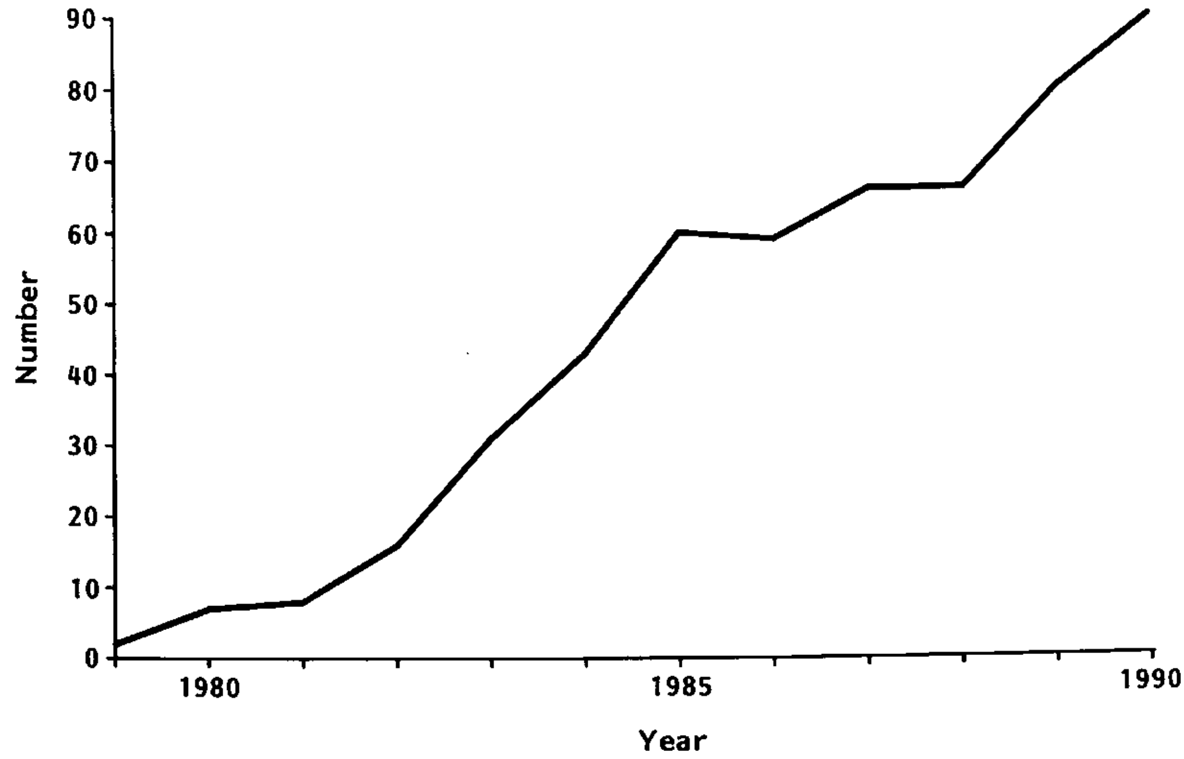


Figure 8. The numbers of grey seals on the Engelschhoek.

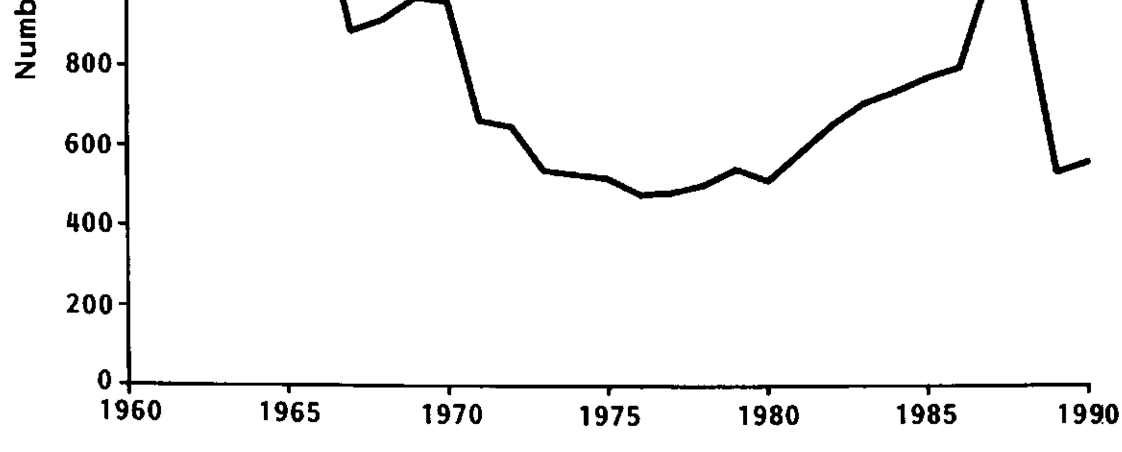


Figure 9. The number development of the common seal in the Wadden area from 1960 up to and including 1989.

Prognosis for the population development of sea mammals

The grey seal. The further development of the colony on the Engelschhoek in the near future, mainly depends on the possible population increase in Great Britain and on the geomorphological changes in the area in which the Engelschhoek lies. As regards the first, there are no indications that a stabilization in the population numbers of Great Britain will occur. It is true that there is a certain regulation of numbers by management measures on the Farne islands, but it seems that the animals are establishing themselves on the east coasts of the until now uninhabited islands, such as the island May. The dispersion will probably decrease slightly but on the other hand, the number of births will increase in the tidal inlet of the Vlie. On the basis of that, an increase of approximately 7% per year in the coming decades may be expected. The Engelschhoek has since the summer of 1990, remained under water during high tide and the number of 120 to 140 animals, is the estimated maximum on other banks in the tidal inlet of the Vlie. Currently, the trend is that the animals are going to the nearby Richel, but the numbers are smaller than those that occurred in 1989 on the Engelschhoek. Should this tendency of change in height and configuration continue, then the true growth will be considerably smaller and could even decrease. It is obvious that, under the present circumstances no good, alternative places are available at the moment.

The common seal. Apart from the direct effect of the epidemic, which resulted in a decline in population, immigration to the Dutch Wadden Sea will also decrease. By using a population simulation model, it has been calculated how the future population development could progress. The assumptions for this are: 1) an increased death rate as a result of the epidemic (will no longer occur after 1989), 2) the reproduction will be the same as before 1988, 3) the age groups of 1987 and 1988 have for the large part died (90%) and 4) the amount in percentage of immigration as well as the release of rehabilitated animals, is equal to the one before the epidemic. These assumptions have been derived from the brief data that has become available via air counts and analyses (age distribution and sex) of dead animals collected before and after the epidemic. The reliability of this cannot be tested yet and therefore, the predictions on the future population trends must be regarded with some reserve. There are two possible developments: 1) the virus does not play a further role; for example, via mutation or, because immunity is passed onto the pups and 2) if the density of animals without antibodies has become high enough, a new epidemic will break out and a cyclic trend will arise. Both developments are shown in figure 10. In case of a repeating trend, a cycle of about ten years can be expected and the population size will never be larger than 1500 animals. This number is to be regarded as an upper limit. With this density of animals without antibodies, the epidemic could break out in 1988. The critical density is very likely to be lower and with that, the final population level will be lower and the repetition will progress faster. Until now, too little data is available for attaching a probability on one or more of the trends.

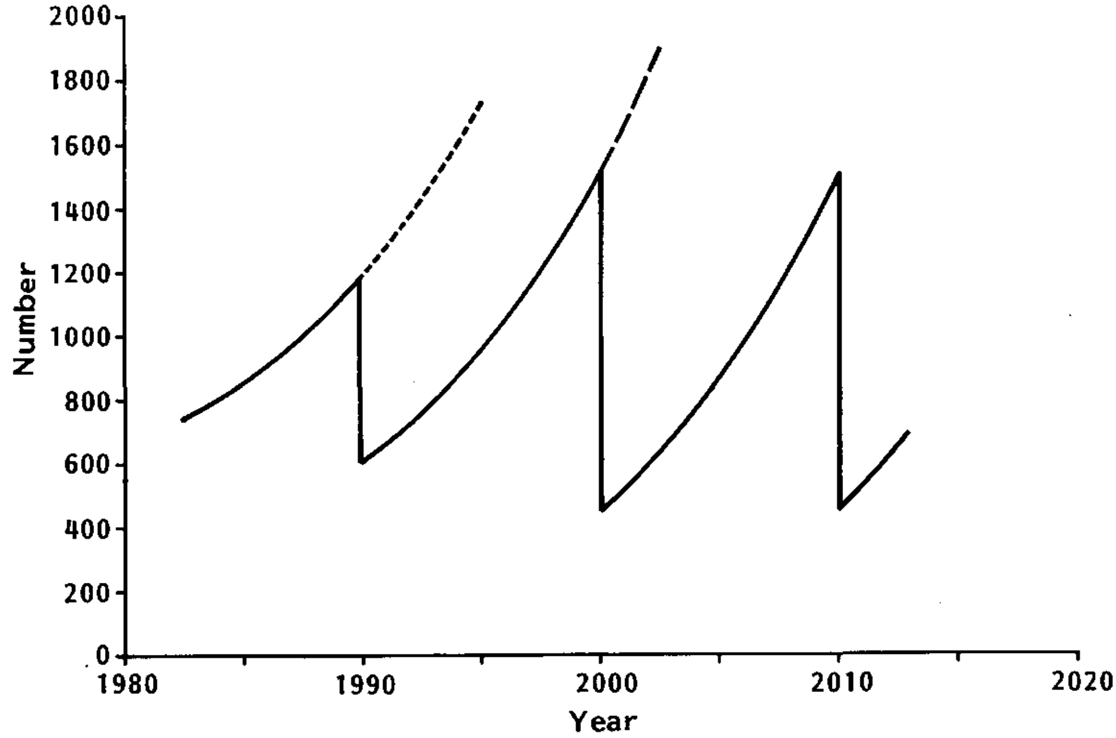


Figure 10. Simulations of the future population progress of the common seal in the Wadden Sea; no (- - -) and a new (——) virus break-out.

4 A REFERENCE FOR THE WADDEN SEA

4.1 Introduction

It is of great importance for policy and management, to have a reference of the Wadden Sea at their disposal. Reference is understood to mean; the way the most natural Wadden Sea possible, looks like. The term 'as natural as possible' is however, not always applied consistently. Human interferences that count as hard limiting conditions (eg. dikes), are considered as being restrictive for the most natural Wadden Sea possible. Small-scale human activities that have been occurring for centuries, may also be regarded as being a part of the natural ecosystem. This will certainly be the case if these activities have had an enriching influence such as sand dikes have had. A reference is in the first place necessary in order to be able to test, within the scope of the extension of licences, whether an intervention or action will cause the system to move away from the reference. In the second place, a reference is necessary so that policy can use it as a standard in the development of a target objective. A sectoral policy can cause the target objective to substantially deviate from the reference but it is also possible to develop a target objective that, through interventions and measures, approaches the reference more closely than is possible under natural development.

If the reference cannot be approached by a development on a natural basis and management measures, (eg. due to the subsequent delivery of contaminants, permanent changes as a result of the Afsluitdijk, the rise in sea level etc.), it is useful to introduce the term 'attainable situation' for the situation that could be attained.

4.1.1 *The choice of references*

A reference can be determined in three ways: 1) A similar system can be studied on geographical grounds or an undisturbed area within the Wadden Sea can count as a reference for disturbed or otherwise similar areas. 2) In the determination of a reference, historical research can also offer insight. Here, account must be taken of the fact that succession can occur and that as a result of fluctuations, other reference years or averages of a number of years must be used for the different variables. 3) Another method includes theoretical considerations with which, on the grounds of ecological knowledge, it is determined what a system could look like. In practice, all three methods are used in the development of a reference.

References can be described on the basis of very different parameters. Each choice has specific advantages and disadvantages. The parameters used most frequently are:
- the numbers of individuals of, or the space taken by, one or more selected species;
- the degree of action of a number of abiotical and biotical processes;
- the size of a number of abiotical parameters.

A reference that is focussed on species will usually choose the numbers of a species as its parameter. The advantage is that policy and management then have a relatively easy to measure parameter with which developments can be compared. The disadvantage is however, that natural dynamics and shifts between species can scarcely be accounted for.

The reference can also be based on biotical and abiotical processes. A system in which the most important processes are able to behave and develop naturally, may be seen as the reference. On the grounds of ecological knowledge, it can be attempted to indicate which species in which numbers will occur there, so that in the evaluation of the management pursued, the numbers of a species have nevertheless an indicative value. Here, account can be taken of the natural dynamics. The reference can therefore clearly deviate from the historical situation if the most important limiting conditions have been altered in the system or the surrounding systems. Here, for policy and technical management reasons, a distinction must be made between a) natural, b) irreversible and c) reversible changes caused by human actions.

A reference based on abiotical parameters will usually use parameters such as current speeds, nutrient levels, concentrations of micropollution, oxygen levels and the degree of disruption or fishing activities, as a reference. Supporters of this approach point out that, striving for the references of these parameters will automatically lead to a system that resembles the natural situation as closely as possible. The historical values of most of these parameters are known, or calculable by assuming a system under a minimum of human influence. This is therefore, a very practicable concept for policy and management. Causal relationships between abotical parameters and the system's condition are only quantified to a certain degree. That is why it is not really possible to indicate to what extent a system that looks natural can be approached, if the abiotical parameters are only partly influenced (or could only be partly influenced) by management measures.

Ten Brink et al. (1990), point out that the use of processes as a parameter in the determination of a reference has a great number of disadvantages. Processes have little social appeal and are harder to define and measure than parameters of species. Of course, processes and knowledge of the relationship between process and parameter certainly are extremely important to nature managers. Once the relationship between process and the number of a species is known, the effects of an intervention into the numbers of a species can be taken into consideration by the management policy, moreover, by steering a process, it is possible to influence the development of the species. A disadvantage is that the cause and effect networks and the processes connected to these, are mostly unknown. That is why it will not always be clear why numbers deviate from a reference norm. There is a risk that management measures geared to the achieving of a reference are taken by intervening in a process not responsible for the deviation in the level of reference. Those management measures then take on the characteristics of symptom treatment.

Policy bodies can assume a reference and the target objective based on processes, connected to this. With this, the acceptability of the management measures can also be tested. This prevents the management measures from merely taking on the characteristics of symptom treatment.

In this report, a reference is described on the basis of processes. An indication is given where possible, of the numbers that can be expected under those conditions. This prevents the management from focussing on an attempt to achieve, via technical measures, a target objective based on numbers and derived from the reference.

The Wadden Sea is one of the most natural areas in the Netherlands, in which natural processes have led to a highly esteemed ecosystem. In the General Management Policy, the formulated management aim for primarily the preservation, the restoration and the undisturbed progress of natural processes may be seen as a target objective. That target objective is based on processes. That is also the reason for basing the reference from which the target objective is derived, on processes. It is assumed then, that all structures, plant and animal species which belong to the Wadden Sea by nature, can maintain, develop and restore themselves there. The reference can, within a number of assumptions, be seen as an ideal situation for the Dutch Wadden Sea. Policy bodies responsible for nature management can use the reference as a target objective. It may sometimes be necessary to take active management measures in order to achieve this target objective.

4.1.2 *Assumptions*

A number of developments and interventions that have an influence on the ecosystem of the Wadden Sea, are considered as being unable to be influenced. These have been handled in the description of the reference as fixed assumptions.

- The Afsluitdijk. This has caused the surface of the Wadden Sea - Zuyder Zee complex to be reduced. The gradual transition from fresh water to salt water in the western Wadden Sea has ended and the herring and the anchovy that spawned in the Zuyder Zee have disappeared. The tidal range and the current speeds in the western Wadden Sea are also higher now than in the past.
- High-tide dams. The present position of the storm-surge flood barriers is seen, in view of the social interest in conservation, as an assumption. Summer dikes are expressly not included here.
- The sea level rise. Because of the generally expected world-wide sea level rise and the drop in the northwest European sea-floor, a relative sea level rise of 35-80cm per century is expected in the Wadden Sea.
- The subsequent delivery of nutrients/contaminants. Even if the pollution of water is immediately stopped, a subsequent delivery will still occur from the polluted silt sunk in the bottom of the Wadden Sea, and from the seeping through of contaminants dumped onto the land. Due to the northwest European population and agricultural businesses, the nutrient load of the surface water and the air will always remain higher than the natural one.
- Salt marshes. Due to the interaction between natural processes and human activities, salt marshes have repeatedly developed and been diked-in since the Middle Ages. Human activities have gained the upper hand, which has as a result that new salt marshes cannot or can hardly develop in a natural manner. Through reclamation techniques, the salt-marsh surface area is kept at a high level.

On the basis of the previous discussion, references are developed for the aspects mentioned in chapter 3. Although these are based on natural processes, it is, on the basis of knowledge of the system, often possible to give an indication of the surface of a biotope or the number of organisms of a species. This was done wherever possible in order to give a rough indication of the numbers that occur in a reference. It must be emphatically mentioned that these numbers have at the very most, the value of a standard and should only have a limited function in the determination of policy and management plans for the achieving of a target objective.

4.2 Hydraulics, the geomorphological structure and turbidity

As for the hydraulics, it must be assumed that this is a natural process which has hardly been influenced by human activities since the enclosure of the Zuyder Zee and the Lauwers Sea. Only large-scale dredging works, embankments and coastal defences such as dikes and dams, could have an effect on the hydraulics. Assuming the present 'natural' hydraulics, a specific geomorphological structure and turbidity is fixed. Only after a period of many decades to hundreds of years can a substantially different geomorphology be expected. The western Wadden Sea would then take on the character of the eastern Wadden Sea. For the moment, the present condition of the Wadden Sea concerning the hydraulics, the geomorphological structure and the turbidity (insofar that it is caused by suspended silt), can be regarded as the reference.

There are many indications that the amount of suspended silt has increased during the last few years. If this is caused by natural erosion and sedimentation processes, then that must be accepted. According to the *Dienst Getijdewateren* (Department of Tidal Waters) of the Department of Public Works, a part of this increase is caused by human activities (IJsselmeer drainage, dredge spoil dumping in loswal Noord, sand extraction etc.). In that case, the reference value for turbidity should be lower than the current value. Further research and analysis of existing data is necessary for this.

4.3 The most important biological processes

The important processes in the food chain of the Wadden Sea are regulated by the amount of available light, the temperature and the import and export of nutrients. Toxic materials also can have an influence. The amount of sunlight and the temperature must be regarded as being natural limiting conditions unable to be influenced by the Wadden-Sea policy. The light available for the primary production is dependent on the time of submergence of the tidal flats and the transparency of the water. The time of submergence of the tidal flats depends on the geomorphological structure and hydraulics. As fixed earlier for these parameters, the current situation in relation to the time of submergence can be regarded as the reference.

The transparency of the water is determined by the amount of suspended dead and living matter. The dead matter consists of silt and detritus (mainly particles of eroded peat banks). The amount of suspended dead matter depends on hydraulical processes. Unless it is indicated that the amount of suspended particles has increased due to human activities, the current situation can also be regarded as the reference.

