

The effects of shellfish fishery on the ecosystems of the Dutch Wadden Sea and Oosterschelde

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Final report on the second phase of the scientific evaluation of the Dutch shellfish fishery policy (EVA II)

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ABSTRACT

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This publication summarises the findings of the scientific research projects carried out as part of EVA II, the second phase in the evaluation of shellfish fisheries policy in the Zeeland Delta and the Wadden Sea, and relates these findings to other studies on the ecological effects of shellfish fisheries in the Wadden Sea and elsewhere. Four policy questions were at the heart of the project: (1) what are the ecological impacts of shellfish fishery?, (2) did the policies implemented in 1993 achieve their objectives, (3) is current shellfish fishery in line with international obligations, (4) what possibilities for improvement do exist? These policy questions were translated into research questions. Numbers of large shellfish-eating birds declined. Some restoration of seagrass beds occurred, but restoration was not maximal. The area of littoral mussel beds in the Wadden Sea increased to more than 2000 ha, after having disappeared completely in 1990.

Keywords: *Cerastoderma edule*, closed areas, cockle, cockle fishery, common eider, *Crassostrea gigas*, EVA II, evaluation, food reservation policy, *Haematopus ostralegus*, mussel, mussel fishery, *Mytilus edulis*, Oosterschelde, oystercatcher, Pacific oyster, sea grass, shellfish fishery, *Somateria mollissima*, Wadden Sea, *Zostera*

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Preface

This publication summarises the findings of the scientific research projects carried out as part of EVA II, the second phase in the evaluation of shellfish fisheries policy in the Zeeland Delta and the Wadden Sea, and relates these findings to other studies on the ecological effects of shellfish fisheries in the Wadden Sea and elsewhere. We incorporate new insights that emerged after the publication of the public version of the EVA II research (Ens *et al.*, 2003b). Thus, this report includes new findings that were presented at a symposium, organised by the Centre for Ecological and Evolutionary Studies (CEES), on the ecological effects of cockle fishery in January 2004. This report also includes the results of an intensive scientific debate on the relationship between declining levels of nutrients, shellfish stocks and bird numbers. The research is to provide the foundation for new policy on cockle and mussel fishing. The evaluation must also chart the relationship between shellfish fishing and the natural values of the ecosystem.

EVA II consisted of a total of 22 research projects. These projects were largely implemented by a consortium consisting of Alterra (belonging to Wageningen University and Research Centre), the Netherlands Institute for Fisheries Research (RIVO, belonging to Wageningen University and Research Centre), the National Institute for Coastal and Marine Management (RIKZ) and the National Institute for Fresh Water Management and Waste Water Treatment (RIZA). Other institutes and organisations also contributed to some of the projects.

The scientific research on which we report was commissioned by the Ministry of Agriculture, Nature and Food Quality and the Ministry of Transport, Public Works and Water Management. The cooperative producers' organisation for Dutch mussel culture (PO Mossels) co-financed the experimental testing of the 'Jan-Louw hypothesis'.

The research was greatly helped by the many data obtained from the producers' organisation for mussels (PO Mossels) and for cockles (PO Kokkels), most notably catch statistics and the black box data, which allowed us to quantify fishing effort.

During the collection of field data we received help from the crew of the various inspection vessels of the ministry of Agriculture, Nature and Food Quality, including the Cornelis Bos, Harder, Kokhaan, Krukel, Phoca, Stern, Stormvogel, Schollebaar and Valk. On many occasions, the enthusiasm and support of the crew members went far beyond the call of duty. A long list of students and other persons offered help with the work at one time or another.

Comments on a draft version of this report were received from Jan Beukema (NIOZ), Sytze Braaksma (LNV directie Noord), Norbert Dankers (Alterra), Victor de Jonge (RuG), Herman Eijsackers (Alterra), Joris Geurts van Kessel (RIKZ), Peter Herman (NIOO), Pauline Kamermans (RIVO), Ronald Lanfers (LNV directie

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The research was supervised by the EVA II steering committee, which consisted of representatives from the Ministry of Agriculture, Nature and Food Quality, the Ministry of Transport, Public Works and Water Management, the three leading research institutes, the fishermen (via Productschap Vis) and nature conservationists (via Vogelbescherming and Waddenvereniging).

Before publication, each scientific report was evaluated by the scientific audit committee set up for the purpose, consisting of Prof. W.J. Wolff, Prof. C.H.R. Heip & Prof. P.L. de Boer. The comments of the audit committee were added at the end of each report and it was indicated how the comments were incorporated in the final text. This procedure was also adopted for the final report.

Summary

This report summarizes the results of the second phase of the scientific evaluation of the Dutch shellfish fishery policy (EVA II) and relates these findings to the results of other studies on the ecological impacts of shellfish fisheries in the Wadden Sea and elsewhere. The report begins by sketching the history of the problem, and setting out the policy and research questions. This is followed by an overview of results and findings. The most important results are then summarised again in a chapter with conclusions, followed by a chapter with recommendations. A glossary of terms and an overview of research reports are given at the end of this document. All reports are available from the internet site www.eva2.nl.

Four main policy questions are at the heart of the EVA II research program. These policy questions (in bold) were translated into research questions (underlined), and these were answered on the basis of the research carried out as part of the EVA II project as well as other relevant scientific investigations in the Wadden Sea or elsewhere.

1. What are acceptable effects of shellfish fishing on the benthic biotopes of stable mussel beds, intertidal flats, cockle beds and sea grass fields? What are acceptable effects on birds which feed on the shellfish and are dependent on the biotope in the coastal waters?

1a. How and to what extent do the different forms of shellfish fishing impact on the important benthic biotopes?

Cockle fishery on intertidal flats – direct impacts. Cockle fishery by suction dredging removes cockles of one or more years old. In the Wadden Sea, a good spatfall of cockles occurs on average once every six years. During the past ten years, on average 25% of the surface of the cockle beds in the open areas was touched by a cockle dredge each year. More than half of the surface of the beds in the open areas was fished each year, where fished means that at least 2% of the area was actually touched by the cockle dredge. As a result, a larger proportion of the biomass of mature cockles was to be found in the areas closed for shellfish fishing. Suction dredging has a direct negative impact on mussel beds and sea grass beds, when fishing occurs in these habitats. However, fishing plans effectively exclude mussel beds and sea grass beds from cockle fishing, except for one newly established sea grass bed along the Groningen coast, which disappeared after having been fished for several years. Cockle fishery leads to considerable mortality of non-target benthic fauna in the top layer of the sediment on the fished bed, running into dozens of percent and also removes dispersed mussels. Suction dredging also leads to a decrease in the silt content of the top layer of the sediment in the short term.

Cockle fishery on intertidal flats – indirect effects. There are also indications for a long-term effect of cockle fishery on the sediment. Since cockles capture silt through their pseudofaeces, the long-term effect is probably a consequence of the systematic decrease in cockle stock as a result of cockle fishing. There are no

indications that suction dredging reduces the prospects of re-establishment of sea grass beds, but systematic research is lacking. At the scale of the Wadden Sea there is no evidence for a decrease in the recruitment of mussels as a result of cockle fishing, despite the fact that such evidence does exist at small spatial scales. Less cockle spat developed in the open areas than in the closed areas. However, the difference has disappeared since 2000 and recruitment was even slightly higher in the open areas during the last three years. This may be explained by a negative effect of high cockle densities on recruitment and the fact that high densities of cockles occurred in the areas closed for fishing. There are indications that the densities of the ragworm *Nereis diversicolor* have increased as the result of cockle fishery. In a study in the western Wadden Sea, a more general shift towards worms was observed.

Mussel fishery on intertidal flats. Mussel beds enrich the surrounding sediment, so the biological loss that results from removal of a mussel bed is greater than the loss of the mussel bed itself. Mussel fishery on stable mussel beds may lead to a long-term decrease in the coverage of such mussel beds, as was demonstrated in the Wash. In order to restore mussel bed areas the Sea and Coastal Fisheries Policy does not allow mussel fishery on stable mussel beds in intertidal areas. Large scale recruitment of mussels in the intertidal areas occurred on average once every 4 years over the past 50 years. Successful recruitment is the primary condition for the formation of new mussel beds area. Once established other factors become relevant. In the Dutch Wadden Sea relatively unstable seed beds often disappear during winter storms and observations in lower Saxony suggest that high bird predation may also lead to loss of seed beds. The combination of only some good spatfalls since 1990 and considerable losses of young mussel beds led to a relatively slow recovery of the mussel stocks. In the nineties, after the disappearance of the intertidal mussel beds, a good spatfall occurred in part of the area in 1994, but most of these beds disappeared during the subsequent winter and spring. In 1999 and particularly in 2001 large seed bed areas have established, and about 50% of these new beds survived. At present, after 12 years almost without fishery, about 2100 ha of relatively young, but more or less stable beds are present. A controlled fishing experiment on newly established mussel seed beds showed a decrease in the coverage of such mussel beds directly after fishing, but no evidence was found for either a positive or a negative long-term effect on these beds in terms of coverage. The role of mussels that disappeared naturally during winter was not studied, so it is not possible to make a comparison with the yield of the mussels that were fished and transported to the culture lots.

Mussel fishery and mussel culture in subtidal areas. The Sea and Coastal Fisheries Policy does allow fishery on all mussel beds in the subtidal and this could potentially explain why there are hardly any old mussel beds in the subtidal areas of the Wadden Sea and Oosterschelde at present. By transporting mussels from areas with high recruitment but poor growth, to areas with poor recruitment but high growth, mussel culture increases the average standing stock of mussels, despite subsequent harvest. A first attempt to calculate the overall effect of mussel culture on the subtidal mussel stocks during the 1990s points to an increase of the total subtidal stock in Dutch coastal waters by a factor 2. As a considerable part of seed mussels

and half-grown mussels is transplanted to the Oosterschelde, the net increase in the Wadden Sea was tentatively estimated as ca. 15%. We did not observe effects of sublittoral mussel fishing on mussel seed production and fishing for mussel seed does occur in roughly the same areas year after year. However, fishery effects on spatfall in subtidal areas cannot be excluded because available data for analyses of fishery effects on spatfall are limited, and comparison with reference areas is not possible. We did not study effects of sublittoral mussel fishing on epibenthic species. A more detailed and quantitative assessment of the total effect of mussel farming and fishing on biodiversity in the Dutch Wadden Sea is difficult to make because comparative information from untouched mussel beds, fished beds and culture locations are missing.

1b. How and to what extent does shellfish fishing affect the food supply of oystercatchers and eider ducks, which feed on large shellfish, and other wild birds which are dependent on these biotopes?

Cockle fishery. Cockle fishery reduces the food stock of oystercatchers. On the basis of model calculations, it is estimated that this direct effect of cockle fishery amounts to a decrease of the carrying capacity of Wadden Sea and Oosterschelde for oystercatchers with a number in the order 15000 and 3300 birds respectively, during the evaluation period. These model calculations do not take cumulative effects of cockle fishery on stock sizes, recruitment and age distribution of cockles into account. At present, there is no evidence that cockle fishery has had a negative impact on common eiders, which may be due to the fact that cockles are not a preferred prey for common eiders as a result of their thick shells. Cockle fishery may influence the food supply of knots through its influence on stocks of small shellfish. There are indications that the quality of cockles in fished areas is reduced. It is possible that cockle fishery favours some worm species that are an important food source for birds feeding on worms.

Mussel fishery. The primary reason for the decline in the number of oystercatchers wintering in the Wadden Sea from 260000 to 175000 is the disappearance of the intertidal mussel beds. This disappearance was caused by mussel fishery in combination with recruitment failure and possibly winter storms. The numbers of common eiders which winter in and around the Wadden Sea have also decreased. Under the assumption that mussel fishery does not impact recruitment of mussels in the subtidal, mussel culture has, on average, improved the food supply of common eiders during the evaluation period. However, scarcity of sublittoral mussel seed and the lack of mussel seed fishery from intertidal seed stocks resulted in low stocks of mussels on culture plots in a number of years. As a consequence, common eiders have experienced several years with mass mortality related to low stocks of sublittoral mussels. Fluctuations in shellfish stocks are a natural phenomenon. However, due to lack of data, it cannot be excluded that during years of scarcity, transport of mussels from culture lots in the Wadden Sea to culture lots in the Oosterschelde was increased, thereby increasing the food shortage for the common eiders.

2. One measure currently in use is the closure of areas to fishing. The main aim of this is to restore the most important benthic biotopes, specifically the intertidal mussel beds and seagrass fields. Another existing policy measure is that of food reservation. Have these measures produced the desired effect?

2a. Has the area of intertidal mussel beds been restored to the desired level? If not, is that due to shellfish fishing, other human impact or natural factors?

The policy aim is 2000-4000 ha of stable intertidal mussel beds. If 'stable' is equated to 'having survived at least one winter' it can be concluded that the area has been restored to the desired level at the end of the evaluation period. From 1990 to 1994 there were practically no mussel beds in the Wadden Sea. Since 1995, there has been a recovery to 2500 ha in 2002. This recovery was mainly due to natural circumstances, because almost no fishery was carried out since 1992.

2b. Have the seagrass fields recovered to the maximum possible extent? If not, is that due to shellfish fishing, other human impact or natural factors?

Recovery of seagrass fields has occurred, but it was not maximal, since one new establishment disappeared again due to cockle fishery in the period 1999-2002. About 30% of this fished area showed recovery in 2003.

2c. Are the methods previously used to calculate the food requirements of shellfish-eating birds correct?

The method previously used was not correct. The amount of food that must be present per bird at the start of winter (the ecological food requirement) is around 2.5 to 3 times higher than the physiological food requirement, depending on factors like emersion time, distribution of the prey and the efficiency with which the birds can harvest the food. The ecological food requirement for oystercatchers in the Wadden Sea was estimated at around 200 kilos of cockle flesh per bird in the absence of mussel beds. For the Oosterschelde the figure is 150 kilos. There is a margin for error in this ecological food requirement which is difficult to determine accurately, but which could amount to some dozens of kilos. The margin of error in the estimate of the ecological food requirements of the common eider is greater than for oystercatchers, since our knowledge of the feeding ecology of common eiders is crude compared to the details of our knowledge on the feeding ecology of oystercatchers. The risk of increased mortality among eider ducks rises as the stocks of half-grown and mature sublittoral mussels in the Wadden Sea in December fall below the level of 60 million kilos net fresh weight. Food shortage can also have natural causes, like long periods with poor shellfish recruitment, so food reservation policy does not account for periods of natural food shortage.

2d. How do the observed numbers of birds compare with the target or reference numbers?

The numbers of oystercatchers in Wadden Sea and Oosterschelde have declined as a result of food shortages. In the Wadden Sea from 260000 to 175000. In the Oosterschelde from 64000 (of which an estimated 54400 did not feed on mussels) to 35000. In recent years there are indications of a slight recovery in the Oosterschelde and a stabilization of numbers in the Wadden Sea. The numbers of eider ducks

which winter in and around the Wadden Sea have decreased from 130000 to 100000, partly due to several years of mass mortality.

2e. How can any discrepancies in these numbers be explained?

The decrease in the number of common eiders wintering in Dutch coastal waters is most likely due to several years with high mortality as a result of food shortages. The main food stock in short supply were sublittoral mussels, but other food stocks probably also played a role. The decrease in the number of oystercatchers wintering in the Dutch Wadden Sea is primarily due to the disappearance and subsequent slow recovery of the intertidal mussel beds, and to a lesser extent due to the continuing cockle fishery. The decrease in the number of oystercatchers wintering in the Oosterschelde is primarily due to the lowered stocks of cockles to which cockle fishery has contributed.

3. Is the result of effects and measures such that the Netherlands meets its international obligations under the EU Birds Directive and the EU Habitats Directive? What can we learn from the evaluation of current policy and what possible guarantees are there for the future?

3a. Is the current food reservation policy sufficient to prevent shellfish fishing in the long term having a detrimental effect on populations of shellfish-eating birds?

The policy of food reservation was unable to prevent a food shortage due to fisheries for the reference number of shellfish-eating birds. The current food reservation policy is insufficient, because it is not based on the ecological food requirements of the birds. It should be noticed that the food reservation policy does not account for periods of natural food shortage. In addition, the implicit assumption that the ecosystems of the Wadden Sea and Oosterschelde can return to the state they had during the reference period, may be questioned.

3b. Are there indications that numbers of wading birds which do not feed on large shellfish have improved or declined? And are any such developments the result of shellfish fishing, of other human factors or of natural factors?

In the Wadden Sea, the number of knots has increased during the early 1990s. More recently, numbers have decreased. Both increase and decrease seemed primarily to occur in the open areas, but it is difficult to assign knots counted during high tide to low tide feeding areas. The number of several species of waders feeding primarily on worms has increased during the evaluation period. For most of these species, the increase occurred primarily in the areas open to cockle fishery. It cannot be excluded that the increase of worm-feeding waders is related to an increased density of some worm species as a result of cockle fishery.

3c. Are the effects of shellfish fishing 'significant' in terms of the Habitats Directive?

During the course of the investigations, the ministry of LNV decided that this last question will be addressed in the follow-up to EVA II: experts will be asked to judge if the new shellfishing policy complies with the EU directives.

4. If it is established that shellfish fishing has had any adverse effects, what additional measures could be taken to counter these effects?

It was decided by the ministry of LNV that this question should be addressed in the follow-up to EVA II.

1 Introduction

This report summarizes the results of the second phase of the scientific evaluation of the Dutch shellfish fishery policy (EVA II) and relates these findings to the results of other studies on the ecological impacts of shellfish fisheries in the Wadden Sea and elsewhere. The report begins by sketching the history of the problem, and setting out the policy and research questions. This is followed by an overview of results and findings. The most important results are then summarised again in a chapter with conclusions, followed by a chapter with recommendations. A glossary of terms and an overview of research reports are given at the end of this document. All reports are available from the internet site www.eva2.nl.

1.1 History of the problem

Until the start of the nineteen nineties, the mussel and cockle fisheries in the Dutch Wadden Sea were managed under a de facto open access regime (Steins, 1999). Regulations existed on the period during which fishing could take place and on the sizes that could be fished etc., but fishermen who possessed the required licenses could fish as many seed mussels and cockles as they pleased. This ended when the conflict between fishermen and conservationists started in the late 1980's. The conflict revolved around the question whether shellfish fishery was responsible for mass mortalities of shellfish-eating birds and the nearly complete disappearance of the intertidal mussel beds. In 1990 an attempt by the Dutch government to close large parts of the Wadden Sea for cockle fishery was judged unlawful by the president of the State Council, because Dutch fisheries legislation only provided for fisheries conservation measures and not for nature conservation measures (Keus, 1994). In 1991, the law was changed to allow nature values being taken into account. In 1993 the Dutch government implemented the Sea and Coastal Fisheries Policy (SCFP) after a period of consultation and heated discussions involving the industry, nature conservation groups, government authorities and the government's advisory boards (LNV, 1993b). This policy document set the direction for the national fisheries policy until 2003, when the policy was to be evaluated. The policy aimed at an integration of fishing activities and conserving natural values, where possible, and a separation of these two activities where necessary.

In retrospect, the development of a conflict between shellfish fishery and nature conservation can be seen as the natural outcome of two opposing trends. First, in the second half of the twentieth century, there was an increase in the environmental awareness of the general public, which culminated in giving the Wadden Sea 'nature' as its primary function. This began when the '*Landelijke Vereniging tot Behoud van de Waddenzee*' was erected in 1965 to combat plans to build two large dams connecting the Wadden Sea island Ameland to the mainland. The many plans to embank parts of the Wadden Sea, including the plan to embank the entire Wadden Sea to grow potatoes, were abandoned, following the report by Mazure (1974). In 1980, the

Dutch parliament accepted the ‘PKB-*Waddenzee*’ (planning decision for the Wadden Sea), which states that the prime goal is ‘to conserve, to protect and where necessary to repair the Wadden Sea as a nature area’ (Verbeeten, 1999). Second, the shellfishery itself also changed dramatically. In the course of the twentieth century sailing boats were replaced with engine-powered ships with ever-increasing fishing power (Dijkema, 1997). Cockle boats became so efficient that at the end of the nineteen eighties, they caught on average 60 tonnes of cockles (fresh weight) per day (Ens, 2003). Demand for shellfish increased due to the discovery of new markets, like the market for cockles in Spain. At the same time, the fishery remained essentially open access, as there were no limits on the total catch. It is well known that such open access fishery has a high risk of overfishing (Iudicello *et al.*, 1999; Hall, 1999; Ostrom, 1990; FAO, 1993), due to the so-called ‘tragedy of the commons’, first described by Hardin (1968)¹. This happened to the European flat oyster (*Ostrea edulis*) in the Wadden Sea. The European flat oyster disappeared from the Wadden Sea in the first half of the twentieth century (Dijkema, 1997; Reise, 1998). In the final demise, other factors may have played a role of course. For the disappearance of the European flat oyster from the Dutch Wadden Sea, Dijkema (1997) concludes that ‘in addition to stock depletion, hydrographical changes caused by the closure of the southern Zuiderzee in 1932 may have played a role’². However, this is to be expected. Once stocks are seriously depleted, they become more vulnerable to environmental variation (Pauly *et al.*, 2002). Thus, whereas the technological possibilities of the shellfish fishery to exploit the ecosystem of the Wadden Sea steadily increased, public opinion and the law evolved towards accepting fewer and fewer negative impacts on the ecosystem.

As it happened, the conflict finally erupted around 1990 when shellfish stocks were low after a series of years with poor recruitment of shellfish, in itself a natural feature of shellfish populations (Beukema, 1982; Beukema *et al.*, 1993; Dare *et al.*, 2004). Detailed descriptions of the development of the conflict from the point of view of the social sciences are given by Steins (1999) and Verbeeten (1999). A detailed ecological documentation for the Balgzand area is provided by Beukema (1993) and Beukema & Cadée (1996) and for the area around Griend by Piersma & Koolhaas (1997) and Piersma *et al.* (2001). Especially the disappearance of the intertidal mussel beds made an impression on scientists. In the words of Beukema (1993): ‘Large mussel beds disappeared in areas where they had been present since time immemorial. Mussels survived only on culture plots, on a few very small banks, which were apparently overlooked (Dankers & de Vlas, 1992), and locally on dikes (which were in some places illegally scraped for seed mussels)’. Damage to seagrass beds was reported by de Jonge & de Jong (1992). In this period there was also a noticeable increase in the mortality of common eiders, first properly documented by

¹ The notion that cockles or mussels can be overfished meets with scepticism. However, according to Dare *et al.* (2004) overfishing is the most likely explanation for the disappearance of the intertidal mussel beds in the Wash; see section 4.1.

² There are also examples of oysters being intensively fished, or even overfished, without going extinct. Culture of European flat oysters has a long tradition in the Dutch Delta area for instance. Why some oyster populations are more susceptible to overfishing is not known, but could be related to the substrate. According to de Vlas (pers. comm.) wild European flat oysters depended in the Wadden Sea on banks of dead shells.

Camphuysen *et al.* (2002), and to a lesser extent of oystercatchers (Camphuysen *et al.*, 1996). These mass mortalities among birds that depend on large cockles and mussels gave rise to intense public debate.

In the Oosterschelde, fishermen and nature conservationists initially joined forces to protect the area. Plans to close of the Oosterschelde estuary from the sea by a dam for coastal protection and to create fresh water lakes for agriculture provoked discussions and resistance in society. After large scale concerted protests of fishermen together with nature conservationists the plan changed dramatically in the course of the 1970s and eventually the tidal system was maintained by the construction of a storm surge barrier in the mouth of the Oosterschelde by 1987 (Nienhuis & Smaal, 1994). Conservation of tidal ecosystems for both natural values and fishery is now the main policy aim of the Oosterschelde.

1.2 The sea and coastal fishery policy introduced in 1993

The Ministry of Agriculture, Nature and Fisheries had already closed areas to fishing on several occasions since the end of the eighties to protect the benthic fauna and the bird populations. The Sea and Coastal Fisheries Policy Document was published in 1993 and has since formed the basis for fisheries policy (LNV, 1993b). The policy applies to the Wadden Sea and the Oosterschelde and rests on three keystones: closed areas, food reservation and co-management:

1. Permanently closed areas are aimed at nature management and restoration of important habitats, monitoring and research. When selecting these areas account was taken of the location of seagrass fields. In the Wadden Sea, where the mussel beds had disappeared at the start of the 1990s, the aim is to re-establish 2000 to 4000 hectares of stable mussel beds. For this purpose additional areas have been temporarily closed to fisheries in 1999. The various closed areas are depicted in Figure 1 for the Oosterschelde and in Figure 2 for the Wadden Sea. For seagrass beds the aim is not a fixed target, but maximal restoration.
2. The policy of food reservation is aimed at maintaining numbers of birds feeding on shellfish at the level of the nineteen eighties. Since shellfish fishing is restricted or suspended when the shellfish stocks are in danger of excessive decline, this policy must prevent extra food shortages for wild birds in the lean years.
3. In the case of co-management the government delegates a part of its responsibility for the implementation of policy to the fisheries sector. For this purpose the government and the fisheries sector have entered into binding agreements concerning the management of the shellfish stocks in the open areas. Under co-management the fisheries sector is self-regulating in terms of enforcement and penalties. The sector draws up fishing plans, which require among other things that existing seagrass beds must never be fished, that mussel beds must never be fished by cockle fishermen and that the intertidal mussel beds can only be fished by mussel fishermen under very specific conditions.

The scientific basis for the targets and reference values with regard to shellfish fishery in the Sea and Coastal Fisheries Policy is not specified in the policy document itself, or in later policy documents. The calculations underlying the policy of food reservation are to be found in an unpublished document of the ministry (LNV, 1993a); see Ens (2000). The target of 2000-4000 ha stable intertidal mussel beds for the Dutch Wadden Sea is derived from the habitat map published by Dijkema *et al.* (1989), which is based on aerial pictures taken in the late 1960s and 1970s; see also (Dankers *et al.*, 2003).

On the basis of an interim report in 1998 (LNV, 1998) and new observations in 1999 and 2000 it was decided to take additional measures in order to enhance the restoration of mussel beds in the Wadden Sea and to improve the food availability for eider ducks in the Wadden Sea and for oystercatchers in the Oosterschelde estuary. Additional closure of 5% of the intertidal Wadden Sea area for cockle fishery (and 10% for mussel fishery) aimed at the development of mussel beds. The observation was that mussel bed restoration was slow and on the basis of a habitat model the areas with a relatively high potential were closed in 1999 for fishery. High mortality of eider ducks in the winter 1999/2000 provoked discussion and further analysis of food availability and other possible causes. On the basis of a review of mortality factors and an evaluation of the policy of food reservation (van den Berk *et al.*, 2000; Ens, 2000) new measures were taken in order to prevent food shortage. These included concerted reservation of different prey stocks and reservation of subtidal food stocks (Table 1). For the Oosterschelde estuary a continuous decline of oystercatchers provoked an interim analysis that showed potential food limitation, also because most intertidal mussel stocks have disappeared due to changes in culture practice (Bult *et al.*, 2000). In 1999 a temporary food reservation measure was taken by the ministry (threshold 5 million kg flesh), and in 2000 food reservation was set at 4.1 million kg (Table 1).

Apart from fishing for shellfish, the Sea and Coastal Fisheries Policy also applies to fishing for demersal and pelagic fish and shrimp in Dutch coastal waters and the North Sea. An evaluation of the entire policy was recently completed by van Geffen *et al.* (2002). The following three main conclusions were drawn:

1. Measures to control quota and to prevent illegal landings have proven effective.
2. Management of commercial stocks has been little effective and has hardly contributed to an improvement of the situation.³
3. Measures to develop nature values in the Wadden Sea were initiated, but the effectiveness has proven limited.

³ Close reading of the document suggests that this conclusion applies specifically to the fish stocks and not to the shellfish stocks.