Generally speaking, the living algae cells contribute very little to the reduction of transparency in naturally turbid salty waters such as the Wadden Sea. Only in spring, during the blooming of *Pheaocystis pouchetii*, is the transparency determined by this alga. Because the duration of the bloom of this alga has increased through human activities, a higher value must be maintained for the reference value of water transparency than that of the current situation. Because the transparency has neither in the past, nor today been clearly measured, this reference must be quantified through further research. Because the amount of algae is directly connected to the amount of available nutrients, manipulation of the amount of nutrients coming into the area, will be the most important measure used to approach the reference of transparency. For this, target values must be determined for the supply and amount of nutrients. During the fifties, the nutrient load was determined by the decomposition of organic matter imported from the North Sea. Later, the supply from the IJsselmeer started to dominate (Van Raaphorst & Van der Veer 1990). Because the effects of eutrophication have only been measurable since the seventies, the size of the primary production at the beginning of the seventies could be regarded as the reference for the primary production. The target value for the nutrient pressure does not necessarily need to be based upon the concentration of the past. Within the framework of a nature-aimed norm standard, the target value can be such, that the reference for the primary production is approached. Since the quality of the water is the responsibility of the Ministry of Transport and Public Works, it is not dealt with within this scope.

Since the remaining important biological processes are directly or indirectly connected to the primary production and the geomorphological and hydraulical processes mentioned before, no references are quantified for them.

The density and production of worms and the balthic tellin are lower in the reference than in the current situation. The situation for the suspension feeders is not so clear because these organisms profit relatively little from the increased primary production, mainly provided by the *Phaeocystis*.

4.4 Elevated flats, beach plains, tidal flats and their biota

Elevated flats, beach plains and tidal flats are formed and maintained by physical processes that occur naturally. The current dynamical situation can therefore be regarded as the reference. By accepting the natural dynamics, changes concerning the current situation are also accepted, and therefore, the reference can not be described as an exact and fixed situation. However, the current surface area of these structures can be used as a reference because human activities have hardly had, or have not had an effect on this surface area of these biotopes so characteristic for the Wadden Sea. It is assumed here, that the geomorphological structure remains similar to the current structure in the event of a sea level rise.

The flora and fauna on the beach plains and tidal flats is partly determined by physical processes such as wind, current, sea swell and the stability of the sediment and the sedimentation of silt and organic matter connected to this. Also regarding this, the current situation for the flora and fauna can be seen as the reference. Flora and fauna are however, also influenced by eutrophication and pollution of the system, and by direct human activities. The effects of pollution are not clear, but they certainly should not be ruled out. The description of a reference in regard to the flora and fauna without the influence of pollution is with the current knowledge, not yet possible. More certainty exists concerning the effects of eutrophication. It seems probable that the average biomass of benthic organisms weighs about 20g ashfree dry weight per meter squared in the reference. This piece of information is based on research done at the beginning of the seventies. There are, moreover, indications that the biomass was relatively low in that period of time (C.Swennen, pers. comm.). Pollution is mostly thought to have been the cause of this.

The management would be wise not to be led into striving for the achievement of a quantified target objective in relation to benthic organisms. If the reduction of eutrophication and pollution is strived for, then after a while, the reference would be achieved. Therefore, a quantified target objective is not necessary for policy and management.

Changes in regard to the reference are also demonstrable by direct human activities. Due to good regulation and the difficult accessibility of most of the flats, the changes in relation to the reference are negligible regarding the Wadden Sea as a whole. Fewer mussel beds occur near the coasts than in the reference due to ragworm (*Nereis virens*) digging on and directly alongside the mussel beds. The current situation in relation to mussel beds near the coast cannot be regarded as the reference either. The greatest influence on tidal mussel beds is however, that of seed-mussel fishing. In the years following a bad spat fall, all the tidal mussel beds with young mussels are practically fished empty. In the year following a good spat fall, a great deal is left remaining but the greater part generally disappears through fishing in the first following years. If the beds become very old and high, they will disappear through storm and floating ice.

As a result of the occurrence of very large fluctuations, it is impossible to give a value for the amount of mussels in a reference. It can be concluded on the basis of information gained from aerial photographs of the German, Danish and Dutch Wadden area, that there must be 3200 ha of undisturbed mussel beds present in the Dutch Wadden Sea. In certain years, no more than a few million kg of mussels will be on these beds but in good years, this amount could increase to almost 200 million kg.

The same applies for the cockle population, as a result of fishing particularly in bad cockle years, the number of cockles is kept far below the natural level. No concrete reference value can be given here, also as a result of large natural fluctuations.

4.5 Seagrass fields

Sublittoral seagrass. The sublittoral seagrass fields that consisted of the eel grass (*Zostera marina*) have disappeared through natural causes. The non-reoccurrence is probably partly to blame on human activities. This must be regarded as the current natural situation, as long as the present unfavourable conditions for the seagrass are the result of a changed hydraulical situation due to the building of the Afsluitdijk. The maximum situation attainable can therefore take up less space than the reference, which is based on historical and geographical information.

It can be concluded on the grounds of historical data, that 15,000 ha of sublittoral seagrass occurs in the reference for the western Wadden Sea. However, it must be concluded on geographical grounds that sublittoral seagrass also does not occur at this moment, in similar areas of the German and Danish Wadden Sea. It did occur in Sylt before 1933 but it also disappeared there as in the Netherlands, due to the same disease.

Research into the living conditions of seagrass has made clear that, sublittoral seagrass is able to grow in the Wadden Sea in shallow areas with a slight tidal range. With regard to the available amount of light, the sublittoral seagrass lives on the edge of possible existence. That is probably why survival is only possible if a well developed root system with shoots is present in the spring, which has stored sufficient energy for growth so that the leaves reach the surface of the water. However, if such sublittoral vegetation must re-develop from seed, the following conditions must be met;

- enough seed must be present;
- there must be a stable sea-floor; the young seagrass vegetation has not developed sufficiently in order to be able to create a stable situation itself;
- enough light must be available.

A situation in which all the three conditions are met, probably occurs so now and then and it seems even possible that after the disappearance of the species from the Wadden Sea and the hydraulical changes as a result of the Afsluitdijk, the possibility for the establishment of new sublittoral fields will not occur again.

Supporters of the classical nature management view, can consider the historical situation as the reference. Through the increase of the tidal range, the potential area has become considerably smaller. Supporters of the natural development view, must conclude that a Wadden Sea without sublittoral seagrass is the reference. Because the chance for natural establishment is very small, due to amongst others, human activities, the stimulation of the reintroduction of sublittoral seagrass by planting under protective circumstances, can be therefore defended. If after that, it can support itself independently, then it is realistic to assume a reference that corresponds to the attainable area previously mentioned. Further research is necessary before any concrete statements can be made on the size of this area.

Littoral seagrass. The tidal seagrass vegetation *Zostera marina* and *Zostera noltii* has possibly decreased as a result of human influences. Only a very limited amount of quantitative information is available from the past. On the basis of research into the relationship between the occurrence of seagrass in the German and Danish Wadden Sea and the requirements for development, it can be indicated for the Dutch Wadden Sea also, the surface area of which would be potentially suitable for the growth of seagrass. This can be regarded as the reference. The afore-mentioned research is being done by the

Research Institute For Nature Management and the Agricultural University of Wageningen and will be completed during the course of 1991.

4.6 Salt marshes

It has been previously indicated that the area of salt marshes in the Wadden Sea is determined by the interaction between salt-marsh growth and diking. In the past, more embankments occurred than new salt marshes. That is why the salt-marsh area decreased. A Wadden Sea without, or with only a very few salt marshes cannot be regarded as a 'complete' ecosystem. That is why the artificial stimulation of reclamation salt marshes is, as a compromise, is considered acceptable and reclamation salt marshes are considered to be part of the reference for the Wadden Sea.

Moreover, a certain area of salt-marsh regions is wanted in order to make the long-term existence of a complete collection of species possible. This so-called minimum area is for the invertebrate animals 500 ha, for the birds 800-1000 ha and for the small mammals 1000-2000 ha (Heydemann 1981, Beeftink 1984). Since large salt marshes hardly exist anymore, all salt marshes greater than 500 ha are considered to be of essential importance to nature conservation (Heydemann 1981, Dijkema 1987). Along the Atlantic and Baltic coasts of Europe, lie only eighty of such areas , seven of which are in the Dutch Wadden Sea. The international importance of Wadden-Sea salt marshes is therefore great (Wolff et al. 1988).

Because of the enormous decline of salt marshes in Europe, a group of experts from the Council of Europe has stated that all the smaller salt marshes are also important; they contribute to the maintenance of the geomorphological and biological variation and serve as 'stepping stones' for the distribution of saline-tolerant plants and animal species (Dijkema et al. 1984).

In order to compare the area of salt marshes of various years and areas, the percentages of salt-marsh area in the tidal regions have been calculated. That measure is easier to handle than the absolute surface area, because account is taken of the area of the system of which the salt marsh is a part and of the diminishing size of the system due to embankments. In table 6, such percentages have been calculated for a number of tidal regions. The number of salt marshes seems to vary between 7.5% and 10% in areas with favourable sedimentation conditions or in areas where very little diking has occurred (the Wadden Sea of Denmark, Westerschelde, Wash and Taag), and between 1.5% and 4% in tidal areas where much diking has occurred or with bad sedimentation conditions (the Wadden Sea of Schleswig-Holstein, Niedersachsen, and the Netherlands, Oosterschelde).

Figure 11 shows the salt-marsh percentages in the Dutch Wadden Sea for the years 1600, 1700, 1800, 1860, 1925 and 1987. The pioneer vegetation has not been included in these figures because it is not indicated on the old maps. That is why the final total is lower than in the comparable percentage of table 5. The trends that the salt-marsh percentages show in time (fig. 11) remain the same as is previously described for the surface areas. The surface area of salt marshes in a reference can be derived from figure 11. For this, it is important to know which back-ground view on nature management is being used. The current view can be derived from the General Management Policy.

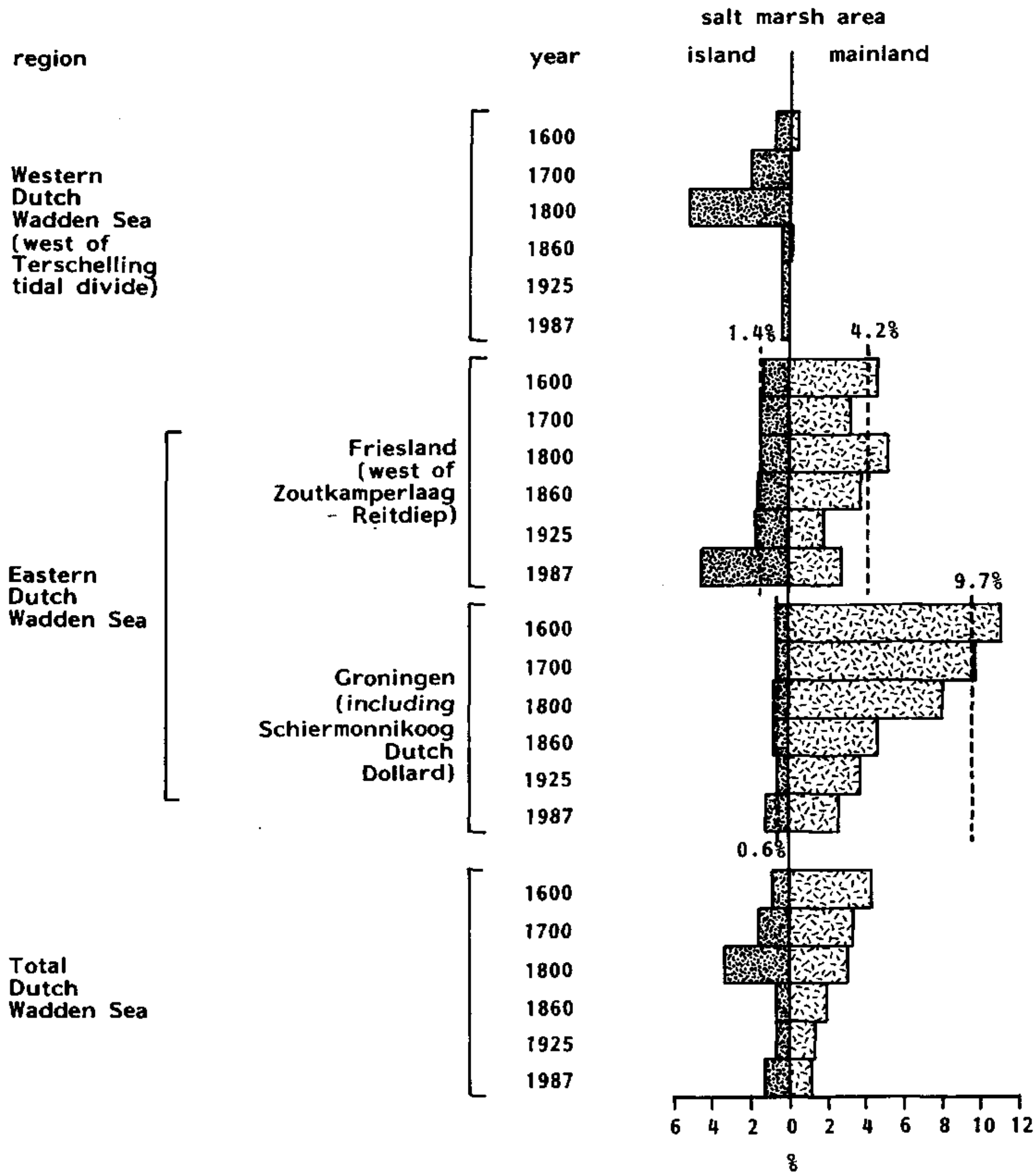


Figure 11. The salt-marsh area of the Dutch Wadden Sea after 1600 as a percentage of the total tidal region; including Huisduinen and the polder lying behind and Wieringen, excluding the salt marshes. Salt marshes in 1985 including the Slufter on Texel, but without summer polders and pioneer vegetation along the mainland. ----- = average % of salt marshes in the years 1600, 1700 and 1800 (from Dijkema 1987a).

Table 5. The area of salt marshes in 1987 (including pioneer vegetation) as a percentage of the tidal region. * = including the summer polders; ** = before the completion of the compartment dams

Country	Region	Percentage of tidal region
The Wadden Sea countries	Denmark Schleswig-Holstein Niedersachsen The Netherlands	9.5 2.0 (2.5*) 4.0 (5.5) 2.8 (3.3)
Southwest Netherlands	Oosterschelde Westerschelde	1.5 (4.0**) 8.4
Great Britain	Wash	7.4
Portugal	The Taag estuary	10.0

In this General Management Policy, the most natural Wadden Sea is strived for, in which all structures and animal and plant species belonging to the Wadden Sea by nature, can maintain, develop or restore themselves. For this, there must be a rough balance between the geomorphological processes of development and decomposition. For salt marshes one can take this to mean, a rough balance between embankments and (natural or artificial) growth, a situation that existed between 1600 and 1800. The average amount of salt marshes from that period (fig. 11) is presented as the quantification for the reference. With this, it is possible to calculate the amount of salt marshes that should now, in a smaller Wadden Sea, be present in a balanced situation between embankments and growth. The value is therefore independent of the area of the whole Wadden Sea.

The eastern Wadden Sea. In table 6, the current percentages for the eastern Wadden Sea have been compared to these values and converted into area measurements. The island salt marshes are 1800 ha above the reference which is a result of salt-marsh growth behind sand dikes. The mainland salt marshes are however, 5500 ha under the reference despite all the results gained by reclamation works. This is because growth during the past centuries, seems to not have been able to compensate the losses suffered through all the embankments. Moreover, erosion is now taking place due to the rising of the average high tide.

The western Wadden Sea. It is not realistic to suggest a reference of salt marsh numbers for the western Wadden Sea. The present situation is definitely bad. The island salt marshes have decreased from 1250-8850 ha in the period 1600-1800, to 400 ha today (fig. 3). It must be mentioned here, that before 1800, a large number of the salt marshes occurred as a result of human activities such as the building of sand dikes. It is not realistic to expect a substantial recovery as all the areas suitable for new growth to occur, in the top of North-Holland and on Texel, have been diked in.

Table 6. The area of salt marshes in the eastern Wadden Sea compared to the suggested reference (from Dijkema 1987a).

Region	Type of salt marsh	Salt marshes 1600-1800 %	Salt marshes		Difference from reference km²
			1987	km²	
Friesland (Tidal divide Terschelling-Zoutkamperlaag)	Islands	1.4	4.5	20.5	+14.0
	Mainland	4.2	2.4	11.0	- 9.5
Groningen (incl. of Schiermonnikoog and Dutch Dollard	Islands	0.6	1.2	7.1	+ 3.7
	Mainland	9.7	2.4	15.0	- 45.2

4.7 Birds

As already indicated in the description of the development of non-breeding bird populations in the Wadden Sea, the numbers are regulated by conditions in the Wadden Sea but also in overwintering and breeding grounds, often situated far from the Wadden Sea. Although the conditions outside of the Wadden Sea can be more important for some of the species, it is certain that a Wadden Sea with too little food available has an influence on the numbers present and the chance of survival of many of the birds. A shortage of food can be caused by a low benthic organism or fish biomass, too much disturbance and unfavourable weather conditions such as storm or floating ice. The transparency of the water can also be of importance to some species. A shortage of food can have an effect on the condition of these birds and therefore, determines whether they will arrive at the following staging place on the way to the overwintering or breeding grounds, with or without enough reserves. The embankment of a part of the Wadden Sea will have an effect on the total number of birds using the area and possibly on the total number of migratory birds. This also counts for more intense forms of disturbance on the understanding that the effects have, in that case, a reversible nature.

The fact that the numbers present in the Wadden Sea are regulated partly outside of this area, means that it is not really possible to give a quantified reference. Considering the fact that the population was artificially low in the past, due to hunting, amongst others, along the migratory route, one must assume that the numbers of many species can increase somewhat in the future. This is especially true for geese and ducks. It is feasible moreover, that the numbers of terns present were also artificially low, due to the aftermath of death caused by pollution in the sixties. The numbers that occurred during that period 1960-1970, are shown in table 7. The Wadden Sea will have to have at least that much food available for that number of birds, and will also have to provide them good living conditions. An increase or decrease in these numbers need not say anything about the quality of the Wadden Sea, but it can be an expression of this.

In regard to the breeding birds, it is possible to give a quantified reference for several species. The numbers of breeding birds are determined by the success of the breeding season and the survival of the growing and older birds. The success of the breeding season depends on peace and quiet in the breeding grounds, the collecting of eggs or not and the availability of food during the breeding season and while raising the young birds. These factors are mainly determined in the Wadden area itself. The survival of the older birds is mainly determined by the presence of suitable staging places and overwintering grounds, and the availability of food. The disappearance of the sandwich tern from the Wadden Sea, as a result of pollution by chlorinated hydrocarbons brought in by the Rhine, has made it clear that the conditions in the Wadden Sea are vitally important to the survival of the breeding-bird populations in the Wadden area. But other factors also play a role. It seems that the protection of the breeding grounds and the availability of supplementary food (rubbish dumps) has led to a sharp increase in the breeding-bird population of the herring gull. However, the striving for supplementary food in the form of rubbish dumps does not fit in with the idea of a most natural Wadden area possible. The creation of peaceful breeding grounds in nature reserves was important for the eider duck. Species such as the shelduck, the curlew and various songbird species also have greatly benefited from the presence of undisturbed nature reserves.

Assuming that there are enough peaceful breeding grounds in the Wadden area and that there is sufficient food, an estimation has been made of the number of birds that might be present in the future. These numbers are presented in table 8. For comparison, the numbers between 1925, 1930 and of the seventies have also been provided. The possible future population size is based on estimations of earlier numbers present (eg. the common tern, the sandwich tern), the developments and size of populations (eg. the population growth of the eider duck, the avocet; the population decrease of the herring gull) and the possible numbers present due to a better protection (eg. the ringed plover, the redshank).