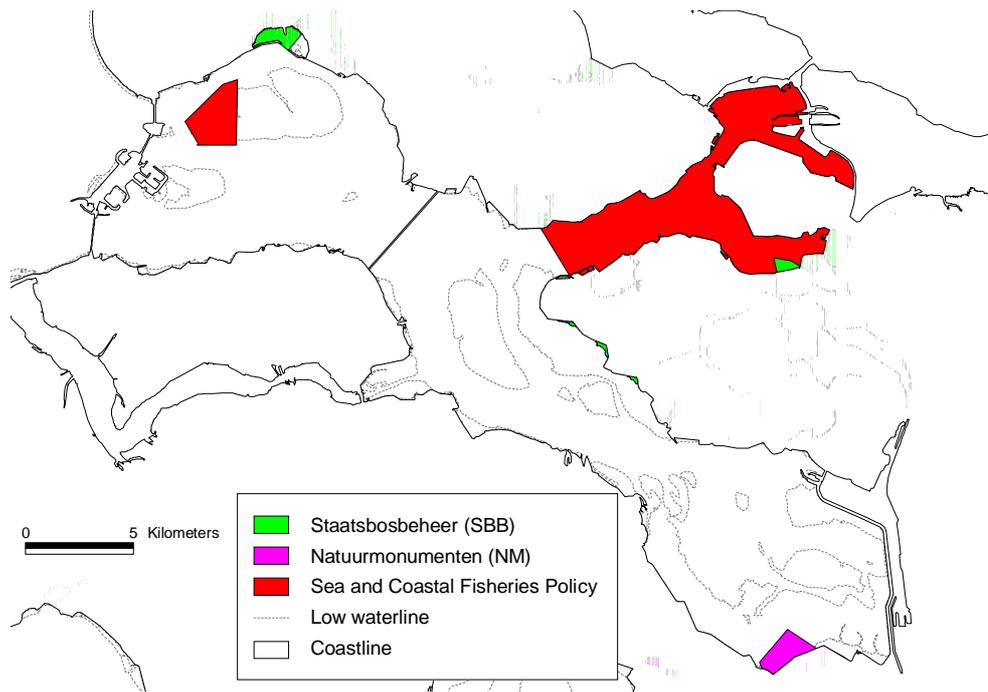


Figure 1: Areas closed to cockle fishery and mussel fishery in the Oosterschelde. Areas that were only closed in some of the years are not indicated. From Kamermans et al. (2003a).

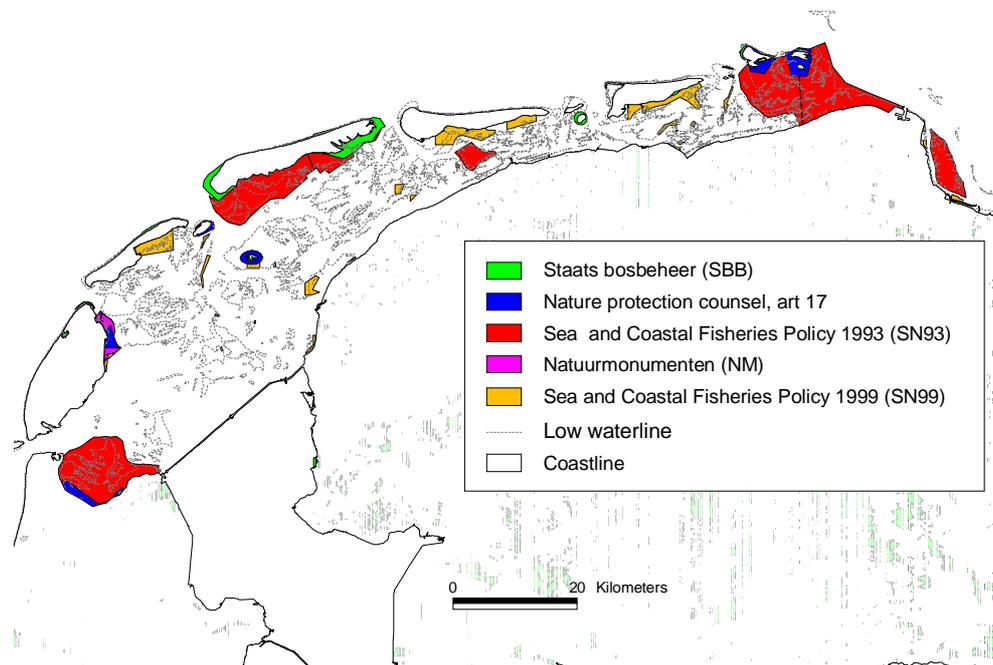


Figure 2: Areas closed to cockle fishery and mussel fishery in the Wadden Sea. Closure of areas by SBB and under article 17 took place in 1980. Most of the areas permanently closed in 1993 under the Sea and Coastal Fisheries Policy (SN93) were last fished in 1990, including the areas closed by Natuurmonumenten. Some of the areas closed in 1999 under the Sea and Coastal Fisheries Policy (SN99) were fished in 2002. From Kamermans et al. (2003a)

Table 1: Food reservation threshold in Wadden Sea and Oosterschelde in million kg flesh. For cockles the amount applies to cockles aged 1 year or older and in densities of at least 50 cockles per m². Food reservation policy was changed for the Oosterschelde in 1999 and 2000 and for the Wadden Sea in 2001. Since the last change there is also food reservation in the subtidal areas of the Wadden Sea, but intertidal stocks of cockles and mussels are exchangeable (*), as are sublittoral stocks of cockles, mussels and *Spisula* (**).

			1993- 1998	1999	2000	2001- 2003	
Wadden Sea	tidal flats	cockles	7.6	7.6	7.6	*	
		mussels	2.5	2.5	2.5	*	
		total	10.1	10.1	10.1	10.0	
	subtidal	cockles	0	0	0	**	
		mussels	0	0	0	**	
		<i>Spisula</i>	0	0	0	**	
		total	0	0	0	8.6	
	Oosterschelde	tidal flats	cockles	2.04	5.0	4.1	4.1

1.3 Protection of the Wadden Sea and Oosterschelde

The political, management and legal context within which shellfish fishery has to be weighed against nature conservation values is quite complex (LNV, 1998). Many international treaties have been signed, like the Ramsar convention and the African Eurasian Waterbird Agreement. Yet, there seems little doubt that the EU Birds Directive and the EU Habitats Directive are legally the most binding. The areas that fall under these directives are called Special Protection Areas (SPA's) and are depicted in Figure 3. According to the directives, member states should take care that the quality of the natural habitats and the habitats of species in the SPA should not deteriorate and there should be no disturbing factors for the species for which the SPA was designated. Human usage is allowed, but should not have significant negative impacts on the habitats or the species. The problem is that there exists no clear and simple operational definition of what constitutes a significant negative impact. Furthermore, it appears that Dutch laws have not sufficiently incorporated the legal framework of the directives (Goedhart, 1998). Recently, the Dutch *Raad van State* has asked the European Court to clarify a number of issues with regard to the EU Habitats Directive. The European Court has not made a final decision yet.

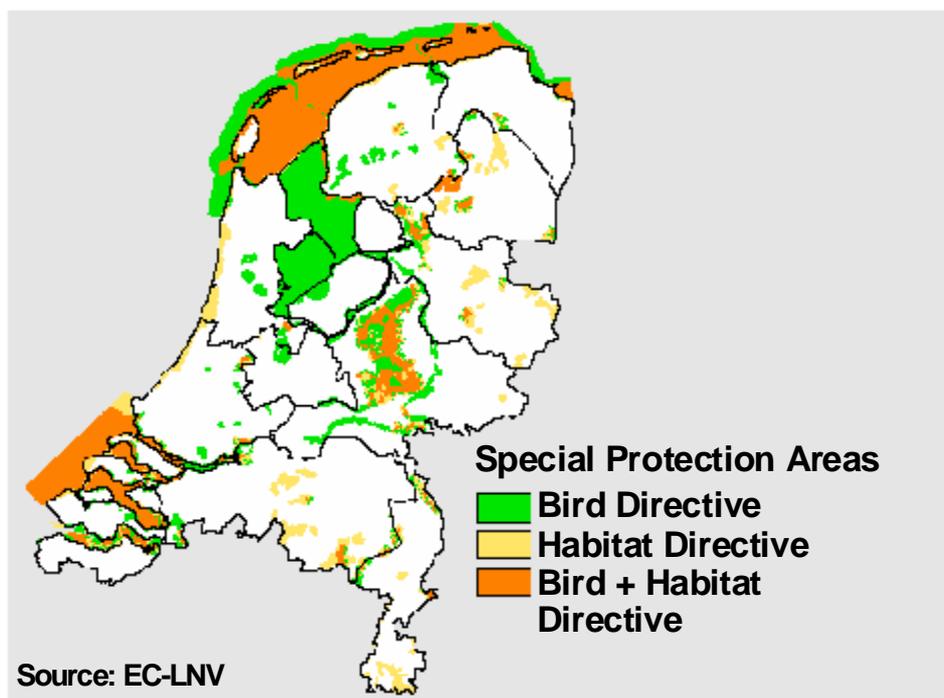


Figure 3: Areas in the Netherlands that fall under the EU-Birds directive, the EU-Habitats directive, or both. Source: EC-LNV.

1.4 Translation of policy questions into research questions

From the outset, the new shellfish fisheries policy has been supported by research. The evaluation research is intended to provide clarity concerning the nature and scale of the impact of shellfish fishing on the nature values in the Wadden Sea and Oosterschelde. It must take place against the background of ‘natural’ developments, independent of shellfish fishery.

An initial evaluation was carried out in 1998 (LNV, 1998). The results provided sufficient grounds for adjusting policy, but many questions remained unanswered. A plan for further research was therefore drawn up in the same year: EVA II. The policy questions formulated in the project plan (LNV & VW, 1999) were translated into research questions (Ens *et al.*, 2000a; Ens *et al.*, 2000b). The development of this plan involved not only the Ministry of Agriculture, Nature and Food Quality, but also the Ministry of Transport, Public Works and Water Management and the main nature conservation and fisheries organisations

The second evaluation research process began in 1999 and ran until 2004. The scientific research under EVA II is intended to produce adequate data on the impact of recent policy. This is required for decision-making on future shellfish fisheries policy. Attention has been given not only to the objectives and measures of the Structure Document and the impact of shellfish fishing, but also to the development of the carrying capacity of the Oosterschelde and the Wadden Sea for shellfish and shellfish-eating birds.

The main policy questions for EVA II were:

1. What are acceptable effects of shellfish fishing on the benthic biotopes of stable mussel beds, intertidal flats, cockle beds and seagrass fields? What are acceptable effects on birds which feed on the shellfish and are dependent on the biotope in the coastal waters?

This policy question gives rise to two concrete research questions:

- a) How and to what extent do the different forms of shellfish fishing impact on the important benthic biotopes?
- b) How and to what extent does shellfish fishing affect the food supply of oystercatchers and eider ducks, which feed on large shellfish, and other wild birds which are dependent on these biotopes?

2. One measure currently in use is the closure of areas to fishing. The main aim of this is to restore the most important benthic biotopes, specifically the intertidal mussel beds and seagrass fields. Another existing policy measure is that of food reservation. Have these measures produced the desired effect?

This gives rise to the following research questions:

- a) Has the area of intertidal mussel beds been restored to the desired level? If not, is that due to shellfish fishing, other human impact or natural factors?
- b) Have the seagrass fields recovered to the maximum possible extent? If not, is that due to shellfish fishing, other human impact or natural factors?
- c) Are the methods previously used to calculate the food requirements of shellfish-eating birds correct?
- d) How do the observed numbers of birds compare with the target or reference numbers?
- e) How can any discrepancies in these numbers be explained?

3. Is the result of effects and measures such that the Netherlands meets its international obligations under the EU Birds Directive and the EU Habitats Directive? What can we learn from the evaluation of current policy and what possible guarantees are there for the future?

Research questions:

- a) Is the current food reservation policy sufficient to prevent shellfish fishing in the long term having a detrimental effect on populations of shellfish-eating birds?
- b) Are there indications that numbers of wading birds which do not feed on large shellfish have increased or declined? And are any such developments the result of shellfish fishing, of other human factors or of natural factors?
- c) Are the effects of shellfish fishing 'significant' in terms of the Habitats Directive? During the course of the investigations, the ministry of LNV decided that this last question will be addressed in the follow-up to EVA II: experts will be asked to judge if the new shellfishing policy complies with the EU directives.

4. If it is established that shellfish fishing has had any adverse effects, what additional measures could be taken to counter these effects?

It was decided by the ministry of LNV that this question should be addressed in the follow-up to EVA II.

1.5 Research program and methods employed

The research program developed at the start of the project, provided only a rough outline of the individual projects (Ens *et al.*, 2000b). As it proved difficult, especially at the start of the project, to find sufficient financial resources to carry out the entire program, individual projects were prioritized and described in more detail, keeping in mind the available budget. Project proposals of individual projects were submitted to the steering committee EVA II for comments. Prioritization of individual projects was also discussed in the steering committee.

Ideally, the effects of shellfish fishery should have been investigated on a strictly experimental basis (Hall, 1999). It is well known how such impact studies should be designed, e.g. Underwood (1996). For various reasons this proved impossible. It was very clear that (1) fishermen have no interest in accepting closure of open areas as part of an experiment⁴, (2) conservationists have no interest in accepting experimental fishing in closed areas and (3) policy makers did not have the legal means, or the political will, to close or open areas, just for the sake of science. Two EVA II projects where it was nonetheless attempted to apply an experimental setup attest to this. A detailed comparison of areas open and closed to cockle fishing proved only possible on one location south of Ameland (Ens *et al.*, 2004). Furthermore, the selection of the closed area was not random, but based on the suitability for the development of intertidal mussel beds. The only true experiment was a test of the so-called 'Jan-Louw hypothesis', which states that fishing of unstable beds of seed mussels may help to stabilize these beds (Smaal *et al.*, 2003). Conservation organizations fought the permit for the experiment, thereby delaying the onset of the experiment by a week, but lost the case in court.

Most of the research carried out as part of EVA II consisted of analysing and combining data series collected for other reasons. Comparison of areas open and closed for fishing served as a quasi experiment. Apart from statistical analysis of the data, mathematical models were developed and employed to investigate causal relationships. In several studies additional data were collected for the specific purpose of EVA II. This included analysis of historical records of mussel beds from fishermen and fishery inspectors (van Stralen, 2002), analysis of historical photographs for the occurrence of mussel beds (Dankers *et al.*, 2003), sampling the sediment to obtain recent estimates of silt content (Zwarts *et al.*, 2004), sampling

⁴ When Hiddink discovered that his study plots were on a cockle bed that was about to be fished, he asked the fishermen not to fish his study plots, which they did. This then became an unintended experiment, giving (Hiddink 2003) the opportunity to study the effect of cockle fishing in a more or less experimental setup.

benthic invertebrates on fished and unfished cockle beds (Leopold *et al.*, 2003a), measuring sediment, benthic fauna and bird densities in a fished and unfished control site (Ens *et al.*, 2004), measuring cockle abundance in autumn to check the extrapolation procedure from the spring survey (Kamermans *et al.*, 2003b) and experiments on the food choice of common eiders (Ens & Kats, 2004). Below, we will provide a short description of the various data sets and models and give the references to more detailed accounts.

1.5.1 Abiotic information

Data for weather variables were obtained from the KNMI. Data on height, average exposure time, orbital speed at a given wind direction etc, including daily measurements of high tide and low tide at various stations, were obtained from the RIKZ. Most of these data were provided as GIS maps, where some interpolation procedure was used to arrive at a map covering the entire area. For the sediment composition of the top layer of the intertidal flats in the Wadden Sea, Zwarts digitized a huge number of sample data and requested additional samples from areas poorly covered. He subsequently constructed calibration curves to correct for the many different ways in which these sediment samples had been analyzed (Zwarts *et al.*, 2004).