Table 7. Maxima of monthly averages for late summer/autumn, winter and spring for 24 of the most characteristic waders in the Dutch Wadden Sea over the years 1960-1980 (source: Smit & Wolff 1981). The species marked * are partly breeding birds.

Sort	July-October	November-January	February-May
Brentgoose	13,000	11,000	54,000
Shelduck	50,000	45,000	20,000
Wigion	77,000	137,000	24,000
Mallard*	13,000	23,000	16,000
Eider*	60,000	134,000	90,000
Oystercatcher*	190,000	190,000	150,000
Avocet*	16,000	3,000	4,000
Ringed Plover	4,000	<1,000	2,000
Grey Plover	14,000	4,000	17,000
Knot	105,000	50,000	97,000
Sanderling	4,000	2,000	1,000
Dunlin	205,000	105,000	180,000
Bar-tailed godwit	61,000	20,000	67,000
Curlew*	81,000	48,000	54,000
Spotted redshank	2,000	0	1,000
Greenshank	5,000	0	1,000
Redshank*	35,000	6,000	8,000
Turnstone	5,000	2,000	2,000
Blach-headed gull*	84,000	8,000	20,000
Common gull*	76,000	13,000	10,000
Herring gull*	42,000	40,000	23,000
Sandwich tern*	4,000	0	2,000
Common tern*	5,000	0	4,000
Little tern*	1,000	0	<1,000

Table 8. Number of breeding couples in the years 1925 - 1930 of some of the breeding birds species, characteristic for the Wadden area. Sources: Teixeira 1979, Smit 1981, Smit & Wolff (1981), Vertegaal & Van der Salm (1988) and information from RIN, Texel.

Sort	Estimated number between 1925-1930	Number in the seventies	Possible potential size of population
Eider	10	4,000	10,000
Shelduck	1,000	1,300-1,450	1,500
Oystercatcher	5,000	8,400-8,800	10,000
Kentish Plover	500	150-200	500
Ringed Plover	40	100	500
Redshank	3,000-3,500	2,300-2,700	4,000
Avocet	1,000?	2,200	5,500
Herring gull	10,000	35,000	30,000
Common gull	60	2,500	3,000
Black-headed gull	5,000?	67,000	60,000
Common tern	15,000	3,000-5,000	20,000
Arctic tern	300	1,100-1,400	5,000
Little tern	500	100-150	1,000
Sandwich tern	20,000	4,000	25,000

4.8 Sea mammals

The grey seal. This species can be considered indigenous on the grounds of historical reasoning. As a result of human influences, particularly hunting, the numbers sharply decreased. During the last few centuries the animals, usually solitary, have seldom been sighted. The grey seal does occur in other areas similar in habitat, outside the Wadden Sea. Sable Island near Nova Scotia, a 40 km long and a 1.5 km wide sand bank, accommodates a colony of approximately 10,000 animals. Here, there is no human inhabitance therefore hardly any disturbance. It can be concluded that, suitable biotopes occur in principle, in various places in the Wadden Sea and that a colony of eighty animals has, in the mean time, established itself and therefore, a number of colonies totalling several hundred grey seals fits in with the sea-mammal reference for the Wadden Sea.

The common seal. A reference for the common seal, expressed in the order of size for the population scale, is able to be given more concretely. For this, a Wadden Sea is assumed in a state of reference. That is to say, that seals occur with a normal hormone regulation, that the disturbance is of such a low level that the weaned pups have a good chance of survival and that drowning in fyke nets does not occur often or does not occur at all. The seal population will then stabilize itself at a natural level. On the grounds of population calculations going as far back as the beginning of this century, taking into account the habitat loss due to the definite enclosure of the Zuyder Zee and the Lauwers Sea and taking into account the numbers of common seals found in comparable tidal areas such as the Wash, the attainable common seal population is estimated to be more than 7500.

5 MEASURES AND CONDITIONS FOR THE STIMULATION OF DEVELOPMENTS IN THE DIRECTION OF THE REFERENCE

5.1 Introduction

This study is not aimed at the giving of a complete overview of all the interventions in the Wadden Sea and the effects thereof on the ecosystem. That has been done earlier in a Research Institute For Nature Management report on the culmination of ecological effects in the Wadden Sea (Dijkema et al. 1985). In that report an overview is constructed in a series of matrices, of the possible interaction between interventions and ecological aspects of the Wadden Sea. Tables 9 and 10 give the end result of these matrices. On the basis of the interaction, the size of the area influenced and the restoration duration after the intervention, it seems that embankments and other hydraulic works as well as oil dumping, materials foreign to the system and fishing activities have the worst effects. By applying regulating measures, the disturbance to the behaviour of birds and seals is, in many cases, kept to a minimum. This is more or less the case with military activities and small-scale aviation.

In the applying of measures, a distinction must be made between direct, mostly technical measures and indirect measures such as the reduction of human influence by making regulations. The reduction of, for example, nutrient and contaminant loads by using technical measures that are outside the planning act area, also falls under the indirect measures. Indirect measures meet with no objection within the main aims of the Wadden area management. The application of direct measures must be tested against the assumption that natural processes should be able to run their own courses.

The acceptance of a dynamical management objective, aimed at the preservation of hydraulical, geomorphological and pedological processes, leads to the fact that the development and break-down of ecosystems or the growth and decrease of populations remain an integral part of processes in the Wadden Sea. As long as the development and break-down, taken over the whole Dutch Wadden-Sea area, are roughly in a state of balance, there is no reason from a management-aim point of view, to intervene. The need for active human intervention (direct measures) in the progress of natural processes, according to the General Management Policy occurs when:
- it involves compensating negative effects of human actions on nature;
this is necessary from a coastal defence point of view;
- the rough state of balance between the natural processes of development and break down over the whole Dutch Wadden Sea is structurally disturbed. On the grounds of the previous argumentation, there are reasons for the direct human intervention in the management of mainland salt marshes, the re-establishment of sublittoral seagrass and oyster beds, and the temporary stimulation of the population growth of seals.

For as far as the present situation of the Wadden Sea is removed from the reference, the taking of indirect measures is generally accepted, through which the conditions are created necessary for developments in the direction of the reference.

Table 9. Duration and frequency of interactions which cause a negative effect between intervention and ecosystem aspects in the Wadden sea.

1 regular interaction, intervention is closely tied to tide, location or season, or a calamity
2 regular short interaction
3 interaction of a longer duration (> 1 year)
4 permanent interaction, can be stopped
5 definite interaction, cannot be stopped
? occurrence of interaction is uncertain
O interaction practically absent because of regulation
:::::: interaction virtually impossible, of no importance with present and future intervention, or practically absent because of regulation.

ECOSYSTEM ASPECT / INTERVENTION	LANDSCAPE			ABIOTIC ENVIRONMENT			BIOCENOSIS			ANIMAL BEHAVIOUR		
	size	wideness	natural quality	water movement	soil composition	composition of water and soil	benthic organisms	water organisms	salt marsh organisms	breeding and resting birds on salt marshes	feeding birds (tidal flats and water)	seals on resting spots (tidal flats)
diking in of salt marshes	5	5	5	5	5	5	5		5	5		
diking in of flats	5	5	5	5	5	5	5	5			5	5
reclamation and sand dikes		4	4									
artificial sand plains	4	4	4		4		4				4	
gas and oil exploitation	4	4	4	?	?	④	④	④	?	④	2	2
high buildings		4										
artificial/dredged channels			4	4	4	3	3	3				
sand mining			2		2	2	2	2				②
large pipes			4	3	3	3	3	3	3	3	3	3
public pipe networks			4		3		3					
oil calamities			1			1	1	1	1	1	1	1
discharge system alien matter						4	4	4	4			
discharge naturally occuring matter						4	4	4				
discharge of cooling water						4	4	4				
dumping of dredge spoil	⑤	⑤	⑤	⑤	2	2	2	2	⑤			
discharge of surface water							4					
mussel culture		4	4		4	4	4	4				②
cockle fishery					1	1	1					①
shrimp fishery								4				
fyke fishery on eel, grey mullet etc.		①						①			1	①
digging lug worms and rag worms					2	2	2			①	1	
summer dikes	4	4	4	4	4				4			
agricultural use of salt marshes												
military activities		4	4							2	2	2
civil aviation										2	2	2
finding mussel and cockle beds											1	①
gas and oil exploration										1	1	①
management and research										2	2	2
watersports											①	②
tidal flat walking										①	1	
shore and salt marsh recreation									②	②	2	
hunting										1	①	①

Table 10. Area of the interaction with a negative effect between intervention and ecosystem aspects in the Wadden Sea.

1 relatively small (eg. strongly tied to location), size corresponding to dose
2 relatively small but enlarged by transport of the dose by wind and/or tide.
3 relatively large, size corresponding to dose
4 relatively large, and yet enlarged by transport of the dose
5 large because of uncontrollable transport of the dose by tide and/or wind
? occurrence of interaction is uncertain
O interaction practically absent because of regulation
::::: interaction virtually impossible, of no importance with present and future intervention, or practically absent because of regulation.

ECOSYSTEM ASPECT / INTERVENTION	LANDSCAPE			ABIOTIC ENVIRONMENT			BIOCENOSIS			ANIMAL BEHAVIOUR		
	size	wideness	natural quality	water movement	soil compo-sition	compo-sition of water and soil	benthic organisms	water organisms	salt marsh organisms	breeding and resting birds on salt marshes	feeding birds (tidal flats and water)	seals on resting spots (tidal flats)
diking in of salt marshes	3	3	3	4	4	4	2		3	3		
diking in of flats	3	3	3	4	4	4	3	3			3	3
reclamation and sand dikes		3	3									
artificial sand plains	1	1	1		1		1				1	
gas and oil exploitation	1	3	1	?	?	⑤	⑤	⑤	?	①	1	1
high buildings		3										
artificial/dredged channels			1	2	2	2	1	2				
sand mining			1		1	2	1	2				①
large pipes			3	4	4	4	3	4	3	3	3	3
public pipe networks			1		1		1					
oil calamities			5			5	5	5	5	5	5	5
discharge system alien matter						5	5	5	5			
discharge naturally occuring matter						2	2	2				
discharge of cooling water						2	2	2				
dumping of dredge spoil	①	①	①	②	1	2	1	2	①			
discharge of surface water							4					
mussel culture		1	3		3	3	3	3				①
cockle fishery					1	2	1					①
shrimp fishery								2				
fyke fishery on eel, grey mullet etc.		①						①			1	①
digging lug worms and rag worms					1	2	1			①	1	
summer dikes	3	3	3	3	3				3			
agricultural use of salt marshes												
military activities		1	1							3	3	3
civil aviation										3	3	3
finding mussel and cockle beds											1	③
gas and oil exploration										1	1	③
management and research										3	1	3
watersports											①	③
tidal flat walking										①	1	
shore and salt marsh recreation									①	①	1	
hunting										1	①	③

5.2 Hydraulics, geomorphological structures and turbidity

Because the present situation is regarded as the reference, it must be guaranteed that the current processes can progress without being disturbed. Large hydraulic interventions such as embankments and dam construction must be avoided, as these have an influence on the hydraulics, the geomorphological structure and the erosion-sedimentation cycle. With the sea-level rise or the dropping of the sea-floor due to gas extraction, the natural supply of sand must be sufficient for the preservation of the geomorphological structures. Because a relationship exists in the regulation of sediment, between the sediment of the deltas outside, the beach plains, the beaches and the Wadden Sea, those areas need to be placed under the scope of action of the Wadden Sea Key Physical Planning Act. As long as it is not clear whether enough sand is being supplied, all activities that increase the need for sand in the Wadden Sea (gas extraction, sand mining) must be avoided. As silt in the water has a negative effect on many organisms, activities that can cause an increase must be looked at critically.

5.3 Biological processes

For the progress of the most important processes at a level that is expected in the reference, a balanced build up of populations of different species is necessary. What is meant by a balanced build up is, that the peaks which do not occur under natural conditions must be kept to a minimum. Eutrophication is suspected to be the main cause for an unbalanced situation. Because of the dominating influence and continued effect throughout the entire system, eutrophication and contamination must be reduced. This must be realized via legal and technical measures outside of the Wadden Sea Key Physical Planning Act area. In order to restrict the delayed discharge from sediment, sediments in sedimentation areas must be disturbed as little as possible.

It is not sufficiently clear what the influence pollution from heavy metals or chlorinated hydrocarbons has on the system. Because of the relationship between the primary production, grazing, predation and mineralization, the influencing of one of these processes has an effect on other ecosystem parameters and processes. Copperpods are for example, very sensitive to micropollution. Fewer copperpods leads to higher concentrations of algae. In this case, a reduction in eutrophication will not have the effect previously calculated.

5.4 Elevated flats, beach plains, tidal flats and their biota

As long as the physical processes can progress undisturbed, the geomorphological structures will be the same as in the reference. Also the organisms that live in these areas, will approach the reference if the effects of eutrophication and contamination are reduced. Characteristic biota that need several years to develop, such as mussel, oyster and cockle beds, can only develop if they are not fished for, or dug out completely for a long time. Activities that physically influence these aged, structured communities (seed-mussel fishing, cockle fishing, possibly in the future oyster fishing and the digging of lug and rag worms), hinder the development of those communities. These activities must be absolutely prohibited in areas where a development of these structures is desired. The assigning of quotas without zoning will not make an undisturbed development possible.

5.5 Seagrass fields

If the tidal seagrass fields have disappeared as a result of human influences (eutrophication, contamination, fishing), they will only return if these influences are reduced. Therefore, as a result of the delayed discharge of materials, no great improvements can be expected for the moment. In areas where seagrasses are returning, they can only maintain themselves if no activities that can disturb the stability of the sediment, occur there.

The key factors for the development of sublittoral seagrass fields are: the turbidity of the water, the tidal regime and the stability of the sediment. Turbidity caused by the blooming of *Phaeocystis pouchetii* can be decreased by the reduction of eutrophication. The sediment stability can be partly improved by a seagrass field with a well developed root system. It is possible that direct measures are necessary in order to give the sublittoral seagrass a good start by planting it in well selected areas.

5.6 Salt marshes

One of the first requirements for the preservation of the salt-marsh area is to no longer embank the salt marshes. The enlargement of the area of the mainland salt marshes, by giving up the so-called summer polders, could also be considered. The restoration of 900 ha of summer polder to salt marshes (Dijkema et al. 1985) leads to the complete achievement of the suggested reference for the mainland salt marshes in Friesland (table 5). Restoration is possible by gaining ownership of the summer polders, to level the summer dikes and to develop a new system of creeks. The measure must be taken in stages in order to be able to check possible erosion of the reclamation salt marshes lying in front.

The sedimentation of the island salt marshes is insufficient to be able to keep up with the expected sea- level rise. The supply of sediment can only occur there, if sand becomes available through an increase in dynamics. The eventual salt-marsh area will be smaller than the current one. Not many results are expected from reclamation techniques on the islands.

In the eastern Wadden Sea, sand dikes have provided a large salt-marsh area on the islands (chapter 3.3.4). Where in the eastern Wadden Sea, the preservation of island salt-marshes is desired, sand dikes must be maintained in areas where enough sediment is available. On parts of the islands where the dynamical processes of development and break-down are desired, measures must, however, not be taken. A division of the areas with the preservation of the existing salt marsh and with dynamical processes must be looked at in the light of a further sea-level rise and a drop in the sea-floor (see the prognosis for the island salt marshes in chapter 3.3.4). In places where the island salt marshes, as a result of not enough available sediment, cannot keep up with the sea-level rise, the best mechanism is a renewed dynamical development in order to ensure the existence of salt marshes on the islands (although smaller in size). Beach nourishments on the North-Sea side of the islands could also be a help.

Further, for the preservation or restoration of the mainland salt marshes, direct measures are necessary (see chapters 4.6 and 5.1). There is enough sediment present for the mainland salt marshes to keep up with the expected sea-level rise. This especially leads, however, to the vertical accretion of the existing salt marshes while the pioneer zone that lies in front of the salt marsh, keeps on descending due to an increasing wave energy. This leads to salt-marsh cliff forming, after which the salt marsh disappears through horizontal erosion (see the prognosis in chapter 3.3.4). The protection or restoration of the mainland salt marshes is possible by applying techniques that encourage growth or, reclamation techniques, a tradition that has existed for centuries in the Wadden Sea. As long as these techniques make use of natural processes in salt-marsh growth (reduction of wave energy, encouragement of draining), they will fit in with the policy pursued up to now for the Wadden Sea. At the very least, the second alternative from the prognosis for the mainland salt marshes (chapter 3.3.4; a stabilizing maintenance including an alteration of the dam distribution) must be carried out. In the case of the erosion problem not being able to be solved by this, and in the case of the sea-level rise and/or the drop in sea-floor playing a greater role, alternative number three (the expansion or the transference of the reclamation works) will then be preferred. This option also has the advantage that reclamation works better tuned to natural processes, can be tested. The completely artificial establishment of salt marshes by the spouting or the mechanical transfer of soil is, on the other hand, undesirable because the restoration of the reference value only, does not correct the disturbed balance between the processes of building up and decomposition.

In the following the General Management Policy, the Nature Management Plan and the recommendations of salt-marsh experts (Ovesen, in prep.), it is strived, for a substantial part of the salt marshes, for such a grazing by farm animals that an alternating pattern of much and less grazed vegetation types is created. This works better on large salt marshes.

5.7 Birds

Breeding birds, particularly those species that breed in colonies, are sensitive to disturbance, both during the establishment stage as well as the breeding season itself. No disturbance in the colony is therefore, an essential condition that can only be guaranteed through effective guarding. The maintenance of guarding activities in the important breeding colonies, is a condition in order to be able to do this. Moreover, an adapted management is necessary such as the grazing of salt marshes, the capture of ground predators in places where they do not belong naturally and possibly mowing if grazing does not occur.

Potentially suitable breeding grounds on beach plains are, in the current situation, nearly all used intensively for recreation and military exercises, through which, they have partly lost their function as breeding ground. That is why the expansion of the protected (and guarded) areas on beach plains, especially there where natural dynamics and succession have been given a second chance, must be strived for. In practice, this means an expansion of the guarded areas on the Texelse

Hors, on the eastern points of Terschelling, Ameland and Schiermonnikoog and on other, still to be allocated places on the North-Sea side of the islands.

The tidal flats are important to the breeding birds, and migrating birds that occur in even greater numbers, as a foraging ground. During high tide, the undisturbed high-tide roosts are of great importance. Hunting, recreation and aeroplanes must be avoided in the vicinity of potential high-tide roosts. This can be done by channeling aeroplane flights and by strictly monitoring the prescribed flight altitudes.

As a result of seed-mussel fishing and cockle fishing, old, wild mussel and cockle beds hardly occur anymore. That is why, especially when it concerns tidal mussel beds, the forage possibilities of bird species other than the ones that only eat mussels, are affected. Although negative effects on birds in regard to bird-population damage in the Wadden area, have not yet been indicated, it is recommended that a number of larger areas be indicated where undisturbed, wild mussel and cockle beds can develop themselves.

5.8 Seals

Comparative population-ecological research has shown that the reproduction of the grey and common seal is too low and that the youth mortality rate is too high. The limiting conditions, that is to say, the conditions of positive influence on the environmental factors that primarily determine the three afore-mentioned parameters in order to make a development in the direction of the reference possible, are not quite the same for both species and are therefore dealt with separately.