1.5.2 Black box data and shellfish landings

Shellfish landings were obtained from Productschap Vis. Data for landings of consumption sized mussels are available from 1936 onwards (Dijkema, 1997; Smaal & Lucas, 2000). Catches of mussel seed must be registered since 1991 (Bult *et al.*, 2003a). For the years 1984-1990 Dankers obtained estimates of the mussel seed catches from questionnaires filled in by the fishermen (Dankers & Zuidema, 1995; Dankers *et al.*, 2003). No systematic data are available on the transport of mussels between culture lots, but civil servants from the ministry of LNV have monitored the mussels stocks on culture lots on a regular basis since 1982. These data were digitized (Bult *et al.*, 2003b).

Data for cockle landings are available from 1949 onwards, although for some early years data are missing (Dijkema, 1997). Detailed catch statistics of cockles harvested by suction dredges are available from 1977 onwards (Kamermans *et al.*, 2003c). Information on cockles fished by hand gatherers is incomplete, but the landings are small, compared to the landings of cockles obtained by suction dredging (Kamermans *et al.*, 2003c). Detailed information on the location of cockle catches is obtained from questionnaires since 1992 (Kamermans *et al.*, 2003c).

Since the early 1990s, cockle boats have been equipped with black boxes, which monitor the location of the boats. During fishing, when the pumps are on, the exact location of the boat is registered every minute. An independent organization, DCI electronics, processes the data. Individual registrations were used in some projects,

but more commonly, the area fished was calculated for squares of 2.11 ha. Details on calculation procedures and data selection (so-called ‘false’ registrations were excluded) are given by Kamermans *et al.* (2003c). A fished location consists of areas touched one or more times by the dredge, and areas not touched at all (Figure 4). Assuming that within an area fishing is randomly distributed the area actually touched can be calculated from the black box data (Kamermans *et al.*, 2003c). On the one hand, pictures like Figure 4 suggest the assumption of fishing being randomly distributed may well be true. On the other hand it is clear that the size of the area matters (Kamermans *et al.*, 2003c). When the area is large, only part of it may be covered by cockle beds. As a result, fishing will be aggregated and not randomly distributed, because only the cockle bed will be fished. Similarly, areas may become so small that a single black box recording may represent an area that is larger than the area under investigation. Despite these problems, the one case where the calculations were validated with measurements on the number of cockles that disappeared due to fishing, we observed a good fit (Figure 5).

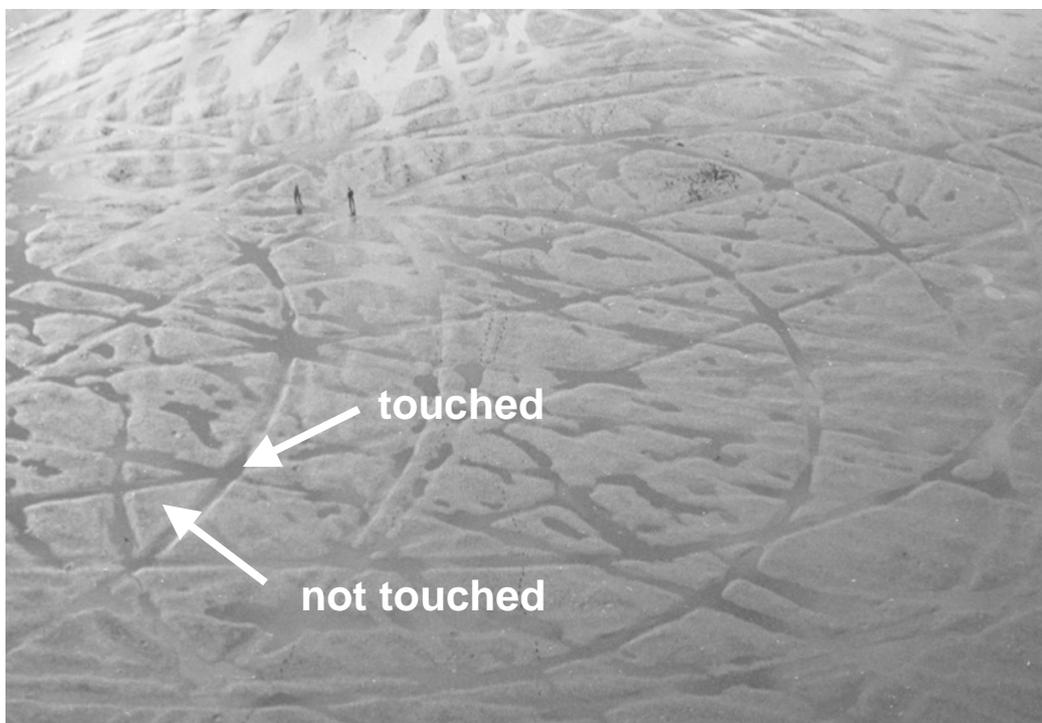


Figure 4: Aerial photograph of tracks left on the mud flats directly after suction dredging for cockles. Two humans are visible at the top left. Arrows indicate an area touched several times by the dredge and an area not touched at all. Photo by Jaap de Vlas.

On mussel boats, black boxes have been installed since 1996 (Kamermans *et al.*, 2003c). Contrary to cockle boats, mussel boats do not have a device whose activity can be used to determine unambiguously whether the boat is fishing or not. Consequently, the activity of the boat is determined from the sailing speed. It is assumed that speeds between 1.3 and 7 miles per hour represent fishing. During fishing the location of the boat is registered every 6 seconds. As yet, it has not been attempted to gauge the area fished from these registrations.

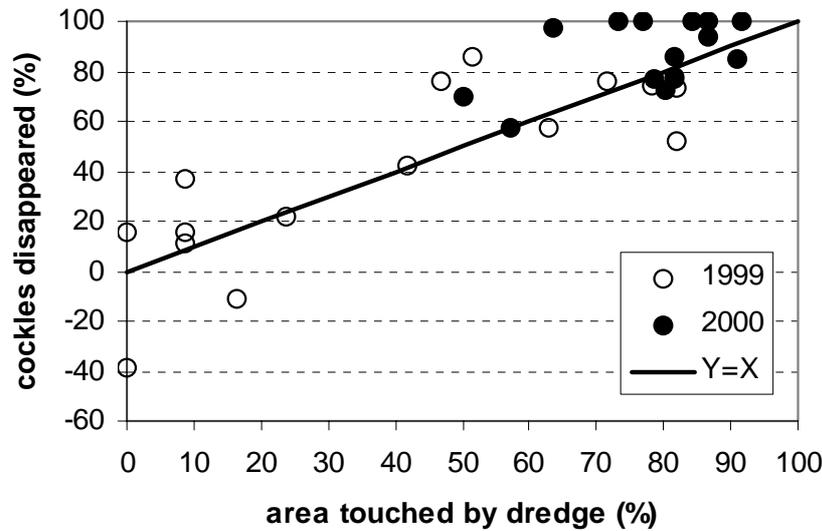


Figure 5: The measured decrease in cockle density (%) plotted against the decrease predicted (%) from the surface fished as calculated from the black box data. Each dot relates to a study square of 50 by 50 m². From Ens *et al.* (2004).

Some illegal fishing occurred during the study period, but it was assumed that the magnitude was so small compared to the legal fishing for which data was available, that it could be ignored in the analysis of the data.

1.5.3 Shellfish surveys

Since the early 1980s, the cockle fishermen have mapped the location of cockle beds in early spring. These maps were digitized (Zwarts *et al.*, 2004). The cockle bed areas estimated from these maps compared favourably to the areas estimated on the basis of the RIVO surveys, but small differences existed (Kamermans *et al.*, 2003b). The fishermen tended to underestimate the surface of cockle beds in permanently closed areas by on average 25%.

RIVO has started extensive surveys of shellfish stocks since 1990 in Wadden Sea and Oosterschelde and since 1992 in the Western Scheldt. A detailed description of the methodology and an estimate of the precision of each of the sampling programs is provided by Bult *et al.* (2003a) and Kamermans *et al.* (2003b). The results are summarized in Figure 6. Precise estimates may still be biased. The cockle stocks in September were extrapolated from the survey in May using a procedure developed by van Stralen (1990). Whether this estimation procedure provided an unbiased estimate of the September stock was tested by resampling selected areas in 1996, 1997, 2000, 2001 and 2002. It appears that the estimates were biased in some years, because growth was overestimated, especially when the stock was high (Kamermans *et al.*, 2003b). As a result, the total stock was overestimated. On the basis of these findings, a new extrapolation procedure was developed.

To arrive at estimates of shellfish stocks before 1990, several methods were adopted. Stocks of sublittoral mussels in the Wadden Sea were estimated from the landings of consumption-sized mussels at the auction in Yerseke (Bult *et al.*, 2003b). Stocks of cockles in the Wadden Sea were estimated from an extrapolation of the stocks measured on the Balgzand since the 1970s by Beukema (Beukema, 1974; Beukema, 1982; Beukema *et al.*, 1993). The extrapolations before 1990 have been compared with three surveys in the whole Wadden Sea during 1970 – 1974 and in 1977 (Beukema, 1976; Beukema *et al.*, 1978), and in 1980 (de Vlas, 1982). During these years, an extrapolation of the Balgzand data fitted rather well with the cockle stocks in the western Wadden Sea and the whole Wadden Sea. When the extrapolation data during the period 1990 – 2002 were compared to the comprehensive RIVO surveys for the 1990s, there was a marked discrepancy during the years 1990-1995, so the procedure before 1990 may have caused inaccuracies (Kamermans *et al.*, 2003b). Stocks of cockles for the Oosterschelde before 1990 were estimated from a variety of sources, which could not be validated (Bult *et al.*, 2000; Bult & Kesteloo, 2001; Kater & Baars, 2002).

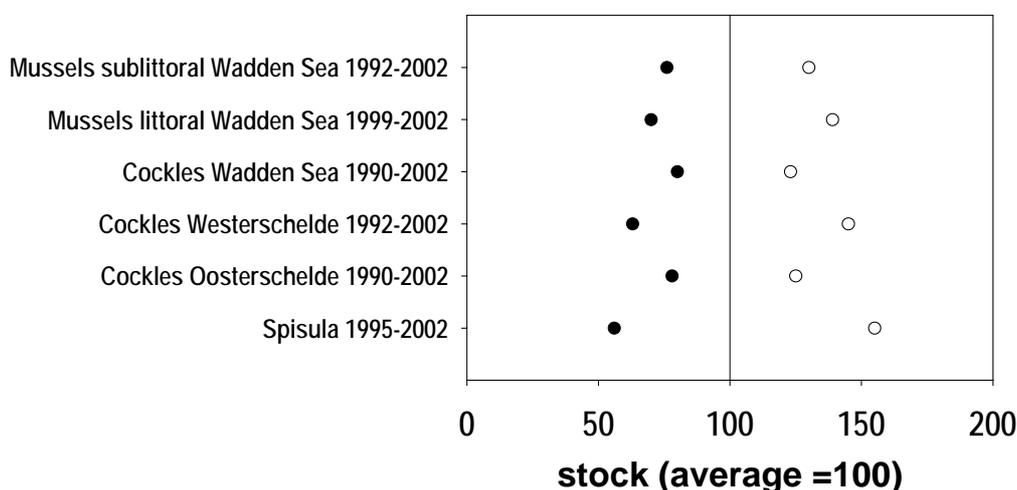


Figure 6: Estimated precision of the various shellfish stock estimates derived from the RIVO surveys. Depicted are the average 95% confidence limits based on a permutation test with the original sampling data. From Bult *et al.* (2003a).

1.5.4 Bird numbers and bird mortality

Common eiders are most efficiently counted from an airplane. The first count covering the entire Wadden Sea, where most common eiders winter as a rule, dates from 1967. Data on counts between 1967 and 1992 were taken from the literature (Ens & Kats, 2004). Since 1993 midwinter counts are performed on an annual basis by the RIKZ (Berrevoets & Arts, 2003). In recent years, additional counts have been performed by Alterra (de Jong *et al.*, 2002; de Jong *et al.*, 2003).

Oystercatchers (and other waterbirds) are counted during high tide on a monthly basis in the Delta area, including the Oosterschelde, since 1989 as part of MWTL by

the RIKZ (Berrevoets *et al.*, 2003). Older counts, which are available from 1978 onwards, have been analyzed as part of EVA II, after correcting for missing counts through imputing (Rappoldt *et al.*, 2003b). Compared to the Delta area, the frequency of counts in the Wadden Sea covering the entire area has been decidedly lower, on average three times a year (Meltofte *et al.*, 1994; van Roomen *et al.*, 2003).

The longest uninterrupted counting series for the Wadden Sea (from 1973/1974 onwards) is available for the month of January. A logical choice is therefore to restrict analyses of bird numbers to this month (Leopold *et al.*, 2003b; Verhulst *et al.*, 2004). However, January counts have a problem due to ice winters. When the mud flats become covered with ice during a sufficiently long period of frost, a large number of oystercatchers may leave the Wadden Sea to winter elsewhere (Hulscher, 1989; Hulscher *et al.*, 1996; Camphuysen *et al.*, 1996). During the past century, such hard-weather movements from the Dutch Wadden Sea have occurred in at least 10 of 92 years (Hulscher *et al.*, 1996). Very low counts of oystercatchers in the winters of 1986/87 and 1996/97 are due to hard-weather movement and not to a change in the number of oystercatchers that arrived in autumn to spend the winter in the area. One solution is to include integral counts for other months in the imputing exercise. To the 29 integral counts for January, 33 counts during other months in the period August-December can be included (Leopold *et al.*, 2003b). This provides only a partial solution. For the winter of 1996/97 there were additional counts in August and December, so the new estimate is clearly higher. However, for the winter of 1986/87 only the January count is available, so the procedure makes no difference.

Apart from integral counts of the whole Dutch Wadden Sea, there are many sites throughout the Wadden Sea that are counted on a much more regular basis. These counts can also be included in the imputing to yield an estimate of the number of oystercatchers in each site in each month. For the studies of Leopold *et al.* (2003b) and Rappoldt *et al.* (2003a) counting data of individual counting sites were first clustered into larger areas and then imputing was done for these larger cluster areas. More recently, SOVON has performed imputing directly on the individual counting sites, without first clustering these sites into larger areas (van Roomen & van Winden, pers. comm.). Including the counts of sites counted more regularly leads to estimated numbers that vary smoothly over the years. Such gradual changes in numbers are what one would expect for a long-lived species like the oystercatcher. We therefore conclude that imputing using all counts offers the best estimate of the number of oystercatchers deciding to spend the winter in the Dutch Wadden Sea. The precise estimate of the total number depends on the details of the imputing and this requires further study.

A distinction was made between areas open for fishing, areas closed for shellfish fishing and areas that could not be classified (Figure 7). Since bird counts take place during high tide, the assignment to the low tide feeding areas had to be based on expert judgement and is open to further improvement. Especially for species that travel long distances to reach the feeding grounds, errors are likely.

Mortality of common eiders and oystercatchers was inferred from beached bird surveys (Camphuysen *et al.*, 2002). Imputing was employed to estimate the total number of dead birds per month per subarea; see Rappoldt *et al.* (2003a) for oystercatchers and Ens & Kats (2004) for common eiders. For the Oosterschelde the extensive ringing data on oystercatchers were analysed to estimate annual local survival (Rappoldt *et al.*, 2003c).

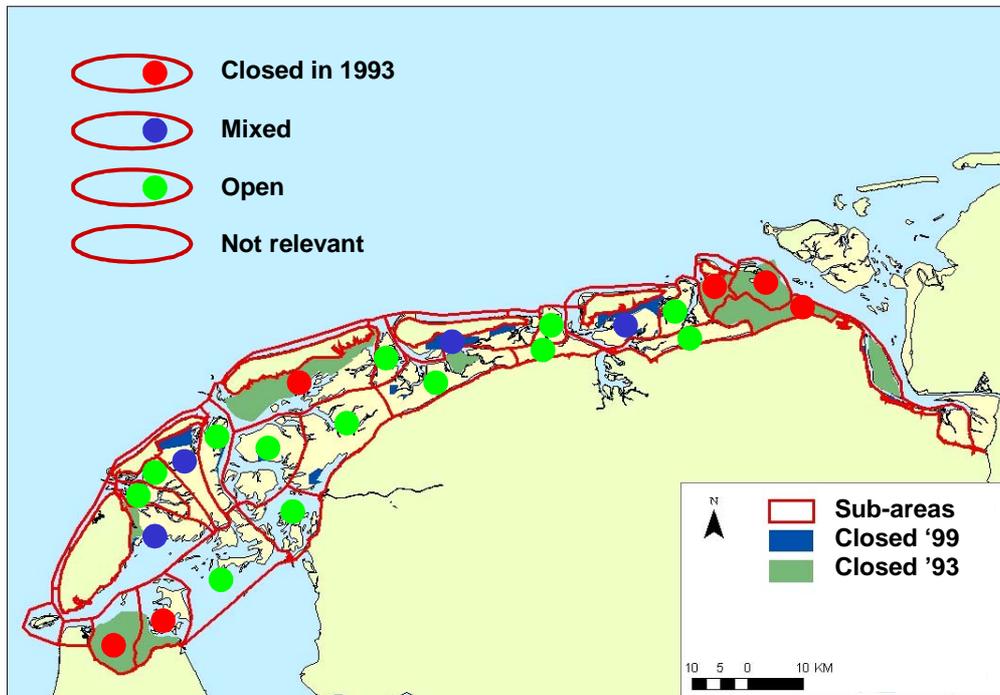


Figure 7: Intertidal areas corresponding to the main counting transects of SOVON. Indicated with a red dot are areas that have largely been permanently closed since 1993 (most of these areas were last fished in 1990). Indicated with a green dot are areas which have largely been open to shellfish fishery during the entire period. Indicated with a blue dot are mixed areas: some contain areas that were closed to fishing in 1999, while others contain a few patches permanently closed since 1993. Areas without a dot and indicated with a contour only, were not considered in the analysis. From Leopold *et al.* (2003b).

1.5.5 Prey choice of birds

The literature was surveyed to arrive at a classification of the prey choice of the birds feeding on the intertidal flats (Leopold *et al.*, 2003b). This allowed birds to be classified as mainly feeding on bivalves, worms or 'other prey', i.e. fish, crustaceans, gastropods etc. (Figure 8). Birds feeding on a combination of bivalves, worms and other prey were classified as having a mixed diet.

For the two species feeding on large bivalves, the common eider and the oystercatcher, the literature was also surveyed for information on factors affecting the profitability of the prey, like shell size, shell thickness etc. (Bult *et al.*, 2003a). The prey choice of oystercatchers has often been studied; see e.g. the review by Zwarts *et*

al. (1996b) and relevant chapters in Goss-Custard (1996), but much less is known for the common eider (Leopold *et al.*, 2001). Studies of captive common eiders were undertaken to improve the knowledge of the prey choice of this species (Ens & Kats, 2004).

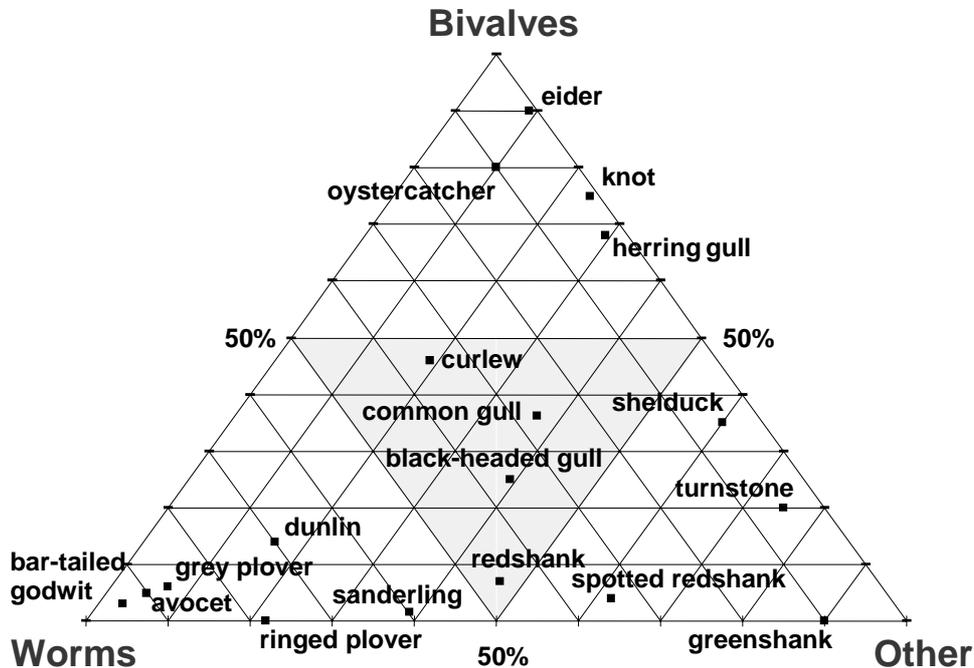


Figure 8: The diet of bird species studied is summarized in this triangle. For each species the diet is indicated as a single dot in the plane. The distance to each of the corners of the triangle indicates the relative importance in the diet of respectively bivalves (top), worms (bottom left) and other prey, like crustaceans, fish etc. (bottom right). The smaller the distance, i.e. the closer the dot is to the corner, the greater the relative importance of the particular group of prey. From Leopold *et al.* (2003b).

1.5.6 Modelling the prey choice and energy budget of common eiders

To gain a better understanding of the prey choice and energy budget of common eiders, a model was developed which integrated the published information on this species (Brinkman *et al.*, 2003b). The model constructs for a diving cycle the heat budget and the energy budget, including all relevant processes: food processing, diving, heating the prey, crushing the shell, heat losses during diving and resting and heat production as a result of muscular activity. The model calculates how many dives are needed to maintain energy balance. The model assumes that only a single prey item is taken during a dive. This assumption is probably wrong, but due to the high costs of crushing the shells (Nehls, 1995), compared to the cost of diving, it is assumed that the effect on the energy budget calculated by the model is small (Ens & Kats, 2004). The model was not validated with new measurements on the energy budget of the common eiders, as such measurements were not part of the EVA II research program. We used the model to calculate the profitability in terms of energy of different prey species and prey sizes and the associated daily energy budget.

In the absence of any quantitative information on the relationship between intake rate and prey density, nor for that matter on interference among feeding eiders, the generalized functional response (van der Meer & Ens, 1997) could not be modelled. Thus, it was not possible to construct a model predicting how a given number of eider ducks would distribute themselves over a given food supply and how they would subsequently deplete the prey.

1.5.7 Modelling the distribution and energy stress of oystercatchers

The Wader Energy Balance and Tidal Cycle Simulator WEBTICS model simulates the food uptake of oystercatchers and a distribution of the birds over exposed parts of tidal areas (Rappoldt *et al.*, 2003d). The mud flats are described on input as a number of spots which have a position, height and surface area. Spots may contain prey items characterized by type, weight and density. The program simulates tidal cycles and calculates the fraction of time the average and ideal bird has to spend feeding in order to meet its energy requirements (Figure 9). These foraging intensities are combined into a stress index for the winter. Besides historical data on weather, prey distribution, tides and fishing, there are bird and prey parameters on foraging, prey growth and energy conversion.

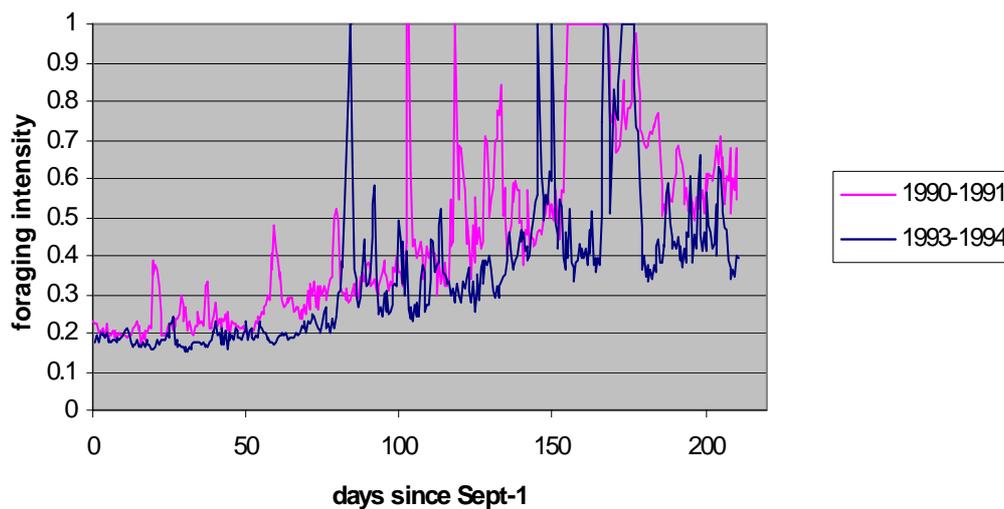


Figure 9: The foraging intensity is the fraction of available foraging time which the birds need to meet their food requirements. The graph shows simulated foraging intensities for area AMS (The Wadden Sea south of Ameland and Schiermonnikoog) in the course of the season. The intensities for the winter 1990-1991 are summarized by a stress index value of 0.42. The intensities calculated for the winter 1993-1994 lead to a stress index value of 0.25. After Rappoldt *et al.* (2003a).

Parameter estimates for the model were obtained from the extensive literature on the feeding ecology of the oystercatcher, e.g. Goss-Custard (1996) and Blomert *et al.* (1996). We included explicit equations of the functional response for cockles, mussels and Baltic tellins. Mussels and cockles are the two most important prey items during winter (Zwarts *et al.*, 1996b) and Baltic tellin is the only non-commercial shellfish species for which the RIVO surveys deliver a complete data set (Bult *et al.*,

2003a). The survey data on cockles and Baltic tellins could be matched easily to our equations on the functional response. This was not the case for mussels, where data were provided in a different format. In addition, the format for the Wadden Sea differed from the format for the Oosterschelde. As a result, our formulation in WEBTICS of the functional response of oystercatchers feeding on mussels leaves much to be desired. Since littoral mussel stocks were low in both the Oosterschelde and the Wadden Sea during the years for which we ran model simulations (1990-2001), the resulting error in the estimate of the ecological food requirement (see chapter 5) for oystercatchers feeding on cockles, will have been small. However, we could not use the model to estimate the ecological food requirement of oystercatchers feeding on mussels in a situation without cockles.

A small fraction of the diet during low tide was assumed to consist of other prey, like *Mya arenaria* and spat of cockles. It is known that cockle spat are marginal prey and intake rate of oystercatchers feeding on cockle spat is low, even when densities are very high (Zwarts *et al.*, 1996b); see also Figure 2.8 in Bult *et al.* (2003a). Oystercatchers are most likely to feed on marginal prey like cockle spat, when they are stressed for food. Furthermore, the RIVO surveys are in May when settlement of spat has not occurred yet. Thus, the policy of food reservation does not include cockle spat. For these reasons we did not attempt to estimate the density of cockle spat in year t from the density of first-year cockles in year $t+1$. This is not to say that efforts attempting to estimate the contribution of cockle spat to the diet are futile. On the contrary, gaining such estimates might increase our understanding of how oystercatchers survive (or do not survive) in years of food scarcity. Other marginal prey oystercatchers can feed on are earthworms and tipulids in the fields. This was included in the model as a fixed low intake rate the birds could achieve during high tide, except when the fields were frozen during a frost period.

The model was partially validated by comparing the cockle stocks calculated to remain at the end of winter, to the cockle stocks actually observed during the survey the next season for both the Oosterschelde (Rappoldt *et al.*, 2003b) and the Wadden Sea (Rappoldt *et al.*, 2003a). The results of these validations were encouraging as can be seen from Figure 10.

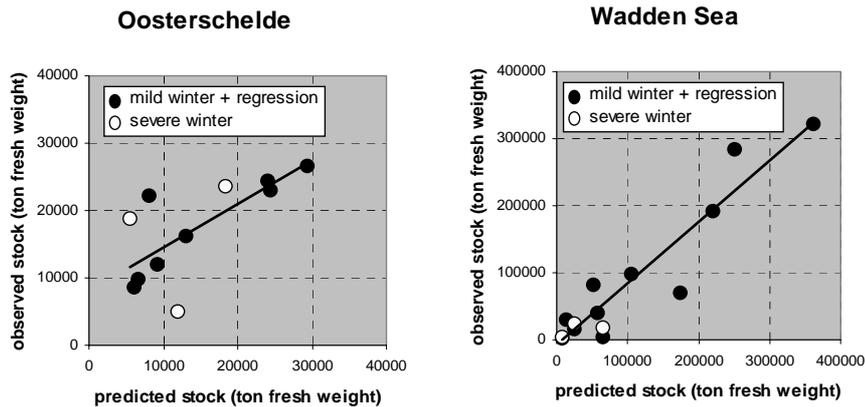


Figure 10: Cockle stock in spring (ton fresh weight) according to the RIVO-surveys, plotted against the cockle stock remaining at the end of winter according to the calculations with WEBTICS for (a) the Oosterschelde (Rappoldt et al., 2003b) and (b) the Wadden Sea (Rappoldt et al., 2003a).