The grey seal. The causes for the low reproduction are not known. The data on the population structure and the contaminant load on older animals, is too concise for the giving of an decisive statement on how far a distorted (relatively young) age distribution and/or contaminant load play a role. The high youth mortality rate is mainly caused by the fact that the sand banks now being used, are not high enough and are too often flooded during the birth season and during the beginning of the nursing period. This causes the new-born pups, who cannot swim for very long, to be washed from the sand banks and to loose their mothers.

Disturbance by, amongst others, shipping is the same kind of threat. Immigration and the release of rehabilitated animals are positive contributions and the main causes of the population growth up to now.

Before management measures are made, a choice must be made in the policy whether 1) one wants to allow this species to increase to several hundreds in the middle term and in order to do this, to take active measures or 2) to allow the developments to run their own courses and to let the colony(ies) benefit from general protection measures.

In the case of 1 being chosen, several areas could be indicated where the seals can occupy places that are situated above the high-water spring tide and that they are closed to the public for the first ten years to come, until definite colonies have been formed. Here, one could think of the eastern point of several islands (Ameland, Schiermonnikoog, Rottumerplaat, Rottumeroog) and of areas such as the Punt van Reide, the Richel and the Razende Bol. It would be preferable for the rehabilitated animals to be released there.

In the case of 2 being chosen, the area used by the existing colony must be placed under the jurisdiction of the Nature Protection Law during the approximate period of 15 November to 15 May, so that the risk of disturbance is limited and also that the choice of resting places is stimulated. If there are indications that new places are being chosen, an identical regime could also be applied there. Further, the pollution of water, in particular the PCB load, must be reduced and the hunting prohibition must remain in force.

The common seal. The main threats to the common seal are: a reproduction that is too low and a high rate of youth mortality. Besides, seals, mainly juvenile and sub-adult animals, drown in nets. The low reproduction rate is a result of high PCB concentrations found in the tissue and organs of the seals. The high rate of youth mortality is not caused by one specific factor; the disturbance of nursing pups, a possible weakening of the immunity system due to pollution and a reduction of the weight at birth due pollution work synergetically.

Since the present seal population number is far below the level of the reference, an accelerated population growth should be strived for during the first years to come. In the long term, the abiotical conditions should be such, that the population will remain physically healthy. The PCB load must be reduced. Reflections on the reduction percentage such as is often found in various documents, do not seem very useful. Firstly, delayed delivery from the sediment will occur for a long time to come. The speed of this and for example, the half-life are not yet sufficiently known. Besides it is impossible to give a 'no-effect level'. Added to the fact that PCBs are materials alien to the system, the only adequate management plan is a total prohibition of the production and use of PCBs and related compounds. Moreover, a policy must be made that is aimed at the collecting of PCBs, which then prevents them from entering into the environment. Simulation calculations concerning the effect of changes in the reproduction and mortality on the growth rate of a population, show that the mortality rate of the adult animals (in particular sexually mature females) is the most sensitive parameter, followed by the juvenile mortality rate. The reproduction parameter is clearly less sensitive. Measures that stimulate the chances for survival of adult females and juveniles, are therefore extremely effective. According to the current management, all seal-occupied places fall under the jurisdiction of the Nature Protection Law and are managed as article-17 areas. The protection that is offered, is not complete. Disturbance by professional activities, aviation and shipping is not excluded and does actually occur. In order to give the restoration of the population a real boost in the short term, a more stringent protection should be applied. A zoning in the protected areas is suggested, in order to be able to do this. The areas where pups are regularly born and therefore, where the groups sensitive to disturbance lie, ought to acquire the status of nature reserve. That implies that all professional activities in and above those areas are forbidden, certainly in the period in which all the rules for pleasure cruising and other forms of recreation are in force. In the rest areas, all measures remain in force as long as the population number is under the level of before the virus epidemic. If the number is above that level, then it is feasible that the colonies in which pups are never born, are protected less strictly than now under the present rules. However, specific research must be done first before this can occur, into the exact effects of disturbance on survival chances, the choice of resting place and on other seal behaviour.

The release of bred and rehabilitated seals can, under the present circumstances, be a factor of importance in the future population development rate. Population dynamic considerations connected to pathological, epidemiological and ecological knowledge, justify an extensive discussion between the departments involved, on the desirability and the scale thereof. The result of this, would be very useful in making the decision, whether a reserved policy or not should be pursued on this point. Drowning in fyke nets can be prevented by installing small meshed netting to stop the seals or by using an open chamber (Reijnders 1985). An accelerated introduction of the obligation to do this, is an effective measure.

It is theoretically possible that hunt on seals could be re-opened. The placing of the species under the jurisdiction of the Nature Protection Law would rule out this theoretical possibility also.

ACKNOWLEDGEMENTS

This report would not have been possible without the contribution of and discussions with persons in and outside the Research Institute For Nature Management. The members of the guidance group, F. Bouwers, R. Hillen, A. Kleinmeulman, M. de Vriend and A. van der Wekken, supplied a constructive contribution to the creation of this report. Their comments also greatly improved the readability. J. de Vlas and R. Uyterlinde from the Department of Nature, Environment and Fauna Management, were closely involved in the guidance of this report and their expert contribution is very much appreciated. M. Scholl took care of the editing of many concept versions. Thanks to her effort, a version ready for the press was delivered to the reproduction department.

LITERATUUR

Abrahamse, J. & H. Veenstra 1976. Waddengebied van Nederland. In: J. Abrahamse, W. Joenje & N. van Leeuwen-Seelt (ed.), Waddenzee, natuurgebied van Nederland, Duitsland en Denemarken. Land. Ver. Behoud Waddenzee, Harlingen/Natuurmonumenten, 's Graveland; 47-61.

Bartholdy, J. & M. Pejrup 1990. Sedimentology of the Danish Wadden Sea. The Common future of the Wadden Sea. Expert report. WWF, Husum.

Battjes, J.A. 1961. Studie van Texel. Hoofdontwerp Hydraulica. Nota 62.4. Rijkswaterstaat, Studiedienst Hoorn. 64 p.

Beukema, J.J. 1976. Biomass and species richness of the macrobenthic animals living on the tidal flats of the Dutch Wadden Sea. Neth. J. Sea Res. 10, 2: 236-261.

Beukema, J.J. 1981. Quantitative data on the benthos of the Wadden Sea proper. In: N. Dankers, H. Kühl & W.J. Wolff (ed.), Invertebrates of the Wadden Sea. Balkema, Rotterdam; 134-142.

Beukema, J.J. 1989. Long-term changes in macrozoobenthic abundance on the tidal flats of the western part of the Dutch Wadden Sea. Helgoländer Meeresuntersuchungen 43: 405-415.

Beukema, J.J. & G.C. Cadée 1986. Zoobenthos responses to eutrophication of the Dutch Wadden Sea. Ophelia 26: 55-64.

Beeftink, W.G. 1975. The ecological significance of embankment and with respect to the vegetation of the South-West Netherlands. J. Ecol. 63: 423-458.

Beeftink, W. 1984. Geography of European halophytes. In: K.S. Dijkema et al. (ed.), Salt marshes in Europe. Council of Europe, Nature and Environment Series 30; 15-33.

Behre, K.E. 1979. Zur Rekonstruktion ehemaliger Pflanzengesellschaften an der deutschen Nordseeküste. In: O. Williams & R. Tüxen (ed.), Werden und Vergehen von Pflanzengesellschaften. Cramer, Vaduz; 181-214.

Bouwsema, P., J.H. Bossinade, K.S. Dijkema (ed.), J.W. Th. M. van Meegen, R. Reenders & W. Vrieling 1986. De ontwikkeling van de hoogte en van de omvang van de kwelders in de landaanwinningswerken in Friesland en Groningen. Nota ANA-86.05, Rijkswaterstaat Directie Groningen/Rapport 86/3, Rijksinstituut voor Natuurbeheer.

Brink, B.J.E. ten, S.H. Hosper & F. Colijn 1990. Ecologische normstelling van het waterbeheer: theorie en praktijk van de AMOEBE-benadering. Proc. Symp. Op weg naar een duurzaam milieu, 1-2 feb. 1990, Deel: Strategiën van een ecologische normstelling; het spel en de knikkers; 109-133.

Brolsma, P. 1982. Informatie over kustbeweging en kustverdediging. Nota WWKZ-82.H004. Rijkswaterstaat, Adviesdienst Hoorn. 9 p.

Brouwer, G.A. 1928. De levensomstandigheden van den zeehond (Phoca vitulina L.) in Nederland, I-IV. Levende Natuur 33: 115-119; 149-153; 185-191; 213-218.

Brundtland, G.H. 1987. Our common future. Oxford Univ. Press. 400 p.

Cadée, G.C. 1984. Has input of organic matter into the western part of the Dutch Wadden Sea increased during the last decades? Neth. Inst. Sea Res., Publ. Ser. 10: 71-82.

Cadée, G.C. 1986a. Recurrent and changing seasonal patterns in phytoplankton of the westernmost inlet of the Dutch Wadden Sea from 1969-1985. Mar. Biol. 93: 281-289.

Cadée, G.C. 1986b. Increased phytoplankton primary production in the Marsdiep area. Neth. J. Sea Res. 20: 285-290.

Christiansen, H. 1974. Über den Transport suspendierter Feststoffe in Ästuarien am Beispiel der Elbemündung bei Neuwerk. Hamburger Küstenforschung 1974. Heft 28. 125 p.

Dankelman, I. 1983. Nature conservation in the Waddensea area: methods and present status. In: M.F. Mörzer Bruyns & W.J. Wolff (ed.), Nature conservation, nature management and physical planning in the Wadden Sea area. Balkema, Rotterdam; 39-57.

Dankers, N. 1989. Het zeegras in de Waddenzee. Waarom verdween het, en kan het terugkomen. Waddenbulletin 1989: 120-123.

Dankers, N. & J.J. Beukema 1981. Distributional patterns of macrozoobenthic species in relation to some environmental factors. In: N. Dankers, H. Kühl & W.J. Wolff (ed.), Invertebrates of the Wadden Sea. Balkema, Rotterdam; 69-103.

Dankers, N. & J. Zegers 1985. Maatregelen ter voorkoming van verdrinking van zeehonden en hun effecten op de visvangst in harderfuiken. RIN-rapport 85/18. Rijksinstituut voor Natuurbeheer, Texel.

Dankers, N. & K. Koelemaij 1989. Variations in the mussel population of the Dutch Wadden Sea in relation to monitoring. Helgoländer Meeresunters. 43: 529-535.

Dankers, N., M. Binsbergen, K. Zegers, R. Laane & M. Rutgers van der Loeff 1984. Transportation of water, particulate and dissolved organic and inorganic matter between a salt marsh and the Eems-Dollard Estuary, The Netherlands. Estuarine-, Coastal and Shelf Science 19: 143-165.

Dijkema, K.S. 1983. Landscape and vegetation map of the Wadden Sea islands and mainland coastal areas 1:100,000, 1976. In: K.S. Dijkema & W.J. Wolff (ed.), Flora and vegetation of the Wadden Sea islands and coastal areas. Balkema, Rotterdam. (4 sheets).

Dijkema, K.S. 1987a. Changes of salt-marsh area in the Netherlands Wadden Sea after 1600. In: A.H.L. Huiskes, C.W.P.M. Blom & J. Rozema (ed.), Vegetation between land and sea. Junk, Dordrecht; 42-49.

Dijkema, K.S. 1987b. Selection of salt marsh sites for the European network of biogenetic reserves. RIN-rapport 87/9. Rijksinstituut voor Natuurbeheer, Texel. 29 p.

Dijkema, K.S., W.G. Beeftink, J.P. Doody, J.M. Gehu, B. Heydemann and S. Rivas Martinez 1984. Salt marshes in Europe. Council of Europe, Nature and Environment Series 30. 178 p.

Dijkema, K.S., N. Dankers & W.J. Wolff 1985. Cumulatie van ecologische effecten in de Waddenzee. RIN-rapport 85/13. Rijksinstituut voor Natuurbeheer, Texel. 105 p.

Dijkema, K.S., J. van den Bergs, J.H. Bossinade, P. Bouwsema, R.J. de Glopper & J.W.Th.M. van Meegen 1988. Effecten van rijzendammen op de opslibbing en op de omvang van de vegetatiezones in de Friese en Groninger landaanwinningswerken. Nota GRAN 1988-2010, Rijkswaterstaat Directie Groningen; RIN-rapport 88/66, Rijksinstituut voor Natuurbeheer; RIJP-rapport 1988-33 Cbw., Rijksdienst voor de IJsselmeerpolders. 108 p.

Dijkema, K.S., G. van Tienen & J.G. van Beek 1989. Habitats of the Netherlands, German and Danish Wadden Sea 1:100,000. Research Institute for Nature Management, Texel/Veth Foundation, Leiden. 24 kaarten + 6 p.

Dijkema, K.S., J.H. Bossinade, P. Bouwsema & R.J. de Glopper 1990. Salt marshes in the Netherlands Wadden Sea: rising high tide levels and accretion enhancement. In: J.J. Beukema, W.J. Wolff & J.J.W.M. Brouns (ed.), Expected effects of climatic change on marine coastal ecosystems. Kluwer Academic Publishers, Dordrecht; 173-188.

Dijksen, A.K. & L.J. Dijksen 1977. Texel vogeleiland. Thieme, Zutphen. 246 p.

Dillo, H.G. 1960. Sandwanderungen in Tideflüssen. Mitt. des Franzius-Inst. der TU Hannover H. 17.

Dronkers, J. 1984. Import of fine marine sediment in tidal basins. Neth. Inst.f. Sea Res. Publ. Ser. 10: 83-106.

Dücker, H.P. 1982. Suspensionsgehalte in Flachwassergebieten - Messungen im Watt von Scharhörn. Die Küste 37: 85-184.

Duin, B. van de & M. de Boer 1981. Sedimentatieonderzoek zeegebied: Zwin-Javaruggen, 1928/1934 en 1975. Notitie WWKZ-81.H229. Rijkswaterstaat, Studiedienst Hoorn.

Ebbinge, B.S. 1989. Individuele verschillen in pleisterplaatskeuze bij brandganzen. In: A.L. Spaans (ed.), Wetlands en watervogels. Pudoc, Wageningen; 79-85.

Ehlers, J. 1988. Morphologische Veränderungen auf der Wattseite der Barriere-Inseln des Wattenmeeres. Die Küste, Sonderdruck Heft 47: 1-30.

Eisma, D. 1981. Supply and deposition of suspended matter in the North Sea. Spec. Publ. int. Ass. Sediment. 5: 415-428.

Evans G. & M.B. Collins 1975. The transportation and deposition of suspended sediment over the intertidal flats of the Wash. In: J. Hayns & A. Carr (ed.), Nearshore sediment dynamics and sedimentation. Whrigley, London; 273-304.

Eysink, W.D. 1979. Morfologie van de Waddenzee. Gevolgen van zand en schelpenwinning. Rapport R 1336. Waterloopkundig Laboratorium.

Glim, G.W., G. Kool, M.F. Lieshout, M. de Boer et al. 1987. Erosie en sedimentatie in de binnendelta
van het Zeegat van Texel 1932-1982. Rapp. ANWX-87.H201. Rijkswaterstaat, Directie Noord-Holland. 33 p. + bijl.

Glim, G.W., N. de Graaff, G. Kool, M.F. Lieshout, M. de Boer et al. 1988a. Erosie en sedimentatie in de binnendelta van het Zeegat van het Vlie 1933-1983. Rapp. ANWX-88.H204. Rijkswaterstaat Directie Noord-Holland. 32 p. + bijl.

Glim, G.W., G. Kool, M.F. Lieshout, M. de Boer 1988b. Erosie en sedimentatie in de binnendelta van het Eierlandse Gat 1934-1982. Rapp. ANWX-89.H202. Rijkswaterstaat Directie Noord-Holland. 31 p. + bijl.

Griede, J.W. & W. Roeleveld 1982. De geologische en paleografische ontwikkeling van het noordelijk zeekleigebied. KNAG. Geografische Tijdschrift 16, 5: 439-455.

Gry, H. 1942. Quantitative Untersuchungen über den Sinkstofftransport durch Gezeitenströmungen. Folia Geogr. Danica II, 1. 183 p.

Haaften, J.L. van 1974. Zeehonden lands de Nederlandse kust. RIN-mededeling 104.

Harkönen, T. 1987. Feeding ecology and population dynamics of the harbour seal (Phoca vitulina) in Kattegat-Skagerrak. Thesis, University of Gothenburg.

Halliwell, A.R. & B.A. O'Connor 1966. Suspended sediment in a tidal estuary. Proc. 10th Conf. Coastal Eng., Tokyo. Vol. 1; 687-706.

Havinga, B. 1933. Der Seehund in den holländischen Gewässern. Tijdschr. ned. dierk. Vereen. 3: 79-111.

Hayes, M.O. 1979. Barrier island morphology as a function of tidal and wave regime. In: S.P. Leatherman (ed.), Barrier islands, from the Gulf of St. Lawrence to the Gulf of Mexico. Academic Press, New York; 1-27.

Heydemann, B. 1981. Ökologie und Schutz des Wattenmeeres. Landwirtschaftsverlag, Münster: 232 p.

Hustings, M.F.H., R.G.M. Kwak, P.F.M. Opdam & M.J.S.M. Reijnen (ed.) 1985. Vogelinventarisatie. Achtergronden, richtlijnen en verslaglegging. Natuurbeheer in Nederland, deel III. Pudoc, Wageningen. 495 p.

Jackson, W.H. 1964. An investigation into silt in suspension in the River Humber. The Dock and Harbour Authorities.

Jong, D. de & V. de Jonge 1989. Zeegras. Een ecologisch profiel en het voorkomen in Nederland. Nota GWAO 89.1003. Rijkswaterstaat. 31 p.

Jonge, V. de 1983. Relations between annual dredging activities, suspended matter concentrations and the developments of the tidal regime in the Eems estuary. Can. J. Fish. Aq. Sci., Vol. 40, Suppl. 1: 289-300.

Kamps, L.F. 1962. Mud distribution and land reclamation in the eastern Wadden shallows. Rijkswaterstaat communications 4.

Klok, B. & K.M. Schalkers 1978. De veranderingen in de Waddenzee ten gevolge van de afsluiting van de Zuiderzee. Notitie 78.H238. Rijkswaterstaat, Studiedienst Hoorn.

Lorentz, H.A. et al. 1926. Verslag Staatscommissie Zuiderzee 1918-1926. Sept. 1926. Alg. Landsdrukkerij, Den Haag. 345 p.

Lüneburg, H. 1939. Hydrochemische Untersuchungen in der Elbemündung mittels Elektrokolorimeter. Arch. Dtsch. Seewarte 59, 5: 1-27.

Lüneburg, H. 1953. Die Probleme der Sinkstoffverteilung in de Wesermündung. Veröff. Inst. Meeresf. Bremerh. 2: 15-51.

Lüneburg, H. 1955. Beiträge zur Hydrographie der Wesermündung. III. Teil: Vergleichende Wattuntersuchungen im Bereich der Wesermündung. Veröff. Inst. Meeresf. Bremerh. 3: 66-104.

Lüneburg, H. 1958. Untersuchungen über den quantitativen Wasser- und Sinkstofftransport im

Fedderwarder Priel (Wesermündung). Veröffentl. Inst. Meeresf. Bremerh. 5: 257-298.

McCave, I.N. 1981. Location of coastal accumulations of five sediments around the southern North Sea. Rapp. p.-v. Reun. Cons. int. Explor. Mer. 181: 15-27.

Mes, R., R. Schuckard & H. Smit 1980. Flora en fauna van de Engelsmanplaat. Med. 5 Werkgroep Waddengebied, Leiden. 95 p.

Mohr, E. 1952. Die Robben der europäischen Gewässer. Schöpps, Frankfurt/Main.

Monval, J.-Y. & J.-Y. Pirot 1989. Results of the IWRB international waterfowl census 1967-1986. Population estimates, trends and distribution in selected species of ducks, swans and Coot (Fulica atra) wintering in the Western Palearctic and West Africa. IWRB Special Publ. 8: 145 p.

Mörzer Bruyns, M.F. & S. Braaksma 1954. Vogeltellingen in het staatsnatuurreservaat Bosplaat van 1951 t/m 1953. Ardea 42: 175-210.

Natuurmonumenten 1985. Handboek van natuurgebieden en wandelterreinen in Nederland. 's Graveland. 394 p.

Oordt, G.J. van 1932. Verslag van een tocht met Hr. Ms. Watervliegtuig L7 boven de Nederlandse Waddenzee op 5 oktober 1931. Jaarverslag Stichting 'Vogeltrekstation Texel' 1: 25-29.

Ovesen, H.C., in voorber. Proceedings Second Trilateral Working Conference on Saltmarsh Management in the International Wadden Sea Area. Rϕmϕ 1989.

Philippart, M.E. 1989. Simulatie van de getijveranderingen in de westelijke Waddenzee. Rapport nr. R-89-2. Inst. v. Meteorologie en Oceanografie RU Utrecht. 41 p. + 39 bijl.

Piersma, T. 1987. Hink, stap of sprong? Reisbeperkingen van arctische steltlopers door voedselzoeken, vetopbouw en vliegsnelheid. Limosa 60: 185-194.

Polderman, P.J.G. & C. den Hartog 1975. De zeegrassen in de Waddenzee. Wetensch. Med. KNNV 107: 1-32.

Ponsioen, T. 1985. z. titel. Waterkampioen 3: 77.

Postma, H. 1954. Hydrography of the Dutch Wadden Sea. Arch. Neerl. Zool. 10: 405-511.

Postma, H. 1981. Exchange of materials between the North Sea and the Wadden Sea. Marine Geol. 40: 199-213.

Postma, H. 1982. Hydrography of the Wadden Sea. Balkema, Rotterdam. 75 p.

Postma, H. 1982. Hydrography of the Wadden Sea: movements and properties of water and particulate matter. Balkema, Rotterdam. 75 p.

Pons, L.J. & A.J. Wiggers 1960. De holocene wordingsgeschiedenis Noord-Holland en het Zuiderzeegebied. Deel II. Tijdschr. Kon. Ned. Aardrijkskundig Gen. 77: 3-57.

Prys-Jones, R.P. & J.S. Kirby 1987. Waders. In: D.G. Salmon, R.P. Prys-Jones & J.S. Kirby, Wildfowl and wader counts. 1986-87. Wildfowl trust, Slimbridge/Nature Conservancy Council; 63 p.

Prys-Jones, R.P. & J.S. Kirby 1989. Waders. In: D.G. Salmon, R.P. Prys-Jones & J.S. Kirby, Wildfowl and wader counts. 1986-87. Wildfowl Trust, Slimbridge/Nature Conservancy Council; 68p.

Raad voor het Milieu- en Natuuronderzoek 1988. Vijf visies op natuurbehoud en natuurontwikkeling. Publikatie nr. 30. Rijswijk. 66 p.

Raaphorst, W. van & H.W. van der Veer 1990. The phosphorus budget of the Marsdiep tidal basin (Dutch Wadden Sea) in the period 1950-1985: importance of the exchange with the North Sea. Hydrobiologia 195: 21-38.

Rappoldt, K., M. Kersten & C. Smit 1985. Errors in large scale shorebird counts. Ardea 73: 13-24.

Reijnders, P.J.H. 1976. The harbour seal (Phoca vitulina) population in the Dutch Wadden Sea: size and composition. Neth. J. Sea Res. 10: 223-235.

Reijnders, P.J.H. 1978. De grijze zeehond in het Waddengebied. Waddenbulletin 13: 500-502.

Reijnders, P.J.H. 1980. Organochlorine and heavy metal residues in harbour seals from the Wadden Sea and their possible effects on reproduction. Neth. J. Sea Res. 14: 30-65.

Reijnders, P.J.H. 1983. The effect of seal hunting in Germany on the further existence of a harbour seal population in the Dutch Wadden Sea. Z. Säugetierk. 48: 50-54.

Reijnders, P.J.H. 1984. De lotgevallen van de zeehonden in de Nederlandse kustwateren. Argus 9: 5-9.

Reijnders, P.J.H. 1985. Verdrinking van zeehonden in fuiken. RIN-rapport 85/19. Rijksinstituut voor Natuurbeheer.

Reijnders, P.J.H. 1986. Reproductive failure in common seals feeding on fish from polluted coastal waters. Nature 324: 456-457.

Reijnders, P.J.H. 1988a. Gevolgen virusuitbraak voor zeehonden in het internationale Waddengebied. Waddenbulletin 23: 201-203.

Reijnders, P.J.H. 1988b. Hoeveel zeehonden in de Waddenzee en de Voordelta: keuzes voor het beheer. In: Th. van Rossum & J. Veen (ed.), Aspecten van wildbeheer. Uitgave Natuur-, Milieu- en Faunabeheer, Ministerie van Landbouw en Visserij en Rijksinstituut voor Natuurbeheer, Arnhem.

Reijnders, P.J.H. 1989. The recent virusoutbreak amongst harbour seals in the Wadden Sea: possible consequences for future population trends. Wadden Sea News Letter 1989: 10-12.

Reijnders, P.J.H. & W.J. Wolff (ed.) 1981. Marine mammals of the Wadden Sea. Balkema, Rotterdam. 64 p.

Reineck, H.E. & W. Siefert 1980. Faktoren der Schlickbildung im Saklenburger un Neuwerker Watt. Die Küste 35: 26-51.

Reise, K. 1979. Forschungsvorhaben zur Bodenfauna im Gebiet der Nordstrander Bucht. Zool. Institut der Universität Göttingen. 166 p.

Reus, R.H. de 1981. Slibproblematiek Waddenzee. Nota WWKZ-81.H019. Rijkswaterstaat, Adviesdienst Hoorn. 17 p. + bijl.

Reus, R.H. de 1982. Stand van zaken ersoie/sedimentatie-onderzoek. Nota WWKZ-82.H012. Rijkswaterstaat, Adviesdienst Hoorn. 14 p.

Riesen W. & K. Reise 1982. Macrobenthos of the subtidal Wadden Sea: revisited after 55 years. Helgoländer Meeresunters. 35: 409-423.

Rietveld, C.F.W. 1963. The natural development of the Dutch Wadden Sea after the enclosure of the Zuider Zee. Proc. 18th Conf. Coast. Eng.; 765-781.

Rooth, J. 1960. Vogeltellingen op Vlieland van 1953 t/m 1956. Limosa 33: 134-159.

Rooth, J. 1966. Vogeltelling in het hele Nederlandse Waddengebied in Augustus 1963. Limosa 39: 175-181.

Scheibel. W. & H. Weidel 1988. Zum Vorkommen von Kegelrobben (Halichoerus grypus, Fab. 1791) in Schleswig-Holstein. Zool. Anz. 220: 65-70.

Schultz, Et al. & H.B. Simmons 1957. Freshwater-saltwater density currents, a major cause of siltation in estuaries. US Army Comm. on Tidal Hydr. Techn. Bull. 2.

Slagmolen, H.C. 1983. Transportmechanismen in de Waddenzee. Nota nr. WWKZ-83.H007. Rijkswaterstaat, Adviesdienst Hoorn. 22 p.

Smet, L.A.H. de & A.J. Wiggers 1960. Einige Bemerkungen über die Herkunft und Sedimentationsgeschwindigkeit der Dollardablagerungen. Kon. Ned. Geol. Mijnb. Gen., Geol. Serie 19: 129-133.

Smit, C.J. 1981. Distribution, ecology and zoogeography of breeding birds on the Wadden Sea islands. In: C.J. Smit, J. den Hollander, W.K.R.E. van Wingerden & W.J. Wolff (ed.), Terrestrial and freshwater fauna of the Wadden Sea area. Balkema, Rotterdam; 169-231.

Smit, C.J. 1989. Perspectives in using shorebird counts for assessing long-term changes in wader numbers in the Wadden Sea. Helgoländer Meeresuntersuchungen. 43: 367-383

Smit, C.J., in druk. Monitoring van steltlopers in de Waddenzee: verleden en toekomst. De Levende Natuur.

Smit, C.J. & W.J. Wolff (ed.) 1981. Birds of the Wadden Sea. Wadden Sea Working Group report 6. Balkema, Rotterdam. 308 p.

Smit, C.J. & T. Piersma 1989. Numbers, midwinter distribution, and migration of wader populations using the East Atlantic flyway. In: H. Boyd & J.-Y. Pirot (ed.), Flyways and reserve networks for water birds. IWRB Special Publ. 9, Slimbridge; 24-63.

Smit, C.J., R.H.D. Lambeck & W.J. Wolff 1987. Threats to wintering and staging areas of waders. Wader Study Group Bull. 49, Suppl./IWRB Special Publ. 7: 105-113.

Smith, P.W. & N.T. Houghton 1984. Fidelity of Semipalmated Plovers to a migration stopover area. J. Field Orn. 55: 247-250.

SOVON 1987. Atlas van de Nederlandse vogels. Arnhem. 595 p.

Spaans, A.L. 1967. Wadvogeltelling in het gehele Nederlandse Waddengebied in december 1966. Limosa 40: 206-215.

Spaans, A.L. & N. Noordhuis 1989. Voedselconcurrentie tussen kleine mantelmeeuwen en zilvermeeuwen. In: A.L. Spaans (ed.), Wetlands en Watervogels. Pudoc, Wageningen; 35-47.

Stichting Avifauna van Friesland 1977. Vogels in Friesland, Vol. 1. De Tille, Leeuwarden. 432 p.

Stichting Avifauna van Friesland 1977. Vogels in Friesland, Vol. 2. De Tille, Leeuwarden. 495 p.

Stommel, H. 1953. The role of density currents in estuaries. Proc. Minnesota Intern. Hydr. Convention, Minneapolis; 305-312.

Straaten, L.M.J.U. van 1949. Quelques particularités du relief sousmarin de la Mer des Wadden

(Hollande). C.R. Congrès Sedim. et Quatern., France 1949, Bordeaux 1951; 139-145.

Straaten, L.M.J.U. van 1954. Composition and structure of recent marine sediments in the Netherlands. Leidse Geol. Meded. 19: 1-110.

Straaten, L.M.J.U. & Ph.H. Kuenen 1958. Tidal action as a cause for clay accumulation. J. Sed. Petrol. 28: 406-413.

Stratingh, G.A. & C.A. Venema 1855. De Dollard of Geschied-, Ardsrijk- en Natuurkundige beschrijving van dezen boezem der Eems. Oomkens, Zoon & Schierbeek, Groningen.

Tanis, J.J.C. 1963. De vogels van Terschelling. Fryske Akademy, Leeuwarden: 160 p. + bijl.

Teixeira, R.M. 1979. Atlas van de Nederlandse broedvogels. Natuurmonumenten, 's Graveland. 431 p.

Thijsse, J.Th. 1950. Veranderingen in waterbewegingen en bodemreliëf in de Waddenzee. Tijdschr. Kon. Ned. Aardr. Gen. 67: 334-335.

Valk, A. 1976. De broedvogels van Ameland. Wetensch. Med. KNNV 112. 92 p.

Veen, J. & J. van de Kam 1988. Griend, vogeleiland in de Waddenzee. Terra, Zutphen. 160 p.

Veenstra, H.J. 1971. De herkomst van de wadafzettingen. Waddenbulletin 6, 2: 2-8.

Veer, H.W. van der 1989. Eutrophication and mussel culture in the western Dutch Wadden Sea: impact on the benthic ecosystem; a hypothesis. Helgoländer Meeresuntersuchungen 43: 517-527.

Veer, H.W. van der, W. van Raaphorst & M.J.N. Bergman 1989. Eutrophication of the Dutch Wadden Sea: external nutrient loadings of the Marsdiep and Vliestroom basin. Helgoländer Meeresuntersuchungen 43: 501-515.

Verhoeven, B. 1976. Landaanwinning, dijkbouw en waterbeheersing. In: J. Abrahamse et al. (ed.), Waddenzee. Land. Ver. Behoud Waddenzee, Ver. Behoud Natuurmonumenten, Harlingen, 's Graveland; 249-259.

Vertegaal, C.T.M. & J.N.C. van der Salm 1988. Ecologische profielen: kust- en zeevogels. Duin en Kust, Leiden. 121 p.

Vijfhuizen, C. & S. Haringsma 1984. Broedvogels van de kwelders in Friesland. Stage-verslag HLS/Staatsbosbeheer: 18 p. + bijlagen.

Verwey, J. 1952. On the ecology and distribution of cockle and mussel in the Dutch Wadden Sea. Their role in sedimentation and the source of their food supply. With a short review of the feeding behaviour of bivalve molluscs. Arch. Neerl. Zool. 10: 172-239.

Weijman, W. 1980. Verslag bewaking Rottumeroog en -plaat 1978-1979. Rapport Staatsbosbeheer consulentschap Natuurbehoud, Groningen. 23 p. + bijlagen.

Westhoff, V. 1987. Salt marsh communities of three West Frisian Islands, with some notes on their long-term succession during half a century. In: A.L. Huiskes, C.W.P.M. Blom & J. Rozema (ed.), Vegetation between land and sea. Junk, Dordrecht; 16-40.

Wit, J.A.W. de, F.M. Schotel & L.E.J. Bakkers 1982. De waterkwaliteit van de Waddenzee 1971-1981. RIZA nota nr. 82 065. 67 p.

Wolff, W.J. 1973. The estuary as habitat. Zool. Verh. 126. 242 p.

Wolff, W.J. 1983. Ecology of the Wadden Sea. Balkema, Rotterdam.

Wolff, W.J. 1988. Getijdewateren. In: W.J. Wolff (ed.), De internationale betekenis van de Nederlandse natuur. Rijksinstituut voor Natuurbeheer, Leersum; 125-132.

Wolff, W.J. (ed.) et al. 1988. De internationale betekenis van de Nederlandse Natuur. RIN-rapport 88/32. Rijksinstituut voor Natuurbeheer, Leersum. 174 p.

Appendix 1

VIEWS ON NATURE PRESERVATION, NATURE MANAGEMENT AND TARGET OBJECTIVES FOR THE WADDEN SEA.

1 INTRODUCTION

In 1988 the 'Raad voor Natuur- en Milieuonderzoek (RMNO)' (Council for Nature and Environmental Research) published a report entitled 'Five views on nature preservation and nature development'. The main objective of this report was 'To give a survey of the long-term basic views on nature preservation and nature development relevant to the Netherlands, related to concrete objectives concerning aspects of (possible) natural elements typical for the Netherlands'.
The survey distinguishes three movements which have as main points:
- nature as functional as possible;
- entirely self regulating nature;
- a technological development not harmful to man or environment.

From these movements five basic views were derived:

1. Classical view on nature. Protection, conservation and restoration of natural and scenic values. Human activities can play a positive and essential role. This view has been developed especially in valuable man-made landscapes.

2. Natural development view. Self-regulating ecosystem with natural processes and completeness of ecological communities. Hardly any human interference. (In the view of the RMNO the term nature development has a completely different definition compared with later policy statements where nature development is virtually equal to constructing semi-natural habitats).

3. Functional view on nature. Nature in the service of man, who accepts the dynamics and shows flexibility in the use and planning of land.

4. Ecosophical view on nature. Man lives in harmony with nature in small-scale communities. Limited harvesting of natural resources is acceptable.

5. Sustainable technological view, making optimum use of innovative and durable technology. Zoning creates room for so-called weak function among which nature preservation and nature development.

Though the principles underlying the latter two basic views are widely differing it can be said that, as far as the Wadden Sea is concerned, both views consider this stretch of water as a nature reserve which should not, or hardly, be polluted by applying good technology and where small-scale harvesting should be possible.

In the classical view (1) the Wadden Sea is a nature reserve where a number of other functions are tolerated provided that they do not interfere with the natural function. Intensive management is allowed to protect salt marshes, high tidal flats etc. in order to maintain a varied system.

In the natural development view there is no interference in natural processes. Human use is only possible if the effects are cancelled out by the 'background noise' of the natural dynamics.

In the functional view (3) there is large-scale human interference. The area is organized for the benefit of a great number of functions relevant to man (fishing, mining etc.), in such a way, however, that the ecological processes of the system are not disturbed. The construction of natural habitats results in a greater diversity of biotopes and species.

The basic views can be found back in the current practice of Wadden Sea management. The various views seem to agree that the natural development view is to be preferred for this area, where there has been relatively little influence in the past. However, from a sectoral point of view each sector usually adheres to the functional view, i.e. making optimum use of the area on behalf of one's own sector, taking into account the natural function as defined in the classical view.

This classical view is mainly based on experiences on land where man has had an enriching influence on the values (especially the diversity) of the ecosystem. This is not, or hardly, the case in the Wadden Sea. However, the value of the greater part of the border areas (salt marshes, vegetated beach plains etc.) is the result of human activities. In the classical view these activities must be continued, whereas the nature development view rejects these activities. The discussion about this difference of opinion has not been wound up yet in the Netherlands.

2 VIEWS OF THE GOVERNMENT

The views of the government have been laid down in a number of policy statements like the 'Nationale Milieubeleidsplan'(National Environmental Policy Plan), the 'Natuurbeleidsplan' (Nature Policy Plan) and the 3rd 'Nota Waterhuishouding' (Water Management Plan). The 'Planologische Kernbeslissing Wadden Sea' (PKB) (Key Physical Planning Act) can be considered to be the result of national plans aimed at this particular area, on the basis of the PBK the 'Algemene Beheersvisie' (General Management Objective). On the basis of these views target objectives are developed, which are sometimes implicit and not always quantified. These target objectives refer to a reference (also more or less quantified) but take a number of sectoral interests into account as limiting condition.

2.1 The Planologische Kernbeslissing Wadden Sea

The policy concerning the management of the Wadden Sea has been laid down in the PKB Wadden Sea. The main objective of the policy is:

'The protection, preservation and, where necessary, restoration of the Wadden Sea as a nature reserve.' A number of limiting conditions like protection of the coast, fishing, shipping etc. must be taken into account.

A more concrete statement is that, according to the PKB, the policy is aimed at protection, preservation and, where necessary, restoration of:

1. tidal movements and geomorphological and soil processes;
2. quality of water, soil and air;
3. optimum condition of flora, fauna and nursery function for North Sea fish;
4. foraging, roost, nursing and rest area for birds and seals;
5. flora and fauna in salt marshes and summer polders;
6. scenic qualities;
7. perception of the value of nature and landscape;
8. importance of scientific research.

The main objective of the PKB defines the Wadden Sea as a nature reserve. Elsewhere it is clearly stated that the value of this nature reserve is determined by the fact that the natural elements have to a great extent free play and that the Wadden Sea is characterized by a high degree of dynamics. Implicitly this means that in the management of this area high priority is given to the preservation of natural processes and natural dynamics. The PKB assumes the possibility of a great number of social activities in the Wadden Sea, the effects of which must be tested against the main objective. Regulation takes place on the basis of sectoral management plans. It can be concluded that the PKB has a clear view of policy and management in the Wadden area. However, this view is so general that no quantified target objective can be derived from it.