1.5.8 Modelling cycling of nutrients in the western Wadden Sea

An exhaustive description of the EcoWasp model is provided by Brinkman & Smit (1993) and Brinkman (1993). The application for the EVA-II project is reported by Brinkman & Smaal (2003). Here we provide a brief outline. In EcoWasp, the western part of the Dutch Wadden Sea is divided into a number of compartments. Each compartment has a littoral, a sublittoral and a deep water part, each including sediment. External input from Lake IJssel, internal exchange between compartments and exchange with the open North Sea is described, all in terms of flows and concentrations of matter. In each compartment primary and secondary production, and degradation of organic matter is described, as is the exchange of matter between air and water and between water and sediment.

In the model, among other components, phosphate, nitrate, ammonium and silicate are described as dissolved components. For algae, a distinction is made between pelagic diatoms, non-diatoms and benthic diatoms. Detritus consists of several components, defined through their composition and breakdown rates. As fauna species, filter feeders (mussels) are implemented to represent all filter feeding shellfish (thus including cockles). Mussels thus serve as model organism in this case, and all results have to be seen in terms of mussel equivalents. Four age classes are distinguished, from the larval phase to the adult phase. Animals grow as a result of food uptake, and their numbers decrease as a result of mortality. The description of mortality is kept simple. The mortality rate constant is an allometric function of individual mussel mass in such a way that small mussels show a higher mortality rate constant than large mussels. Under poor food conditions, mussel numbers decrease faster than under rich conditions. Mortality is independent of other processes like fishery and reflects average conditions. In addition, mortality lumps 'normal' predatory activities of other animals with 'normal' weather conditions. Implementation of special predation mechanisms in the model, like birds for instance, would require additional mortality parameters.

In the sediment, several layers are distinguished, and exchange with the overlying water of dissolved components is computed following a zero- or first-order diffusion-reaction equation. Adsorption of phosphate and silicate onto sediment is part of the description. Sedimentation and biogenic deposition is steering the downward flow of solids, and resuspension of solids is wind-driven. An overview is given in Figure 11. The implementation of mussel sizes and numbers is crucial for the simulation.

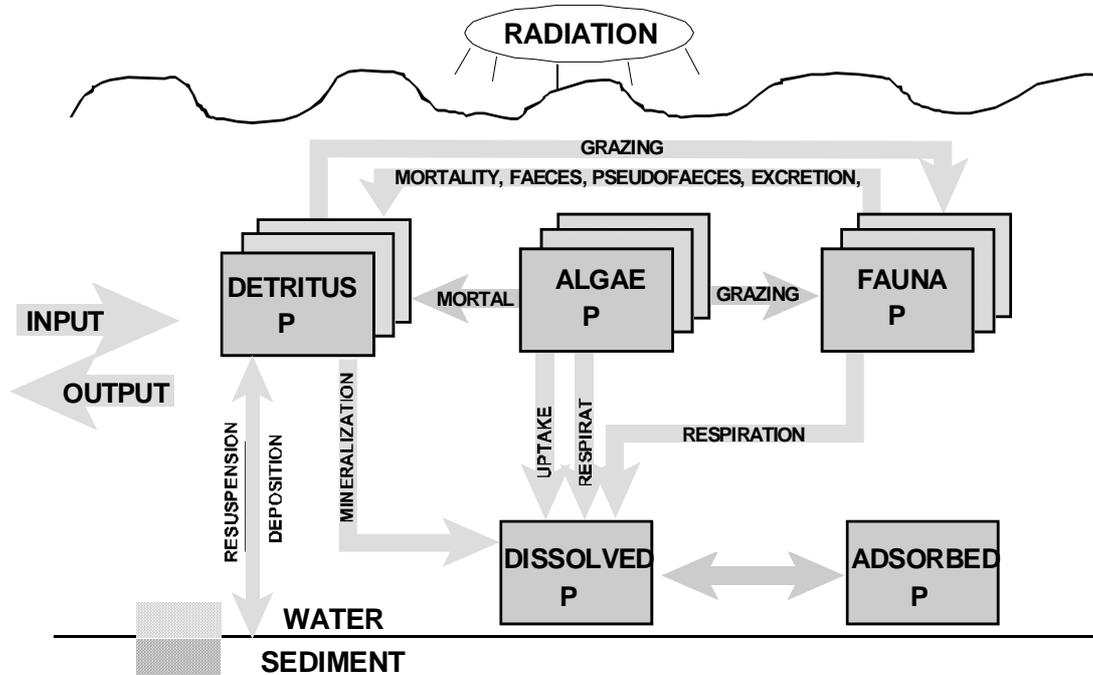


Figure 11: Overview of the EcoWasp ecosystem model. 'P' stands for all kinds of nutrients. All processes run in every compartment, and also in the sediment, if relevant. From Brinkman & Smaal (2003).

As a result of its construction, EcoWasp neither assumes a priori limitation of nutrients nor of light on primary production. Instead, the model uses Monod-equations to test each time step which nutrient is most limiting, and also what the light-limitation factor is according to a Smith-equation. For more details see Brinkman & Smaal (2003).

In order to assure that the model response indeed was a result of the external conditions, the model was run 14 years using the conditions for the first simulation year (1976) only. The results at the end have been used as starting conditions for the whole simulation, and by this, unsteady state problems at the start of the simulation were avoided as much as possible.

Since neither mechanisms leading to a very weak recruitment, nor processes causing high mortality of shellfish, like fisheries, storms, or ice winters, were an integral part of the model, the model computed maximum possible shellfish stocks. In order to simulate some sort of extraction, the model was also run with artificially low levels of shellfish. At a chosen date in each year, the shellfish stock in the model was reduced to a predetermined level. By doing this, grazing on phytoplankton was reduced, and

higher phytoplankton biomasses were found. According to the model, this may result in a 2 to 3 fold increase in phytoplankton content.

1.5.9 Comparing areas open and closed for fishing

1.5.9.1 Selection and size of closed areas in the Wadden Sea

Most of the areas that were permanently closed in 1993 under the Sea and Coastal Fisheries Policy, were last fished for cockles and mussels in 1990, when nearly the entire Wadden Sea was open for fishery. The areas were selected on the basis of the following criteria:

1. The use of tidal flats for long-term research and monitoring. This criterion led to the closure of the Balgzand-Breehorn area, the Piet Scheveplaat and a proposal to close the east part of the Andelbulten.
2. The presence of seagrasses (*Zostera marina* and/or *Zostera noltii*). This led to the closure of the flats south of Terschelling, the Hond and Paap and to the proposal to close the east part of the Andelbulten.
3. The point of view that at least one complete tidal basin or one complete watershed area between two tidal inlets should be protected, as an undisturbed reference area for nature protection.
4. A relatively virgin state of this larger area, as it should serve as reference area in the sense of the international Wadden Sea cooperation, as agreed upon in one of the preceding trilateral Minister's conferences on the Wadden Sea. In combination with criterion 3, this led to the selection of the tidal flats between the islands Rottumeroog and Rottumerplaat and the mainland coast. That area was considered as the most natural and untouched part of the whole Dutch Wadden Sea. A seagrass location was included in this area.
5. The closed areas should be bordered, as far as possible, by shipping lanes or larger gullies for easy recognition and control.
6. The closed areas should have a good distribution over the Wadden Sea.
7. The closed areas should contain a percentage of the potential shellfish stock that was proportional to the surface. For cockles, maps with cockle beds present in the preceding years were used. About 23% of the cockle beds had been present in the selected areas, which was judged a satisfactory match with a closure of 26%. About 28% of the mussel beds, as marked on the habitat maps for the Wadden Sea (Dijkema *et al.*, 1989) was present in the closed areas, which was also considered a satisfactory match.

It proved difficult to combine criterion 6 with the others. Selection of the tidal flats south of Schiermonnikoog and Simonszand (instead of Rottumerplaat / Rottumeroog) could have given a more even distribution over the total area, but the Schiermonnikoog area showed a very poor cockle stock in the preceding years, contained no seagrass and was far from untouched after the closure of the bordering Lauwerszee in 1970. But this part of the Wadden Sea was considered suitable for an extra closure in 1998 or 2003 (LNV, 1993b).

The total size of the closed areas was a political choice between the nature protection goals for the Wadden Sea on the one side and the social and economic benefits on the other. Another 14% was designated as potential additional closure area after 5 years (LNV, 1993b).

Earlier proposals exceeding 26%, were not put forward because they were considered unrealistic by the Ministry of Agriculture, Nature Conservation and Fishery. This taxation proved to be correct: the proposed 26% got barely enough support from the Dutch parliament.

As it happened, the intended 26% was not realised because the eastern half of the Andelbulten (criteria 1 and 2) was forgotten on the map with closed areas, but two very small areas near Texel and Griend, together less than 1% of the tidal flats in the Dutch Wadden Sea, owned by a nature conservation body ('Natuurmonumenten'), were closed as well. The end result was that 26% was permanently closed.

The additional closure of 14% of the tidal flats, south of Schiermonnikoog and Simonszand (LNV, 1993b), has never been carried out. Instead, in 1999, an additional surface of 5% of the Wadden Sea, spread over several locations, was closed for the cockle fishery (and 10% for the mussel fishery). These locations were chosen because of their high potential for the development of mussel beds, and were part of the measures that were taken to restore 2000 to 4000 ha of mussel beds. In 2002 part of the 5% area was opened for cockle fishery.

1.5.9.2 Comparability of open and closed areas in the Wadden Sea.

The selection of closed areas depended partly on the presence of seagrass. That criterion led to the choice of the area south of Terschelling, instead of one of the other islands, and of incorporation of the Hond en Paap in the Ems estuary. The area south of Terschelling fitted well in another criterion: the good distribution of the closed areas over the Dutch Wadden Sea. The incorporation of the monitoring plots, which were chosen to represent different parts of the Wadden Sea, was favourable for the selection of more or less 'normal' and representative areas. The check on the presence of cockle and mussel beds was important for the stakeholders involved, but at the same time indicated a good representativeness of the closed areas.

Although the selection process assured that shellfish stocks did not differ between areas that were permanently closed in 1993 and areas that remained open, a proper experimental treatment would have required a random allocation to the treatment 'open' or 'closed'. Lacking a truly experimental design, treating the open and closed areas as an experiment was the next best option. Leopold *et al.* (2003a) reviewed the evidence for systematic differences between open and closed areas. No such evidence was found, leading Leopold *et al.* (2003a) to the conclusion that comparing open and closed areas was justified. Table 2 summarizes the quantitative information that is available. The most important comparison is that between the areas permanently closed since 1993 (many of which were last fished in 1990) and the

other areas. Before closure, there were no differences in the silt content and the benthic biomass density. Cockle beds were slightly less common, whereas mussel beds were slightly more common than expected on the basis of relative area. There was no difference in the presence of habitat suitable for the development of mussel beds. However, according to Zwarts *et al.* (2004), the areas permanently closed in 1993 were on average 14 cm higher than the rest. This difference is related to the locations of the closed areas. Tidal flats near mainland and island coasts (the closed areas Balgzand, Terschelling, Texel) are higher than most flats in the middle of the Wadden Sea. Tidal flats in areas with larger tidal ranges in the eastern part of the Dutch Wadden Sea (the closed areas between Rottumeroog and Rottumerplaat and the Hond-Paap area) have higher levels too (Hoeksema *et al.*, 2004). Also, during the 1980s, the density of oystercatchers was higher in the areas that were closed in 1993, compared to the rest (Table 2). Perhaps, oystercatcher densities were higher due to the longer exposure time and/or the slightly greater presence of mussel beds. Other factors that might play a role are the presence of safe roosting sites, distance to the roost and possibilities to feed in the fields during high tide. Such factors can make mud flat areas that are similar with regard to food supply, dissimilar from the point of view of the oystercatcher.

Thus, on most accounts, the open and closed areas were comparable before closure. Various means were adopted to correct for specific habitat differences. Zwarts *et al.* (2004) made a pairwise comparison of closed areas adjacent to comparable open areas. In many other studies, sediment composition and height were included as variables correcting for habitat differences in comparisons of open and closed areas, e.g. Kamermans *et al.* (2003a) and Leopold *et al.* (2003a).

In 1999, an extra set of closed areas was chosen in an attempt to speed up the slow recovery of the stable mussel beds. The selected areas had the right combination of abiotic conditions to make them especially suitable for the establishment of mussel beds (Brinkman & van Stralen, 1999). Indeed, they contained a disproportionate amount of mussel bed area in the 1970s (Table 2). Although their share of cockle beds was as expected in the 1980s, they proved to be very rich in cockles in the 1990s (Kamermans *et al.*, 2003a), and were probably relatively rich in other benthic fauna as well. So these newly closed areas were clearly different from other areas in the Wadden Sea. As such, they presented a problem in our analyses comparing open and closed areas, e.g. Leopold *et al.* (2003a).

The overall conclusion is that open and closed areas that were selected in 1993 can be used for comparisons for most parameters in order to evaluate fishery impacts⁵.

⁵ The exact timing of the closure is important for statistical analyses. Maps of the closures in each year are provided by Kamermans *et al.* (2003a). The closed area around Rottumeroog, Rottumerplaat and Hond/Paap was already closed in the years 1988 and 1989. In 1990 LNV attempted to close the western part of the Wadden Sea, but was overruled by the *Raad van State*. Thus, the entire Wadden Sea was open to fishery in 1990. In 1991 the entire Wadden Sea was closed. In 1992 nearly all of the areas permanently closed in 1993 were closed, as well as some additional areas. Since the RIVO survey takes place in spring and fishery in autumn, the years 1990, 1991 and 1992 are our best estimates of the situation before closure. The estimates are not perfect, because a sizable part of the areas permanently closed in 1993, was already closed in 1988 and 1989.

Additional corrections for sediment and height enable comparisons in case of more specific questions. The closed areas that were selected in 1999 are not suitable for comparisons.