2.2 General Management objective of the Wadden Sea

The General Management objective is the concrete result of the objectives of the PKB. The General Management objective has a coordinating function and defines general limiting conditions for various activities. The possible effects of the sectoral activities are tested against the main objective. This is done separately for each sector, not in a combination of activities.

Starting point of the General Management view is that nature management must as much as possible contribute to maintaining the total richness of natural processes, structures,plant and animal species and ecological communities in the Netherlands and the world. On the basis of this objective a number of (especially qualitative) target objectives are defined and weighed.

a. a situation which is practically equal to the situation in a certain reference year.
b. a situation which has an abundance in biotopes and plant and animal species;
c. a situation with an improved profusion of food so the highest number of individuals, e.g. fish and birds, will occur;
d. a situation which is as natural as possible;
e. a situation which contributes as much as possible to the preservation of processes, structures and plant and animal species which are threatened.

Option c is rejected because the consequences are uncertain, and because it does not fit in the Dutch view on the protection of nature. Option b is rejected specifically for the Wadden Sea policy because it would require relatively drastic interference, and because it would be contrary to the aim to maintain the dynamic character of the Wadden Sea.

Aiming at the situation in a certain reference year is thought to be contrary to the dynamic character. Moreover, the situation in that year may not have been ideal with regard to a number of parameters, while quantitative information is often lacking. A more important reason may be that human interference (Afsluitdijk, protection of the coast, maintenance of channels etc.) has changed a number of limiting conditions like current velocity, water exchange, tidal range and availability of sediment in such a way that there is now a new, 'natural' situation. Restoring system properties which depend on the limiting conditions mentioned above to the level of the reference year would require drastic technological interference, which does not fit in with the natural character of the area.

Aiming at a situation which is as natural as possible (d) is, according to the General Management objective, closest to the policy as laid down in the PKB and the Interprovincial Structuurschets (Interprovincial Structural Plan) for the Wadden area. The Wadden Sea is one of the most natural areas in the Netherlands where natural processes have led to a highly valued ecosystem. In exceptional cases corrections may have to be made if (due to human activities) characteristic processes or organisms are seriously threatened. In these cases a natural situation must be aimed at (option e).

According to the General Management objective management should primarily aim at 'the preservation, restoration and undisturbed course of the natural processes in the Wadden Sea so that all structures, plant and animal species which naturally belong in the Wadden Sea can survive, develop or be restored'. Activities with negative consequences should be limited as much as possible, but negative consequences of permitted activities should be compensated as fully as possible.

The General Management objective is clearly formulated. However, on the basis of the view no well quantified target objective has been developed. For instance, it has not been made clear which forms of interference are acceptable in the compensation of negative consequences. If one wishes to aim at a situation which is as natural as possible the target objective will have to be related to a reference. This reference cannot be based on an undisturbed situation abroad as such an area does not exist. The reference will have to be defined on the basis of all kinds of information like the situation elsewhere, the earlier situation, theoretical considerations etc.

2.3 Views of various ministries

In the Nationale Milieubeleidsplan of the Ministry for Housing, Regional Development and the Environment the strategy for an environment policy for a medium long period is defined.
Starting point is a sustainable development.The definition of 'sustainable development' as used in the Nationale Beleidsplan is: 'a development which meets the needs of the present generation without endangering the possibility for future generations to meet their own needs'.

The notion 'sustainable development' is illogical because development in principle implies change. The term durability would be preferable. Those who use the notion 'sustainable development' usually take the functional view on nature (see chapter 2.1) as a starting point. In a mainly sectoral policy each sector will wish to develop in such a way as to allow for a sustainable use of the ecosystem. Sectors will have to be geared for each other because sustainable use by one particular sector may carry limitations for an other sector. Nevertheless, within the scope of the main objective 'Wadden Sea nature reserve' in the functional view on nature many sectors can be greatly extended and the carrying capacity can be maintained.

In order to develop a target objective on the basis of the Nationaal Milieubeleidsplan it is essential to define the needs of present and future generations. Among other things the scale is important here. The needs of the sectors which make direct use of the Wadden Sea and influence it may not be the same as the needs of the Dutch, Northwest European or world population. On a local or sectoral scale a target objective may mean making optimum use of the ecosystem,while on a larger scale there may be a need for nature reserves where natural processes prevail. Also in the so-called Brundtland report, where the notion sustainable development is the basis of the more detailed functional view on nature this possibility is explicitly mentioned (Brundtland 1987, page 13).

In the Natuurbeleidsplan of the Ministry of Agriculture and Fisheries the main objective of a nature policy is: 'sustainable preservation, restoration and development of natural and scenic values'.

The sustainable preservation of natural elements requires specific environmental conditions. Optimum functioning of natural processes is a prerequisite here. Human interference in the environment should not have an essential influence on natural processes: not only the physical, but also the physicochemical and biological processes.

In the Natuurbeleidsplan priority areas are chosen on the basis of a number of criteria. For several reasons the Wadden Sea is mentioned. Management must emphasize reinforcement of natural processes, the systematic implementation of the Nature Preservation Law, and the pushing back of alien organic and inorganic substances and eutrophication. Social processes and demands must be taken into account.

The Natuurbeleidsplan is a general plan. As far as the Wadden area is concerned it clearly opts for a natural development as laid down in the General Management objective. Constructing semi-natural habitats is not explicitly rejected. A target objective for the Wadden Sea has not been developed while clear references are also missing.

The 3rd Nota Waterhuishouding of the Ministries of Transport and Public Works and Agriculture and Fisheries takes 'integral water management' as starting point: the various functions of water systems are considered as a whole. Previous notes were mainly based on managing the quantity of water. An important function mentioned in the 3rd Nota Waterhuishouding is the so-called natural function. Though not clearly defined it means that a state of the biotic component is realized which has been formulated by the government (Ministry of Agriculture Nature Management and Fisheries). For this purpose the abiotic components must meet demands. With regards to the quality of salt water the 3rd Nota Waterhuishouding takes the standards of the Indicatief Meerjaren Programma 1987-1991 as a starting point.

Developing general target objectives is essential in the philosophy of the 3rd Nota Waterhuishouding. For the Wadden Sea this global target objective is: 'The Wadden Sea is primarily a nature reserve. Apart from that there is limited room for fishing and recreation. Signs of eutrophication are a thing of the past. The seal stock is in keeping with the carrying capacity. The porpoise, Sandwich tern and migrating fish are common, just like natural mussel beds, cockle banks, fields of seagrass and tube-worms. A rich soil fauna serves as food for migratory birds. The Wadden Sea is a wetland in *optima forma*. In certain zones and seasons the area can also be used for recreation. Fishing is geared for the functions of the area. Shipping has slightly increased in certain zones. There is limited sand extraction and cockle collecting. In the Eems-Dollard shipping, nature preservation and development and fishing are geared for each other. Restoration of natural elements in the Dollard has been realized. Existing industries do not have harmful effects on the ecosystem'.

The general target objective must be translated into testable aims for management. For the Wadden Sea this can first of all be done by determining the desired conditions for plants and animals. Rijkswaterstaat has recently done this for a number of organisms in so-called ecoprofiles. Management must be aimed at realizing such conditions. In the second place a quantified target objective must be developed as a testable management aim.

For the various water systems the preceding must be developed into action plans . In the Wadden Action Plan Rijkswaterstaat takes 1930 as a year of reference for the development of a target objective. Not counting all land reclamation the Wadden Sea would have been in an almost natural condition then, although it should be mentioned that in 1930 practically all oyster banks had already disappeared, and that, compared with the present situation, there were few birds and a relatively small area of salt marshes. In developing the ecoprofiles 1930 is not considered as a fixed situation, but for each organism a reference is developed which may be higher or lower than the 1930 value. As a result of social developments, the impact of civil engineering etc. the target objective differs from the reference. As visual presentation of the reference and the current situation the so-called 'AMOEBA approach' has been chosen (Ten Brink et al. 1990). Starting point of the is that a sustainable development is possible if deviation from the reference value is within the 75% and 200% limit. Because the Wadden Sea must primarily be considered as a nature reserve the tolerance is lower, and the target value for each organism must be within the 90% and 150% limit of the reference. In the Wadden action plan the target objective is quantified solely on the basis of biotic aspects. Abiotic matters and processes only play a role as limiting condition.

The Wadden action plan must be credited for being the first to have developed a quantified target objective for the Wadden Sea. For the salt marsh area this has been done before by Dijkema (1987a).

3 VIEWS OF THE USERS

The Wadden Sea Advisory Council, which has representatives of practically all users of the Wadden Sea, has recently advised the minister of VROM concerning the revision of the PKB. For a medium long period the PKB must be the integral result of the national plans (4th Nota Ruimtelijke Ordening (Note Environmental/Town and Country Planning), Nationaal Milieubeleidsplan, Natuurbeleidsplan and 3rd Nota Waterhuishouding) with attention focused on the ideal ecological system (target objective). This target objective should have a 'lasting' character, also in the light of the General Management view which emphasizes natural processes. In order to realize the target objective it is necessary to develop concrete demands (limiting and target values) for the quality of ecology, surroundings, water and sediment.

Regarding the target objective the WAC does not take a reference year as starting point but refers to the General Management view and the importance of natural processes.In order to develop limiting and target values of environmental parameters, resulting in a quantified target objective, the WAC thinks it is necessary to gain insight into:
- the buffer capacity of the ecosystem;
- the cause-effect networks and related processes;
- the cumulative and after effects.

The Wadden Sea Advisory Council clearly prefers a target objective which is as natural as possible but which must also be realistic in the light of existing or possibly future limiting values.

Appendix 2

PHYSICAL ASPECTS AND PROCESSES IN THE WADDEN SEA

1 INTRODUCTION

Hydraulics, morphology, erosion, sedimentation and turbidity are closely related.

In a general article on the exchange of materials between the North Sea and the Wadden Sea and the turbidity connected with it Postma (1981) stated that this is a complex process. It is mainly determined by the hydrodynamics of the system and that again depends on the morphology. Also important are the sources, composition and conversions of the dissolved and particulate matter, the interchange between water and soil and what is lost from the system through export or permanent sedimentation.

Postma came to the conclusion that in the North Sea there is a shorewards transport. It causes a turbidity minimum at a distance of some twenty or thirty kilometers from the coast. Directly off the shore, however, there is a lot of suspended matter. The coastal waters move to the north with a residual current and a large part of it flows into the Wadden Sea with the flood. An extensive survey on sediment transport has been published by Postma (1982).

Brolsma (1982) approached the transport problem of sediment and sand in a different manner. For the various tidal basins in the Wadden Sea he calculated the relation between surface and volume and discovered a clear linear correlation. From this he concluded that a relation existed. However, a causal relation was never proved.

Due to the rising of the sea level the volume increases, so on the basis of Brolsma's theory the volume should decrease again through the supply of sediment. Sand is supplied from the coastal area, but the tidal water also contains silt. This is partly taken out again on the tidal current and if the balance between input and output shifts, sedimentation on a net scale may occur. The net transport through the tidal outlets is mostly slight compared to the transport with each tide so that the surplus cannot be determined by measuring the inflowing and outflowing water (Slagmolen 1983). Sand and silt transport is one of the results of a number of processes that are interrelated (De Reus 1982). In running water, particles will by carried along on account of turbulence. The higher the current velocity the larger the particles that can stay in suspension. With current velocities that are normal for the Wadden Sea, only silt will be in suspension. In tidal inlets during spring tide and the accompanying high current velocities also a lot of sand can be in suspension (Postma 1982).

As mentioned before, a residual current along the coast, directed towards the north, supplies turbid water to the outlets that carry water towards the Wadden Sea. A number of mechanisms provides inward transport. The first of these mechanisms is related to the system that holds the silt in the estuaries. Particles from the lighter upper layer (fresh or of higher temperature) sink to the lower layer. The residual current of this layer flows inside, the particle included (Stommel 1953, Schultz & Simmons 1957). A second mechanism is described by Postma (1954). It is based on the principle that a particle needs time to settle down. If at high tide the current velocity decreases to such an extent that a particle starts settling down it is still carried along part of the distance before it reaches the bottom. During ebb tide it is not carried back as far as the place where it originally came from. Moreover further inward the tidal flows are less strong than they are at the outlets. This process continues until a balance between supply and removal, due to diffusion of a high concentration (inside) to a low concentration (outside) has been reached.

The phenomenon described by Postma was called the 'settling-lag effect' by Van Straaten & Kuenen (1958), and they refined the theory by describing a third mechanism. A settled down particle is only eroded at a current velocity much higher than the velocity with which such a particle is normally transported. So the tidal flow will have to reach a high velocity in order to whirl up an already settled down particle once again. This mechanism was called the 'scouring-lag effect' A fourth mechanism that Van Straaten & Kuenen (1985) employed in their theory was the fact that as one proceeds further inside, the channels are getting shallower. The flats are even very shallow. So a particle can sink to the bottom within a short time. At the end of low tide the volume of water is in the deep channels and then a particle often does not even have time to sink to the bottom before high tide is running again. Postma (1961) further elaborated on this and mentioned the fact that in the Wadden Sea the time between maximum flood current and maximum ebb current is longer than that between maximum ebb current and maximum flood current. This means that around high tide there is a longer period of little current, so that more sediment can settle down than around low tide.

Summarizing it may be said, that a number of mechanisms can be explained by transport of suspended material directed inwardly. A good supply is guaranteed because in the outlets the maximum flood velocities are generally higher than the ebb velocities. In gullies between tidal flats, however, the ebb velocities are higher (Postma 1982, Dankers et al. 1984). These gullies are kept at the right depth by the ebb flow and so they can supply water and sediment for the surrounding flat. On the flats current velocities are seldom high enough for erosion but the action of the waves may cause strong erosion here.

If particles intrude far into the area, they will often settle down at quiet places more or less permanently. In this way the material is removed from the system and it no longer takes part in the transport. It appears that very small particles (fine silt and clay content) will hardly settle down at all and that they are easily eroded once more. Due to the collating effect of diatoms on the flat surface and the formation of pseudofaeces, however, the small particles can settle down. Among the vegetation in sea grass fields and on salt marshes such quiet conditions may prevail that also small particles will settle down there.

According to Van Straaten (1954) in the Wadden area some four sedimentation processes may be distinguished:

1. Filling up of channels. In this connection one should think of the cutting off of meanders and

the silting up of channels no longer used. Generally fine silt will settle down here on account of the current velocity. During a storm the waves will regularly whirl up a lot of sand which can settle in the deeper channels.

2. Lateral sedimentation in the inside bends. Often sedimentation of the inside bends will coincide with erosion of the outside bends and in this way the channels will be shifted. Van Straaten (1949) discovered shiftings of up to 10 m within 18 days, but occasionally it was observed that a channel through a tidal flat would be shifted several meters within a few hours. (Ponsioen 1985)

3. Vertical sedimentation on flats. Because current velocities will strongly decrease outside the channels sedimentation on flats will occur quickly. On account of the waves, however, most of the sediment will regularly be eroded again. Due to this regular settling down and eroding, especially sand will stay behind at most places and the fine silt will settle down at places that are very quiet. There will probably be a balance between the average water level and the height of the flat. i.e. more wave erosion will occur as the height of the flat increases. In that case permanent sedimentation will only occur when the sea level is rising or if the gradual formation of a slope from the shore diminishes the force of the surf.

4. Sedimentation among vegetation. On salt marshes large quantities of sediment can settle down among the vegetation. In the Dollard salt marshes it is estimated that 15 kg per m^2 settles down annually (Dankers et al. 1984). Also the salt marshes in the rest of the Wadden Sea can retain a lot of sediment. Dijkema et al. (1988) indicate figures for land reclamation areas between 15 and 30 kg per m^2 annually.

According to Postma (1981) 15% of the material from the North Sea exists of organic matter. In the North Sea an average of 35% of the suspended material is of an organic nature; in winter 0.1% consists of live plankton but in summer 20%. In the Wadden Sea yet another 25% is added to the organic matter by primary production. These are small planktonic organisms in particular. In the Wadden Sea also large quantities of peat residue are set free by the erosion of ancient peat layers. In the Wadden Sea 12% of the suspended material consists of organic particles, 55% is sand, 8% clay particles and the rest is shell rests and iron oxide (Verwey 1952). An extensive part of the organic matter is broken down in the Wadden Sea, so that the soil sediment in the Wadden Sea only contains 3% organic matter.

In the Wadden Sea 90% of the sediment consists of sand, of which in turn 90% consists of quartz (Eijsink 1979). The bottoms of the channels are generally very sandy, whereas 85% of the flats above MHT (Mean High Tide) of sand and less than 3% of it consists of clay. Along the coast of the Wadden Sea the soil exists for 5% of light sandy clay and for 10% of heavy soil with 8-30% clay content. Reineck & Siefert (1980) found a clear correlation between type of sediment and location in relation to the sea and the prevailing wind direction.

It is a generally known fact that in the Wadden Sea the concentrations of suspended material increase in the direction of the shore (among others: Lüneburg 1939, 1953, 1955, 1958, Gry 1942, Postma 1954). Postma (1961) showed that the coarse fractions (>128 µm) did not increase, but the fraction < 64 µm did. On the causes of this the opinions are, however, divided. According to Lüneburg it is the result of density currents and accordingly of a transport directed inwardly. Gry (1942) stressed the erosion of the local clay banks and mud areas, whereas Postma (1954) and Van Straaten & Kuenen (1985) attributed the availability of fine material to the 'scouring-lag' and the 'settling-lag effect' mentioned before. Dücker (1982) assumes that turbidity is caused by wave erosion on the flats, after which turbid water flows into the channels at ebb. Gry (1942) stressed the fact that the sand content depended on the local current velocity and current force, but that the mud content depended on the origin of the water.

At a high tide turn the water will in general be clearer than at a low tide turn because then relatively clear water from the North Sea will be present and because at high tide mostly a longer period of little current occurs.

In the shallow part of the Wadden Sea wave erosion is the most important process responsible for the turbidity prevailing there. Postma (1961) showed that there was a strong correlation between the tidal phase and the concentration of suspended material. This could be accounted for by the occurrence of erosion when the waves whirled up the sediment from tidal flats barely covered by the water. Also Dücker (1982) discovered this connection and he proved that on the tidal flats a one to one correlation existed between wind velocity and concentration. This correlation existed up to wind-force 6. Above wind-force 6 the waves began to break and the turbidity increased disproportionately. Reineck & Siefert (1980) studied the sediment on tidal flats and found that at a wind velocity > 10 m/s silt was washed out of the sediment. Silt concentrations in the water substantially increased at the beginning of a storm, but when the storm continues, there is no further increase, because then all the silt that can be eroded has already been whirled up and removed.

In the shallow channels, also current begins to become an increasingly important element of the erosion process (Postma 1961) but still quite a lot of the suspended material comes from the flats (Dücker 1982). In the deep channels only the current velocity is important (Postma 1961, Halliwell & O'Connor 1966) but the bottom of these channels mainly exists of sand. At low current velocities this sand will not be whirled up and the suspended material mainly consists of silt transported from elsewhere (Gry 1942). At velocities of 30 cm/s Gry (1942) found only 10 mg/ℓ of sand in suspension, part of which probably existed of flocculated silt.

At 40 cm/s the concentration rose to 25 mg/ℓ and at 50 cm/s it rose to 100 mg/ℓ.

In winter the Wadden Sea water is usually more turbid than in summer, in spite of the lower concentrations of phytoplankton in winter. In the six months of winter the average wind velocity is higher than in summer.

The viscosity of water among other things depends on the salinity and the temperature (Dücker 1982). At a low temperature the viscosity is higher and therefore erosion is stronger (Christiansen 1974). The settling down velocities decrease, so that more sediment stays in suspension (Dillo 1960, Jackson 1964, Halliwell & O'Connor 1966). Evans & Collins (1975) found that over a tidal flat in the

Wash, in summer and in winter the same quantity of sand was in suspension, but that in winter much more silt was added.

From what was said before it will have become apparent that the concentrations of silt in the water of the Wadden Sea show much variation in space and time. Nevertheless some of the observed averages will be given as an indication of the order of magnitude.

In August, in the Danish Wadden Sea, Gry (1942) found average values of 10 mg/ℓ in surface samples taken from the tidal outlet (Graadyb) and almost 300 mg/ℓ in samples taken near the bottom in the Hobogt. On the German flats near Scharhörn, Dücker (1982) mostly found concentrations between 100 and 150 mg/ℓ. Only 15% of the measurements exceeded 300 mg/ℓ, but during storms even quantities of more than 500 mg/ℓ were observed. A prolonged measurement at Rottum gave an average of 36 mg/ℓ close to the island and 135 mg/ℓ in the neighbourhood of the land reclamation works (De Reus 1981). In the Ameland region Postma (1961) found an average of 75 mg/ℓ whereas just outside the outlet 30 mg/ℓ occurred. During a tidal period the concentration at a sampling station could vary from 15-900 mg/ℓ. In the western Wadden Sea the average percentage of suspended matter in the water varied from 40 mg/ℓ in summer to 70 mg/ℓ in winter. In 1980 the annual average was 60 mg/ℓ (De Wit et al. 1982). The eastern Wadden Sea is more turbid, with 80 mg/ℓ in summer and 120 mg/ℓ in winter. There the annual average is approx. 100 mg/ℓ.

The water from the rivers is relatively clear. The discharged IJsselmeer water contains 15 mg/ℓ and that of the Eems 23 mg/ℓ. The water from the North Sea along the Dutch coast is also relatively clear. McCave (1981) mentions values at some distance from the coast of less than 5 mg/ℓ. Closer to the coast this increases to 20-50 mg/ℓ.

2 DEVELOPMENTS IN HYDRAULICS, MORPHOLOGICAL STRUCTURES AND TURBIDITY

2.1 Historical review

An extensive literature exists on the origin of the Wadden Sea and the Zuyder Zee (among others: Pons & Wiggers 1960). The situation may be summarized as follows: in Roman times there was a lake Flevo, surrounded by extensive peat bogs. In the 11th and 12th century peat was exploited at a large scale, which caused a lot of flooding at the beginning of the 13th century. In this way the Wadden Sea, Zuyder Zee and the big lakes in North Holland came into being. Soon afterwards the Zuyder Zee began to silt up because a lot of sediment was available and also because a strong density current existed due to extensive river discharge. These so-called Almere deposits are of a brackish/fresh character and they have a thickness of 2 m. After 1600 the discharge of fresh water clearly decreases and the later, so-called Zuyder Zee deposits are of a clearly saline character. At first sand was deposited near the tidal inlets but the supply was not sufficient to fill up the whole area. Nowadays a comparable situation may be found in some estuaries along the American east coast (Postma 1982, pages 42/43). As a result the Wadden Sea was formed as an elongated inland sea with considerable tidal range and tidal flats among the channels and gullies. The bottom was sandy. The Zuyder Zee became a flat, shallow more or less round bowl with not much tide, entering through only one opening. The bottom was silty.

Originally lake Flevo and the Zuyder Zee received their water from the Vlie. Later on the tidal inlet of Texel was formed and because it was situated more favourably with respect to the tidal wave it became more and more important.

When planning and designing the Afsluitdijk the Lorentz-committee did extensive hydrographic research in order to be able to predict the effects of the Afsluitdijk (Lorentz et al. 1926). For that reason relatively much is known about the hydraulogy of the western Wadden Sea and The Zuyder Zee.

The channel systems of the tidal outlet of Texel and the Vlie united to one system in the area between Stavoren and Enkhuizen. Exchange between the two channel systems occurred through the Scheurrak-Omdraai and the Doove Balg. The relation between the Wadden Sea and the Zuyder Zee was very intricate. Battjes (1961) summarizes as follows: 'The tidal wave that entered the Wadden Sea through the tidal inlets was transmitted to the intermediate area between the Wadden Sea and the basin of the Zuyder Zee in a southward direction and thus reached the basin of the Zuyder Zee. At the end of the Zuyder Zee basin the wave was reflected and this reflected wave interfered with the incoming one. On account of the length of the original basin the tide showed a considerable phase shift. The phase difference of the vertical tide between Den Helder and Urk for instance amounted to 180°, i.e. when the tide rose at Den Helder, it fell at Urk and vice versa. The middle part of the tidal basin of the Zuyder Zee, that is the part north of Urk, was mainly filled and emptied by the part south of Urk. So the tidal inlets had to supply a relatively small amount of water to the now closed off Zuyder Zee'.

Under normal circumstances there was little exchange between the Zuyder Zee and the Wadden Sea and in the intermediate area a water mass moved up and down. In case of storm, with increased water levels, the Zuyder Zee functioned as a buffer and large quantities of water flowed into the Zuyder Zee. Lorentz et al. (1926) calculated quantities of 150,000-200,000 m^3/s.

The hydrographical and particularly the morphological developments in the tidal outlet of Texel have been extensively described by Battjes (1961). In the past (17th and 18th century) the Amsteldiep and Malzwin were important. In the 19th century the Noord-Hollandskanaal and the Anna Paulownapolder were constructed. Therefore the tidal basin of the Amsteldiep and the Malzwin diminished and the Texel Stroom behaved in a peculiar way. The deepest part used to run at a distance of 350 meters from the Horntje (Texel) to the south and at the dike of den Helder it turned to the west. At Huisduinen the channel turned south again. Ever since the end of the 19th century the channel has become more and more straight. It began to approach the Texel coast so that in 1910 the bank protection at Horntje had to be constructed. At Nieuwendiep it moved further from the coast, but it approached again under the dike at Huisduinen. For an estuary this was an uncommon situation. The channel wore away at the inside bends and at the moment there is an almost straight channel of 22 km from the Schulpengat to the Burgzand. The cross-sectional area of the Marsdiep increased until 1930. After the Texelse Hors had grown onto the Onrust, probably no stable situation came into being.

2.2 Changes due to the closing off of the Zuyder Zee and the Lauwers Zee

Reduction of the tidal basin has a large number of effects on the remaining area. Some of these effects occur at once, others will only become apparent after some time, when adaptations to the disturbed balance take place. There are also indirect effects, amongst which the physical-chemical effects and biological effects as a result of changes in currents, tidal amplitude and morphology.

Direct hydraulic effects of the Afsluitdijk

With the construction of the Afsluitdijk the western Wadden Sea was reduced from 5200 km^2 to 1500 km^2 (Rietveld 1963). Due to the disappearance of the buffer capacity of the Zuyder Zee the storm flood surges in the western Wadden Sea increased. The storm flood surges at Den Helder and Oudeschild used to be NAP (Dutch Ordnance Level) +2 m, but now levels of 2.5-3 above NAP regularly occur (more than once in every ten years).

The construction of the Afsluitdijk shortened the tidal basin and the reflected tidal wave no longer subdued the tide as before, but strengthened it. Particularly near the Afsluitdijk the tidal prism increased. At Den Helder the increase was 15 cm, at Oudeschild 39 cm, at Harlingen 56 cm and along the Afsluitdijk the tidal amplitude was more than doubled, from 70 cm to 160 cm. On account of the increased tidal amplitude also the current velocities in the outlets increased (Battjes 1961). In the Marsdiep with 25%, the Vliestroom with 10-19% and in the Eyerlandse Gat with 10%.

The flood and ebb velocities did not increase in proportion. At the Marsdiep the increase of the maximum ebb velocity was 40% (from 1.07 to 1.5 m/s), whereas the flood velocity increased with only 10% (from 1.34 to 1.42 m/s) (Philippart 1989).

Apart from the increased tidal amplitudes also other factors influenced the current velocities. The tide used to enter through two parallel channel systems (Vlie and the Texel inlet). After the construction of the Afsluitdijk, the Wadden Sea area near Harlingen came under the influence of the Texel inlet (fig. 1). The tidal basin of the Texel inlet increased from 600 to 700 km^2 whereas the Eyerlandse Gat and the Vlie decreased from 200 to 170 km^2 and 700 to 630 km^2 respectively. Therefore the current through the Zuidoostrak decreased but the one through the Doove Balg increased considerably. In the channels that originally supplied the Zuyder Zee with water and that now no longer have any function, such as Amsteldiep and Vlieter, the current velocities decreased.

When the Zuyder Zee was closed off the characteristic double peaked tide at Den Helder disappeared. The first tidal top became 12 cm lower and the second top became 12 cm higher so that the first one was only just recognizable. For transport phenomena the changes in velocity and duration of the tidal currents are of greater importance. The maximum tidal current occurs, as it did at an earlier period (before 1930), approx. 3 hours before high tide. At that time it stayed at a level of

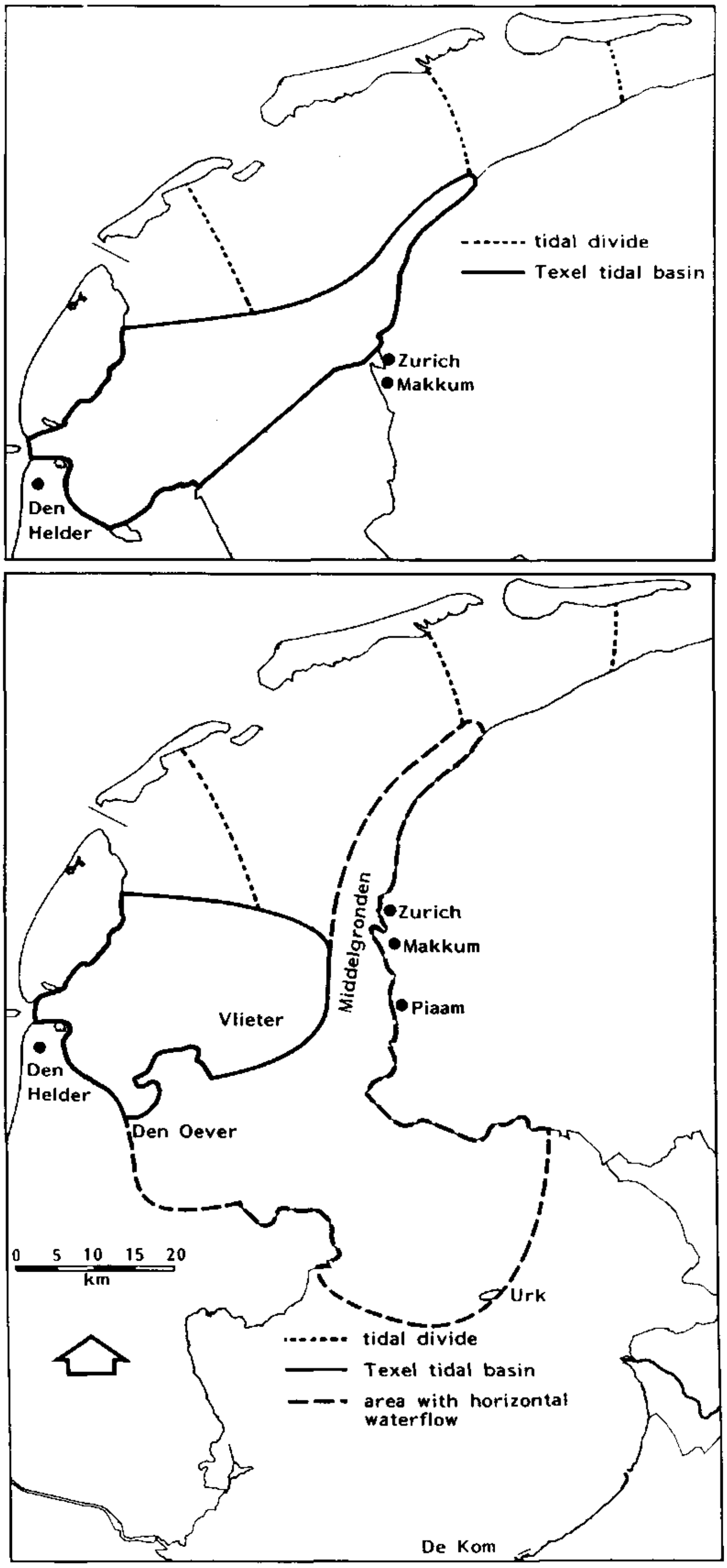


Figure 1. Changes in the tidal basin as a result of the closure (Klok & Schalkers 1978).

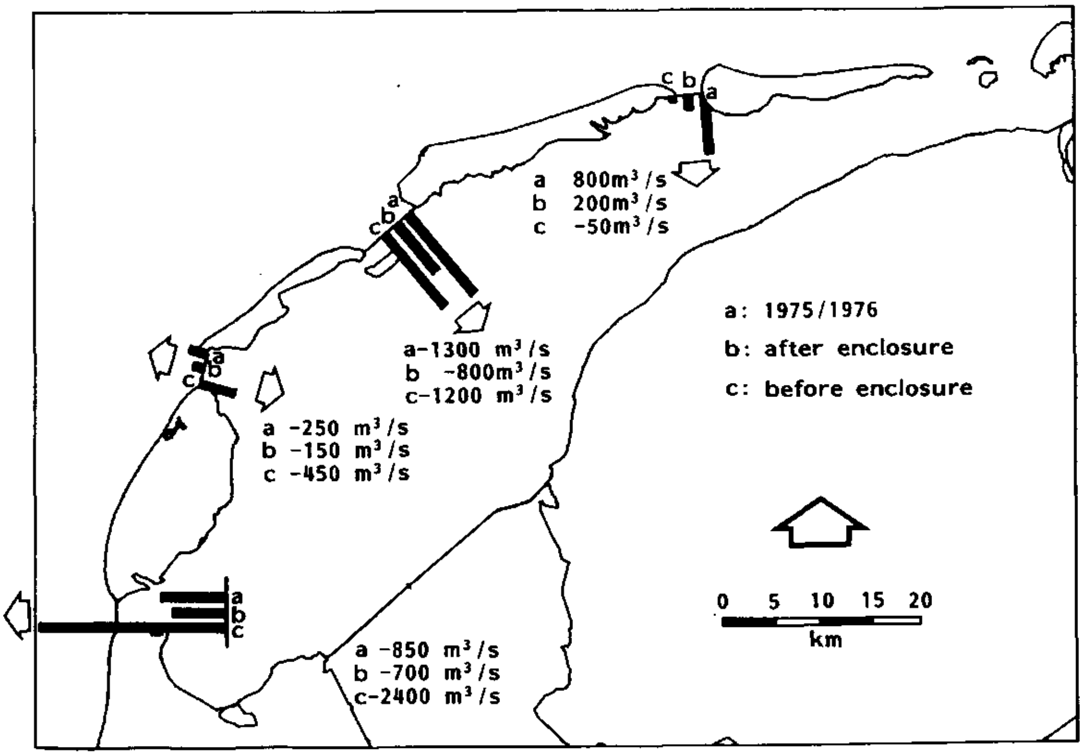


Figure 2. Residual currents through the tidal inlets in the Western Wadden Sea before the closure (c), directly after (b) and in 1976 (a) (Philippart 1989).

more than 80% of its maximum value for a period of three hours. Nowadays this lasts only one hour. However, the tidal current has become somewhat stronger. The maximum ebb current used to occur just before low tide; now it occurs two hours before low tide. The maximum ebb current used to last for three hours; now it only lasts 2½ hours.

Probably of even greater importance for the transport phenomena is the change in the residual currents that occurred after the closure. There used to be a comparatively large residual outward current, through the Marsdiep. After the closure it drastically decreased (Philippart 1989). The changes in the residual current are indicated in figure 2.

Long term morphological adaptations and hydraulic effects

The existing balance between channel section and tidal volume was disturbed and a new balance began to appear. The deviations between actual topography and the balance situation were gradually removed (among other things depending on the availability of sediment). The response time near the tidal outlets seems to be shorter than further inward (Rietveld 1963). Because of the increase of the current in the Doove Balg this channel became much larger in a short time. Therefore the resistance decreased and the tidal amplitude near the Frisian coast still further increased. The opposite occurred in the channels near Wieringen; there the tidal amplitude somewhat decreased later on but it is still much greater than before the closure.

At the moment the importance of the Wierbalg is lessening and at the Visjagersgaatje strong erosion occurs. The Visjagersgaatje is developing as an extension of the Malzwin whereas the Wierbalg is clearly becoming a side channel. It is not clear if this process has anything to do with the Afsluitdijk.

Van de Duin & De Boer (1981) calculated the sedimentation in the area Zwin-Javaruggen between 1928-1934 and 1975. In these old Zuyder Zee channels a lot of sedimentation occurred (2.5-5 m in 40 years was quite common). It was noticeable that most of the sedimentation did not occur in the middle of the channels, but along the eastern edges of the deepest parts. Thijsse (1950) assumes that at the Afsluitdijk approximately 1 milliard m^3 of sediment has to be deposited before a balanced situation can be reached. Rietveld (1963) estimates that every year approximately 9-10 million m^3 is deposited.

Between 1910 and 1930 an annual average sedimentation of 0.2 cm occurred in 'the Abt' (the area of the Vlakte van Oostbierum). After the construction of the Afsluitdijk this rose to 2.8 cm/year and between 1965 and 1975 to 5.7 cm/year. After 1975 it decreased again to 2.8 cm/year. The navigation channel has suffered an annual loss of depth of 10-20 cm. As relatively little sedimentation occurred in the area supplied with water by the Ameland outlet, east of the Terschelling tidal divide, the conclusion may be justified that the sedimentation mentioned is a result of the closing off of the Zuyder Zee.

The background of erosion on some of the flats is less clear than the causes of channel enlargement. It is not apparent whether there is a balance between the height of the flat and the vertical tide and if so how they are related. If the height of the flat depends on the average water level, then the sedimentation or erosion is related to the changes of the sea level, but if the height depends on the low-water level, then a lower low-water level will occur when the amplitude is increased, resulting in erosion of the flats. In case of a relation with the high-water level sedimentation will occur under the same conditions.

Which situation prevails will probably depend on the area. In open areas with a lot of waves, probably the low-water level is important because of the erosion by waves. In quiet 'sedimentation areas' it seems that the high-water level is important because of the supply of sediment. Arguments for this were acquired from research in land reclamation works (Kamps 1962) and saltmarshes (Dankers et al. 1984).

Measuring the annual sedimentation is difficult because local fluctuations are mostly larger than the sedimentation and the measuring accuracy is too small. Many measurements over a long period of time, however, can provide a statistically reliable idea.

Large numbers of soundings from the Western Wadden Sea by the former Study Department Hoorn of Rijkswaterstaat (The Department of Public Works) have been used to produce useful maps indicating erosion and sedimentation in a well-organized way. (Glim et al. 1987, 1988a, 1988b, 1989). It is apparent that at the beginning of the seventies a lot of sedimentation occurred. In the Wadden Sea west of the tidal divide of Ameland the area above NAP (Dutch Ordnance Level) increased with

15.9 km^2 (15%) the area above NAP -2 m with 43.5 km^2 (3.9%). From the beginning of the seventies, however, sedimentation strongly decreased and in some parts erosion prevails now.