Table 2: Quantitative information on areas that were closed to shellfish fishery in 1993 (SN93), 1999 (SN99) and remained open, prior to the closure period in the 1990s. Areas closed by Staatsbosbeheer (SBB) and Natuurmonumenten (NM) before 1993 are lumped with the areas closed in 1993 and labelled SN93. For areas of intertidal flats, cockle beds, mussel beds and good mussel habitat (top 10%), the percentage area in each category is indicated. For oystercatchers calculated densities for closed areas are listed under SN93 and calculated densities for mix and open areas are listed under SN99+open.

	period	SN99		SN99	open	Source
		SN93	+open			
area intertidal flats		26%	74%	5%	69%	This study
cockle bed area	1980s	23%	77%	6%	71%	(Kamermans <i>et al.</i> , 2003a)
mussel bed area	1970s	28%	72%	12%	58%	(Dijkema <i>et al.</i> , 1989) (Leopold <i>et al.</i> , 2003a) using (Brinkman & Bult, 2003)
area good mussel habitat		25%	75%			(Zwarts <i>et al.</i> , 2004)
silt content (%)	1950s	2.44	2.49			(Leopold <i>et al.</i> , 2003a) using (Beukema, 1976)
Benthic biomass (gram AFDW/m ²)	1970s	13.1	13.4			
Density oystercatchers (birds/ha)	1980s	2.5	1.6			This study

1.5.9.3 Closed areas in the Oosterschelde

The aim of the closed areas in the Oosterschelde was nature protection, but cockle fishery should not be disadvantaged too much. Two areas were selected for permanent closure, together covering about 15% of the Oosterschelde tidal flat surface. It was considered that at least one of these areas should contain marketable cockles. For this purpose, a small area on the west side of the Roggenplaat tidal flat in the mouth of the Oosterschelde was selected. The other closed area (the Noordtak) is relatively large, with gullies and tidal flats but with relatively slow cockle growth. The presence of sea grass was not used as argument for the permanently closed areas; known seagrass sites were inspected each year before the fishing season and closed for fishery when seagrass was present. Apart from these permanently closed areas, there were also areas that were closed in some years, but not in other years (Kamermans *et al.*, 2003a).

2 Description current shellfishing practices

2.1 Cockle fishery

Cockles *Cerastoderma edule* bury themselves just below the surface of the mud flat and filtrate the water for algae (Figure 12). Cockles settle on the bottom of the mud flat in June. The following year in September, they may already be large enough to be fished. In less ideal growing conditions, particularly in muddy areas, they grow more slowly. In that case it is at least another year before they reach fishing size. A cockle can grow to a maximum of five centimetres and rarely lives longer than six years. The spatfall of cockles is irregular. About once every four or five years there is a good spatfall, creating many new cockle beds. Cockles of more than one year in age can occur in densities of practically none to over 1000 per square metre. A cockle bed is said to exist where the density exceeds fifty per square metre. For a more detailed description of the ecology of cockles see e.g. Ducrotoy *et al.* (1991) and Dare *et al.* (2004). The latter authors pay special attention to the interaction between the ecology of cockles and fishery.



Figure 12: (a) A half-buried cockle (*Cerastoderma edule*) showing its short siphons and annual growth rings. Photo Jan van de Kam. (b) Sampling a cockle bed during low tide. The cockles all derive from the sampling square, illustrating that cockle densities can be very high. Photo Bruno Ens.

For centuries, cockles have been gathered by hand, using a sort of rake with a net attached, the 'magic claw' (Figure 13). Mechanised cockle fishing was introduced in the 1950s (Dijkema, 1997). The first dredges had to be emptied on board. Since the end of the 1970s, the cockle dredges were emptied hydraulically. This allowed continuous fishing and greatly improved the efficiency. As a result of the introduction of mechanised cockle fishing and the increase in the number of cockle boats (5 in 1961, 24 in 1974 and 32 in 1981), the total catches increased steadily (Figure 14). Before 1990, the daily catch per cockle boat steadily increased until a maximum of 60 tons of fresh cockles per day was reached in 1988 and 1989. From then on, the average daily catch for a given season was clearly limited by the stock, not by the fishing capacity of the boats (Ens, 2003). Presently, the total number of mechanical fishing permits is 37. In total, 22 vessels are in use with 1 or 2 permits per vessel. In most years since 1993, fishing was done with a lower number of vessels, often only 5, in accordance with the expected yield during a particular year.

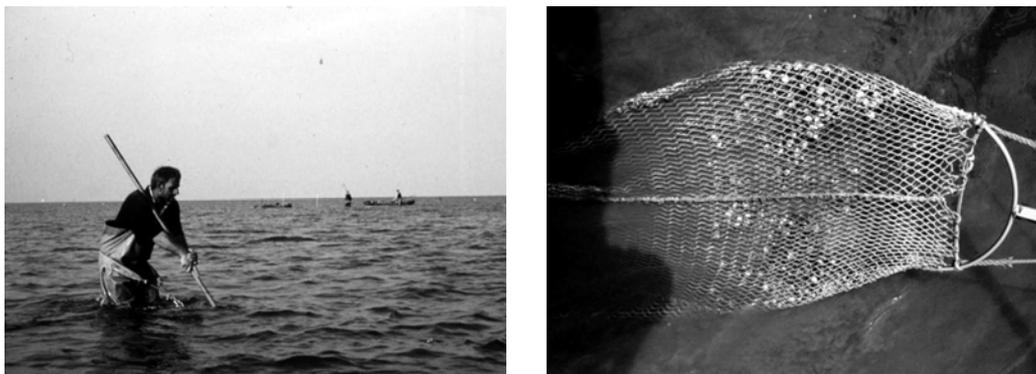


Figure 13: (a) Fishermen gathering cockles by hand. Photo Cardium. (b) A close-up of the device used for hand gathering, the so-called 'Wonderklaauw'. Photo Cardium.

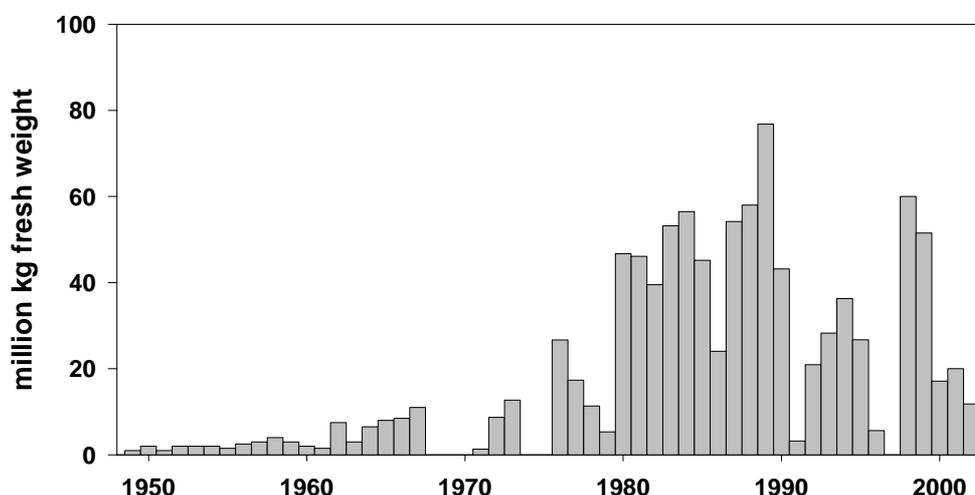


Figure 14: Annual landings of cockles from Dutch coastal waters. Data are taken from Dijkema (1997) for the period 1949-1970, and from Kamermans et al. (2003c) for the period 1971-2002. Data are missing for the years 1968-1970, 1974 and 1975.

The evaluation relates exclusively to mechanised cockle fishing, using boats and dredges (Figure 15). Nowadays, only hydraulic suction dredges are used (Figure 16). They have a permitted maximum width of 1 m. At the front side is a water jet that is directed downwards and backwards. The water from this jet brings the upper layer of sediment in suspension. A strip of metal at the underside of the dredge guides the mixture of water, sediment, cockles and other organisms into the dredge. The dredge is a cage with bars about 15 mm apart, so cockles less than 15 mm wide (and an associated length of about 23 mm) and most other, smaller organisms may escape immediately. If not, they are pumped on board together with the marketable cockles and discarded after a rotating sieve has separated cockles and bycatch. The hydraulic suction dredge can be used to a water depth of over 15 metres. The broad construction and great buoyancy of the cockle boats means they have a draught of only 50 centimetres. This enables them to work the mud flats at high tide where

most of the cockles are found. All 22 cockle boats have two dredges. A black box on board continuously records the position of the boat and whether or not the pumps and suction dredges are in operation. The recorded data is processed by an independent body (DCI).



Figure 15: Cockle boats using suction dredges in action. Photo PO Kokkels.



Figure 16: Close-up of a suction dredge. Photo Jaap de Vlas.

Cockle fishing is subject to binding agreements laid down in an annual fishing plan. Each spring the Netherlands Institute for Fisheries Research performs inventories of the shellfish stocks. Based on these inventories, the Ministry of Agriculture, Nature and Food Quality decides whether to permit cockle fishing that year. If stocks fall short of the agreed minimum reserved for birds, no fishing is permitted. For that reason there was no fishing in the Wadden Sea in 1991 and 1996 and in 1997 fishing only took place below the low water mark. The Oosterschelde was closed to fishing from 1997 to 2000 inclusive, and in 2002.

Mechanised cockle fishing takes place mainly in the Wadden Sea and also in the Zeeland Delta (mainly in the Oosterschelde and the Western Scheldt and sometimes in the Voordelta, which is the coastal zone in front of the Delta). The fishing season runs from the end of August to the end of November. Yields from the Wadden Sea, in years when fishing took place, amounted on average to a good four million kilos wet flesh weight over the period 1990-2002. More details on current practices are provided by Kamermans & Smaal (2002).

2.2 Mussel fishery and mussel culture

People have fished for wild mussels since time immemorial. In the nineteenth century mussel cultivation was introduced into the Zeeland Delta (Korringa, 1976; Smaal, 2002). Mussel cultivation lots were set out in the Oosterschelde (Figure 17), Western Scheldt and Grevelingen. Mussel cultivation started in the Wadden Sea in the early nineteen fifties (Figure 18). At that time a parasite decimated the mussel population in the Delta (Korringa, 1976). Currently there are 7000 hectares of mussel cultivation lots in the Wadden Sea, of which presently about 4000 ha is stocked with mussels. In the Oosterschelde there are a good 2000 hectares (Dijkema, 1997). In total, around 80 companies cultivate mussels. Black boxes have been installed on all mussel boats since 1998 (Kamermans *et al.*, 2003c).

Prior to 1990 it is estimated that 60 to 150 million kilos (fresh weight) of seed mussels (Figure 19) and half-grown mussels were fished annually from the sublittoral areas and 10 to 20 million kilos from the littoral Wadden Sea flats. During the period 1990-2003 fishing for seed mussels was almost exclusively confined to the sublittoral areas of the western Wadden Sea, as on the intertidal areas seed fishery was only allowed under special conditions. Since 1993, there is a policy to allow fishing on tidal flats only if insufficient seed is available in the subtidal and if enough seed on the flats is available. Seed fishery occurs in accordance with a fishing plan drawn up by the PO Mussels on the basis of data from the shellfish inventories. The remaining wild stocks of seed mussels in the Wadden Sea are also fished in spring.

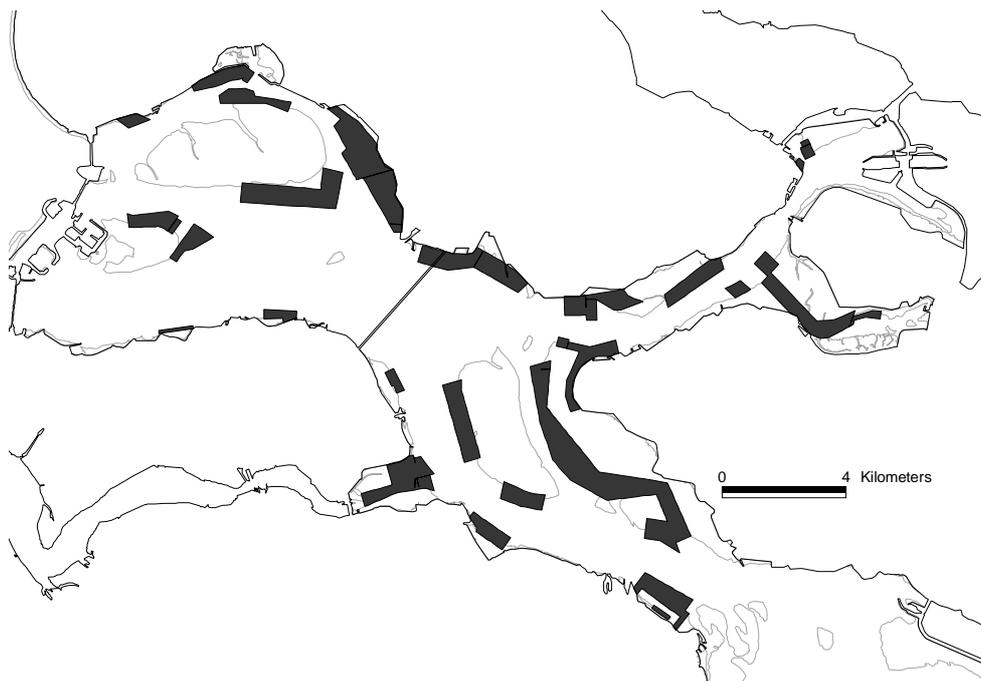


Figure 17: Mussel culture lots, indicated in grey, in the Oosterschelde.

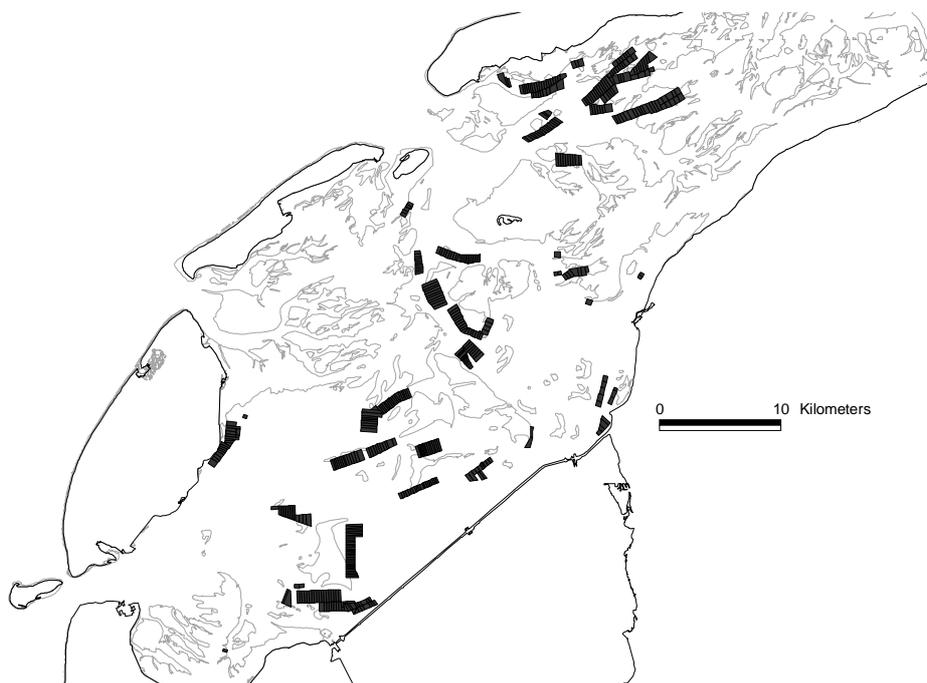


Figure 18: Mussel culture lots, indicated in grey, in the Dutch Wadden Sea.