The quantities of settled down and eroded material are indicated in table 1. From the table Glim et al. conclude that about 1950 the most important adaptations to the changes as a result of the Afsluitdijk had occurred. The diagram only presents a very general idea. Locally, within a tidal outlet, extensive variations may occur. There are indications that along the Afsluitdijk and the Frisian coast sedimentation in particular takes place, whereas behind the islands probably erosion will prevail. The erosion and sedimentation after 1980 is mainly connected with the dynamic character of the area. This also appears from the fact that the sedimentation in the tidal outlet of the Vlie between 1965 and 1982 (49 million m^3) actually should be seen as very strong sedimentation (85 million m^3) between 1966 and 1977 followed by very heavy erosion (approx. 40 x $10^6 m^3$) between 1977 and 1983. Glim et al. (1987) see a connection between the erosion in the Texel outlet in the period 1965-1982 and the sand extraction that occurred there which caused different hydrographic conditions.

Table 1. The sedimentation (+) and erosion (-) in various parts of the Western Wadden Sea.

Period	Texel outlet x $10^6 m^3$	Vlieland outlet x $10^6 m^3$	Eyerlandse gat x $10^6 m^3$
1933-1950	+140	+57	- 21
1950-1965	+ 40	- 19	
1965-1982	- 30	+49	+ 2

Effects of the closure of the Lauwers Sea

By closing off the Lauwers Sea the tidal basin of Zoutkamperlaag was decreased. Because in fact the channel was too large and did not silt up fast enough the channel system of Schildknoopen, Vierhuizergat and Groningerbalg expanded in eastern direction. The Eilanderbalg withdrew and the tidal divide of Schiermonnikoog shifted to the east. The sedimentation in the Zoutkamperlaag at places amounted to more than 5 m within ten years.

Effects on turbidity

Before the closure of the Zuyder Zee large quantities of silt were transported to the Zuyder Zee that could then settle there. In principle it may be calculated from the thickness of the silt layer how much silt settled down every year. It is not certain if an accurate calculation can be made on the basis of the existing information (P.J. Ente, pers. comm.). A rough estimate is possible, however. A layer of 40 cm deposited over a period of 350 years amounts to 1.25 million tons of silt a year. Of this approximately 0.5 million tons may come from the IJssel. In relation to the quantity settling down in the Wadden Sea, as estimated by Eisma (1981) (1 million tons), a lot stayed behind in the Zuyder Zee. According to De Reus (1981) in the Wadden Sea 2.5-3 x 10^6 tons of silt are left behind. However, from this it may not be concluded that the closing off has increased the turbidity, because in case of storm large quantities of Zuyder Zee silt used to come in suspension and flowed back into the Wadden Sea.

The most important effect of the closure of the Zuyder Zee was the increase of the tidal amplitude in the Wadden Sea. As a result a much larger area than before underwent the influence of the waves twice a day. On account of the greater amplitude also the current velocities in the tidal outlets and in the large supply channels increased. At the same time the area influenced by the Texel inlet was expanded so that the current velocities in the Doove Balg increased. Due to increased erosion and the instability of the channel pattern, turbidity may have been increased (De Jonge 1983). On the other hand, the turbidity should have become less because of sedimentation in dead channels. If however, part of the settled down material is whirled up every now and then and the very fine parts stay in suspension during a long period of time, also these areas will keep a high degree of turbidity.

Although the current velocities in the outlets have increased, one may not conclude automatically that therefore the turbidity increased. At present the tidal current reaches its maximum strength for a considerably shorter period than before. As a result the supply could be less. The maximum ebb current occurs a little earlier than before but the maximum current velocities last a shorter time and the quantity of removed material could have become smaller for this reason. It is not possible, on the basis of the available data, to come to a conclusion concerning the increase or decrease of turbidity due to these changes.

RIN-rapporten kunnen besteld worden door overschrijving van het verschuldigde bedrag op postbanknummer 516 06 48 van het RIN te Leersum onder vermelding van het rapportnummer. Uw overschrijving geldt als bestelformulier; toezending geschiedt franco. Gebruik **geen verzamelgiro** omdat het **adres** van de besteller niet op onze bijschrijving komt zodat het bestelde niet kan worden toegezonden.

To order RIN reports advance payment should be made by giro transfer of the price indicated in Dutch guilders to account number 516 06 48 of the Rijks-**instituut voor Natuurbeheer, P.O. Box 46, 3956 ZR Leersum, The Netherlands.** Please note that your payment is considered as an order form and should mention only the report number(s) desired. Reports are sent free of charge.

87/1 W.O. van der Knaap & H.F.van Dobben, Veranderingen in de epifytenflora van Rijnmond sinds 1972. 36 p. f 6,-
87/2 A. van Winden et al., Ruimtelijke relaties via vogels in het Strijper-Aa-gebied gedurende broedtijd en zomer. 97 p. f 14,50
87/6 G.F. Willemsen, Bijzondere plantesoorten in het nationale park de Hoge Veluwe; voorkomen en veranderingen. 92 p. f 14,-
87/9 K.S. Dijkema, Selection of salt-marsh sites for the European network of biogenetic reserves. 30 p. f 5,50
87/14 N. Dankers, K.S. Dijkema, G. Londo & P.A. Slim, De ecologische effecten van bodemdaling op Ameland. 90 p. f 14,-
87/16 J. Wiertz, Modelvorming bij de projecten van WAFLO en SWNBL. 34 p. f 6,-
87/18 Effecten van de kokkelvisserij in de Waddenzee. 23 p. f 5,-
87/19 H. van Dam, Monitoring of chemistry, macrophytes, and diatoms in acidifying moorland pools. 113 p. f 16,50
87/22 B. van Dessel, Te verwachten ecologische effecten van pekellozing in het Eems-Dollardgebied. 71 p. f 10,-
87/23 W.D. Denneman & R. Torenbeek, Nitraatemissie en Nederlandse ecosystemen: een globale risico-analyse. 164 p. f 21,50
87/24 M. Buil, Begrazing van heidevegetaties door edelhert en moeflon; een literatuurstudie. 31 p. f 5,60
87/26 H.A.T.M. van Wezel, Heidefauna in het nationale park de Hoge Veluwe. 54 p. f 8,-
88/30 P.F.M. Verdonschot & R. Torenbeek, Lettercodering van de Nederlandse aquatische macrofauna voor mathematische verwerking. 75 p. f 10,-
88/31 P.F.M. Verdonschot, G. Schmidt, P.H.J. van Leeuwen & J.A. Schot, Steekmuggen (Culicidae) in de Engbertsdijksvenen. 109 p. f 16,-
88/33 H. Eijsackers, C.F. van de Bund, P. Doelman & Wei-chun Ma, Fluctuerende aantallen en activiteiten van bodemorganismen. 85 p. f 13,50
88/35 A.J. de Bakker & H.F. van Dobben, Effecten van ammoniakemissie op epifytische korstmossen; een correlatief onderzoek in de Peel. 48 p. f 7,50
88/36 B. van Dessel, Ecologische inventarisatie van het IJsselmeer. 82 p. f 13,-
88/38 P. Opdam & H. van den Bijtel, Vogelgemeenschappen van het landgoed Noordhout. 65 p. f 9,-
88/39 P. Doelman, H. Loonen & A. Vos, Ecotoxicologisch onderzoek in met Endosulfan verontreinigde grond: toxiciteit en sanering. 34 p. f 6,-
88/40 G.P. Gonggrijp, Voorstel voor de afwerking van de groeve Belvédère als archeologisch-geologisch element. 13 p. f 3,-
88/41 J.L. Mulder (red.), De vos in het Noordhollands Duinreservaat. Deel 1: Organisatie en samenvatting. 32 p.
88/42 J.L. Mulder, idem. Deel 2: Het voedsel van de vos. 78 p.
88/43 J.L. Mulder, idem. Deel 3: De vossenpopulatie. 129 p.
88/44 J.L. Mulder, idem. Deel 4: De fazantenpopulatie. 59 p.
88/45 J.L. Mulder & A.H.Swaan, idem. Deel 5: De wulpenpopulatie. 76 p.
De rapporten 41-45 worden niet los verkocht maar als serie van vijf voor f 25.

88/46 J.E. Winkelman, Methodologische aspecten vogelonderzoek SEP-proefwindcentrale Oosterbierum (Fr.). Deel 1. 145 p. f 19,50

88/48 J.J. Smit, Het Eemland en de polder Arkemheen rond het begin van de twintigste eeuw. 64 p. f 9,-

88/49 G.W. Gerritsen, M. den Boer & F.J.J. Niewold, Voedselecologie van de vos in Nederland. 96 p. f 14,50

88/50 G.P. Gonggrijp, Permanente geologische ontsluitingen in de taluds van Rijksweg A 1 bij Oldenzaal. 18 p. f 4,50

88/52 H. Sierdsema, Broedvogels en landschapsstructuur in een houtwallandschap bij Steenwijk. 112 p. f 16,-

88/54 H.W. de Nie & A.E. Jansen, De achteruitgang van de oevervegetatie van het Tjeukemeer tussen Oosterzee (Buren) en Echten. 18 p. f 4,50

88/56 P.A.J. Frigge & C.M. van Kessel, Adder en zandhagedis op de Hoge Veluwe: biotopen en beheer. 16 p. f 3,50

88/62 K. Romeyn, Estuariene nematoden en organische verontreiniging in de Dollard. 23 p. f 5,-

88/63 S.E. van Wieren & J.J. Borgesius, Evaluatie van bosbegrazingsobjecten in Nederland. 133 p. f 18,50

88/66 K.S. Dijkema et al., Effecten van rijzendammen op opslibbing en omvang van de vegetatiezones in de Friese en Groninger landaanwinningswerken. Rapport in samenwerking met RWS Directie Groningen en RIJP Lelystad. 130 p. f 19,-

88/67 G. Schmidt & J.C.M. van Haren, Achtergronden van een steekmuggenplaag; steekmuggen (Culicidae) in de Engbertsdijksvenen 2. 162 p. f 21,-

88/68 R. Noordhuis, Maatregelen ter voorkoming en beperking van schade door zilvermeeuwen. 48 p. f 7,50

89/3 F. Maaskamp, H. Siepel & W.K.R.E. van Wingerden, Een monitoring experiment met ongewervelde dieren in graslanden op zandgrond. 44 p. f 13,50

89/5 R.J. Bijlsma, Remote sensing voor classificatie van de vegetatie en schatting van de biomassa op ganzenpleisterplaatsen in het waddengebied. 62 p. f 8,50

89/7 R. Ketner-Oostra, Lichenen en mossen in de duinen van Terschelling. 157 p. f 21,-

89/8 A.L.J. Wijnhoven, Effecten van aanleg, beheer en gebruik van golfbanen en mogelijkheden voor natuurtechnische milieubouw. 19 p. f 4,50

89/9 N. Dankers, K. Koelemaij & J. Zegers, De rol van de mossel en de mosselcultuur in het ecosysteem van de Waddenzee. 66 p. f 9,-

89/10 P.G.A. ten Den, Patrijzen op en rond De Hoge Veluwe. 40 p. f 6,50

89/11 C.J. Smit & G.J.M. Visser, Verstoring van vogels door vliegverkeer, met name door ultra-lichte vliegtuigen. 12 p. f 3,50

89/12 R. van Halewijn, Bescherming van zeevogels op het Lago-rif, Aruba, in 1988. 73 p. f 10,-

89/13 K. Lankester, Effecten van habitatversnippering voor de das (*Meles meles*); een modelbenadering. 101 p. f 15,-

89/14 A.J. de Bakker, Monitoring van epifytische korstmossen in 1988. 53 p. f 8,-

89/15 J.E. Winkelman, Vogels en het windpark nabij Urk (NOP): aanvaringsslachtoffers en verstoring van pleisterende eenden, ganzen en zwanen. 169 p. f 22,-

89/16 J.J.M. Berdowski et al., Effecten van rookgas op wilde planten. 108 p. f 16,-

89/17 E.C. Gleichman-Verheijen & W. Ma, Consequenties van verontreiniging van de (water)bodem voor natuurwaarden in de Biesbosch. 91 p. f 14,-

89/18 A. Farjon & J. Wiertz, Milieu- en vegetatieveranderingen in het schraalland van Koolmansdijk (gemeente Lichtenvoorde); 1952-1988. 134 p. f 18,50

89/19 P.G.A. ten Den, Achtergronden en oorzaken van de recente aantalsontwikkeling van de fazant in Nederland. 168 p. f 22,-

90/1 R.J. Bijlsma, Het RIN-bosecologisch informatiesysteem SILVI-STAR; documentatie van FOREYE-programmatuur en subprogramma's. 96 p. f 14,50
90/2 J.E. Winkelman, Vogelslachtoffers in de Sep-proefwindcentrale te Oosterbierum (Fr.) tijdens bouwfase en half-operationele situaties (1986-1989). 74 p. f 10,-
90/4 J.M. de Graaf, De stinzenflora van Leiden en noordelijke omgeving. 95 p. f 14,50
90/5 G.M. Dirkse & P.A. Slim, Naar een methode voor het monitoren van vegetatieontwikkeling in het waddengebied. 40 p. f 6,50
90/6 J.C.M. van Haren & P.F.M. Verdonschot, Steekmuggen (Culicidae) in de Engbertsdijksvenen 3. 61 p. f 8,50
90/8 H. Siepel et al.,Effecten van verschillen in mestsoort en waterstand op vegetatie en fauna in klei-op-veen graslanden in de Alblasserwaard. 50 p. f 7,50
90/9 J.E. Winkelman, Verstoring van vogels door de Sep-proefwindcentrale te Oosterbierum (Fr.) tijdens bouwfase en half-operationele situaties (1984-1989). 157 p. f 21,-
90/10 P.J.H. Reijnders, I.M. Traut & E.H. Ries, Verkennend onderzoek naar de mogelijkheden voor het terugzetten van gerevalideerde zeehonden, *Phoca vitulina*, in de Oosterschelde. 36 p. f 6,-
90/11 M. Elbers & P. Doelman, Studie naar de mogelijke effecten op flora en fauna als gevolg van de inrichting van de Noordpunt Oost-Abtspolder als definitieve opslagplaats voor verontreinigde grond. 128 p. f 18,-
90/12 K. Kramer & P. Spaak, meadowsim, een evaluatie-instrument voor de kwaliteit van graslandgebieden voor weidevogels. 51 p. f 7,50
90/13 P.A. Slim & L.J. van Os, Effecten van natuurbeheer op de vegetatie in het veenweidegebied van de Donksche Laagten (Alblasserwaard). 45 p. f 7,-
90/14 F. Fennema, Effects of exposure to atmospheric SO_2, NH_3 and $(NH_4)_2SO_4$ on survival and extinction of *Arnica montana* and *Viola canina*. 60 p. f 8,50
90/16 J. Wiertz, Ontstaanswijze, grondwater en bijzondere plantesoorten van enkele duinvalleien op Oost-Ameland. 49 p. f 7,50
90/17 J.E. Winkelman, Nachtelijke aanvaringskansen voor vogels in de Sep-proefwindcentrale te Oosterbierum (Fr.). 209 p. f 26,50
90/18 N.J.M. Gremmen & R.J.B. Zwanikken, De haalbaarheid van een kennissysteem voor heidebeheer. 49 p. f 7,50
90/19 N. Dankers, K.S. Dijkema, P.J.H. Reijnders & C.J. Smit, De Waddenzee in de toekomst - waarom en hoe te bereiken? 137 p. f 18,50
90/21 W.J. Wolff, Verslag van de workshop op 2 oktober 1990 te Wageningen gewijd aan het Rapport van de Werkgroep II van het Intergovernmental Panel on Climate Change. 63 p. f 9,-

91/1 L.M.J. van den Bergh, De grauwe gans als broedvogel in Nederland. 31 p. f 5,50
91/2 W.A. Teunissen, De uitstralingseffecten van geluidsproduktie van de militaire 25 mm schietbaan in de Marnewaard op plaatskeuze en gedrag van watervogels in het Lauwersmeergebied binnendijks. 101 p. f 15,-

1991-1 N. Dankers et al., The Wadden Sea in the future - why and how to reach? RIN Contributions to Research on Management of Natural Resources. 108 p. f 16,-

Ecologie van kleine landschapselementen

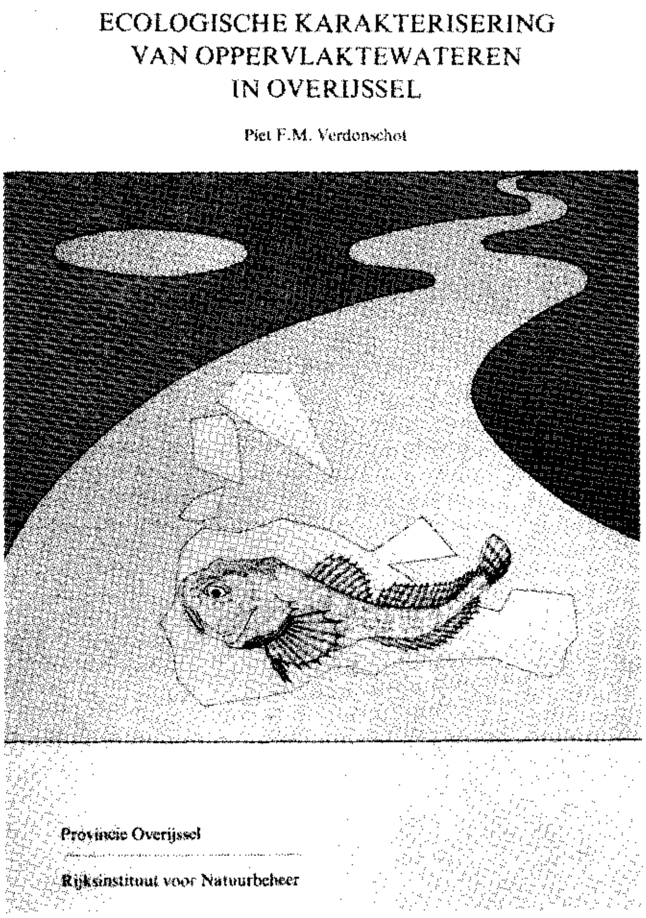
Kleine landschapselementen vormen voor veel soorten planten en dieren van het cultuurlandschap biotoop en ecologische infrastructuur. In 1986 wijdde het RIN een studiedag aan dit thema. In het verslag hiervan werd een overzicht gegeven van de stand van het onderzoek en er is ruime aandacht besteed aan praktijkproblemen van de landinrichting.

88 pagina's, geïllustreerd
prijs *f* 20,-
bestelcode: KLE

Ecologische karakterisering van oppervlaktewateren in Overijssel

Dit boek is een produkt van een jarenlange samenwerking tussen het Rijksinstituut voor Natuurbeheer en de provincie Overijssel. Een ecologische indeling van wateren is nodig voor goed waterbeheer. Met dit boek kunnen ecologische doelstellingen op korte en middellange termijn gerealiseerd worden; het bevat praktische adviezen voor een gedifferentieerd waterbeheer. Ook kunnen de maatregelen op hun ecologische effecten worden beoordeeld.

301 pagina's
prijs *f* 40,-
bestelcode: EKOO



De boeken zijn te bestellen door het verschuldigde bedrag over te schrijven op postbanknummer 516 06 48 van het RIN te Leersum onder vermelding van de bestelcode. Uw overschrijving geldt als bestelformulier. De portokosten zijn voor onze rekening.