Figure 19: Small mussels (*Mytilus edulis*) that are used as seed on culture lots. Photo Bruno Ens.

From 1992 to 2002 an annual average of 11 million kilos net fresh weight of mussels were fished in the autumn. Three quarters went to the cultivation lots in the Wadden Sea and the rest to the Oosterschelde. Seed mussel fishing in the spring yielded an annual average net fresh weight of 20 million kilos. The autumn and spring catches together amounted to an average 31 million kilos net fresh weight (weight of mussels including shell, flesh and water within the shell, but excluding associated silt, shell fragments, dead shells and other debris), corresponding to around 50 million kilos of seed and half-grown mussels (gross, so including silt etc). In the Oosterschelde there is far less spat fall and only incidental fishing for seed mussels (Bult *et al.*, 2003b).

Half-grown mussels are imported from Germany for cultivation. These imports average three million kilos per year. This quantity makes a limited contribution to the total stock on the lots. Based on yield and seed fishing data the average mussel stock on the cultivation lots in the Wadden Sea on 31 December was estimated at 50 million kilos fresh weight. This was made up of 12% seed mussels and 88% half-grown mussels and consumption-sized mussels. The stocks of wild mussels in the sublittoral areas of the Wadden Sea were also estimated at around 50 million kilos on average in the period 1992-2002 (Bult *et al.*, 2003b).

After an average of two growing seasons the fishermen harvest the mussels and offer them at auction. Each mussel boat fishes, using four small nets which trail across the seabed (Figure 20). Despite losses due to washing away, mechanical damage during fishery, and predation, one million kilos of seed mussels grow into 1.7 million kilos of consumption-sized mussels during the cultivation period (Bult *et al.*, 2003b). This represents a more efficient use of the seed resources than previously, when

production efficiencies were less than 1. Before 1990, more than 1 kilo of seed mussels was needed to grow 1 kilo of consumption-sized mussels (Dankers, 1993).

Landings of mussels have been recorded at the auction of Yerseke since 1930 (Figure 21). More details on mussel fishery and mussel culture are provided by Dijkema (1997), Smaal & Lucas (2000), Bult *et al.* (2003b), Smaal *et al.* (2001) and Smaal (2002).



Figure 20: Mussel boat with typical mussel dredges. Photo PO Mossels.

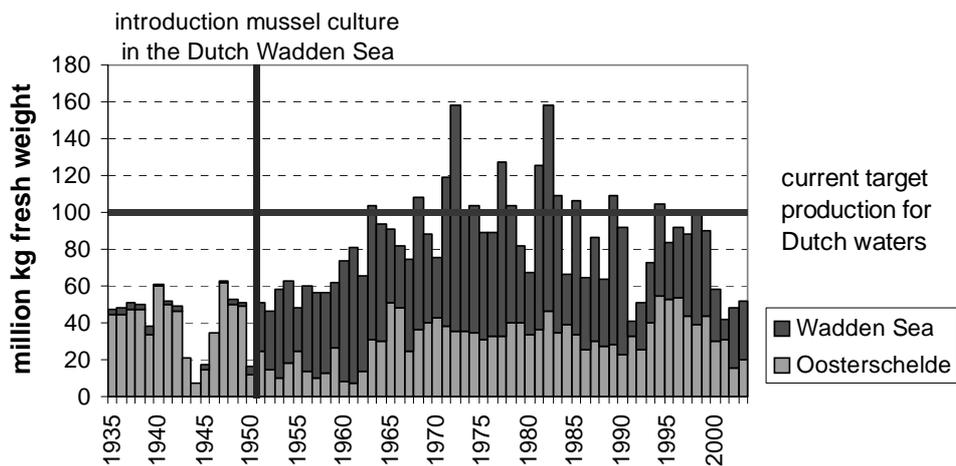


Figure 21: Annual landings of mussels from Dutch coastal waters. A distinction is made between mussels from culture lots in the Wadden Sea and from culture lots in the Oosterschelde. Also indicated the timing of the introduction of mussel culture in the Dutch Wadden Sea and the current target production. From Bult *et al.* (2003b) with recent data added from Productschap Vis.

2.3 Other activities which have an impact on the sea bed

Shellfish fishery is not the only type of human activity disturbing the sea bed that occurs in the Wadden Sea and Oosterschelde. Here we will briefly discuss the most relevant of these other human activities to see if they might have interfered with our investigations of the effects of cockle and mussel fishery on the sea bed.

2.3.1 Sand extraction

In the past (before 1970) regular sand extraction occurred in the Wadden Sea mainly in tidal channels and occasionally on tidal flats (van der Veer *et al.*, 1985). Since 1996, regular sand extraction, unless combined with maintenance of shipping lanes, is reduced. Since, 2000 sand extraction is banned from the Wadden Sea, and is allowed only in the North Sea below the 20 m depth contour. There is no interference with our studies on cockle fishery, as cockles do not occur in these deeper gullies and channels.

2.3.2 Harvesting of lugworms

Lugworms *Arenicola marina* are large worms that are used as fish bait by recreational fishermen. Few benthic animals have burrows as deep as adult lugworms, so digging for lugworms affects all benthic life on the spot (van den Heiligenberg, 1987). Digging for lugworms for personal use is allowed throughout the Wadden Sea and occurs by hand with a fork. In the Wadden Sea, commercial digging by hand is only allowed in designated areas, but so far, no areas have been designated. Locally, aggregations of bait diggers occur at localities that are easily reached from land, but at the scale of the entire Wadden Sea and Oosterschelde, the impact is probably small.

Most lugworms are collected by mechanized harvesting (unpublished internal report LNV written in 1995). Commercial mechanized harvesting of lugworms is carried out by 4 licensed machines in 5 small areas in the westernmost part of the Dutch Wadden Sea (Figure 22). They use a technique similar to that of mechanical cockle fishers, but go as deep as 30 cm. This activity is detrimental to all benthic fauna (van den Heiligenberg, 1987), but replaces the uncontrollable and equally detrimental digging for lugworms by hand that was commonly practised 20 years ago. The total allotted surface is about 2000 ha, of which about 70% can be used for extraction of lugworms. Cockle beds can occur in the granted plots for lugworm digging machines. The impact of lugworm exploitation on the Wadden Sea as a whole is probably small, but this may not be true for the Balgzand area, where three of the four lugworm digging machines are active (Figure 22).

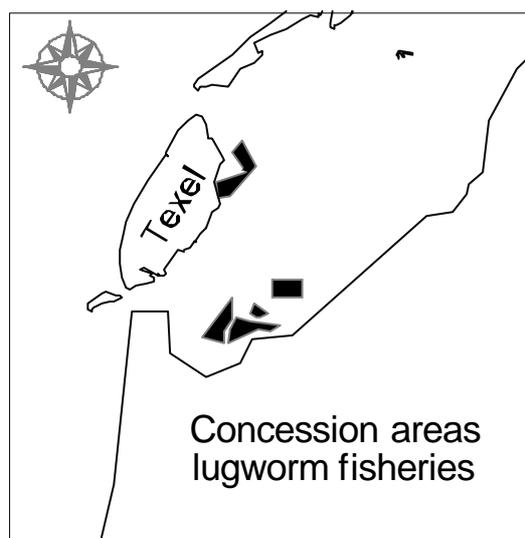


Figure 22: Areas in the Dutch Wadden Sea, where mechanised digging for lugworms is allowed.

2.3.3 Digging for *Nereis virens*

Nereis virens is a large worm that is used as fish bait by recreational fishermen. It lives underneath mussel beds. To collect the worm, bait diggers turn the mussels upside down with a three-pronged fork. In the process, many mussels become buried in the sediment and subsequently die. Clearly, this type of bait digging is highly detrimental to mussel beds. Nonetheless, digging by hand for *Nereis virens* for personal use is allowed throughout the Wadden Sea. It occurs locally, but at such a small scale that it almost certainly played no significant role in either the disappearance of the mussel beds, or the fact that the mussel beds were so slow to return. Commercial hand digging of *Nereis virens* is only allowed in designated areas, but so far no areas have been designated. There is some illegal digging for *Nereis virens* on a very small scale. A request for commercial hand digging for *Nereis virens* on the Balgzand (one of the areas permanently closed for shellfish fishery since 1993) was turned down by LNV-Noord in 1999.

2.3.4 Fishing for shrimp

Fishery of shrimp (*Crangon crangon*) occurs throughout the year. The species is abundant in coastal areas. The Wadden Sea is one of the most important fishing areas. In total 233 fishing permits are in use, of which 90 in the Wadden Sea. Total yield in the Netherlands amounted to 8.6 mln kg in 2000 and 7.5 in 2002 (www.pvis.nl; Welleman, 1999). Fishing for shrimp does not classify as bottom-disturbing fishery according to Dutch law. Shrimp fishery obtained a permit under the nature conservation law in 2001 and is allowed in areas closed under article 17 and in the areas closed for shellfish fishery, as long as no harm is done to either nature values for which the article 17 area was closed (like resting seals) or to

important nature values like mussel beds and seagrass beds. Fishing for shrimp is not allowed on mussel culture lots. Differences between areas open and closed for shellfish fishery are unlikely to be due to shrimp fishery, because shrimp fishery occurs primarily in subtidal areas and low edges of tidal flats, irrespective of the closure of the flat to shellfish fishery. Studies on the ecological impact of shrimp fishery have focused on discarded bycatch, e.g. Berghahn (1994). Little is known on the effect of shrimp fishery on benthic communities, other than the suggestion of Buhs & Reise (1997) that shrimp fishing may have contributed to a decline of epifaunal species during the last 100 years. In the absence of such knowledge, it was not possible to take the effect of shrimp fishery into account in our investigations.

2.3.5 Trawling for bottom fish

Fishery on flounder with a tickler chain can be carried out on tidal flats outside the closed areas, but the draught of the ships involved is such that this type of fishery is mostly restricted to subtidal areas. The fishery on flounder is very limited due to the little market value of flounder. Cockles can occur in the fished areas, but data on interference are not available. There is hardly any bottom trawling for flatfish species like Sole, Place and Dab in the Wadden Sea. The main fishery on these species occurs in the North Sea rather than the Wadden Sea. The current license for bottom trawling in the Wadden Sea is under fishery law. A permit under the nature conservation law has yet to be made. Because bottom trawling is restricted to subtidal areas, it almost certainly did not affect our studies on the effects of cockle fishing on the tidal flats. And because in the subtidal of the Wadden Sea, bottom trawling is rare, compared to fishing for seed mussels, we assumed the effect of bottom trawling could be ignored in our studies on the effects of mussel seed fishery in the subtidal.

2.3.6 Conclusion

Sand extractions, trawling for bottom fish and shrimp fishery are restricted to gullies, and do not interfere with mussel beds and the benthic communities on the tidal flats. Lugworms and *Nereis virens* are collected on tidal flats, but at a very small scale. In our investigations on the ecological impact of cockle fishery and mussel fishery, we have therefore assumed that these other human impacts disturbing the bottom could be ignored.

3 Ecological impacts of cockle fishery in the Wadden Sea

3.1 Introduction

This chapter describes the results of the EVA II studies aimed at measuring the ecological impact of cockle fishery on the Wadden Sea ecosystem. We also describe the results of relevant studies by other scientists in the Wadden Sea, as well as results of similar studies in intertidal areas elsewhere in Europe. In the discussion we address the question whether mechanized fishing for cockles has led to large-scale long-term changes of the Wadden Sea ecosystem.

3.2 Catches and areas fished

From 1993 to 2002 cockle beds were found on around 20% of the flats in the Wadden Sea. In some areas cockle beds are common, in others they occur only occasionally. During this period they covered on average a good 7% of the surface of the flats (Zwarts *et al.*, 2004; Kamermans *et al.*, 2003c).

Cockles stocks are highly dynamic by nature (Figure 23). Over the period 1992 – 2002 natural annual mortality rate in the Wadden Sea was 60% (based on numbers), with low values (30%) in 2000/2001 and high values (95%) in the severe winter of 1995/1996. Annual average mortality due to fishery was 6.6% of total numbers. Total harvest was 9.5% of the total stock calculated on the basis of biomass over the whole period 1992 – 2002 (Kamermans & Smaal, 2002; Kamermans *et al.*, 2003a).

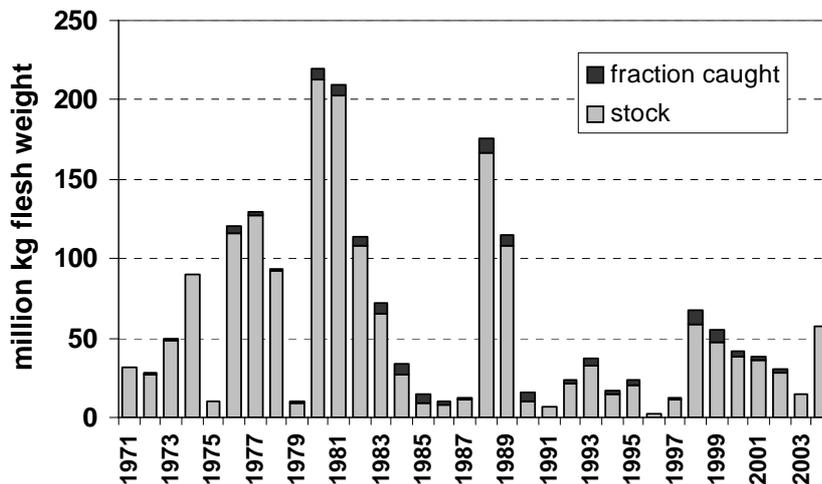


Figure 23: September estimates of cockle biomass (millions of kilos flesh weight) in the littoral areas of the Wadden Sea, 1971-2001. Landings are shown in black. Stocks prior to 1990 are based on extrapolations from Balgzand data, except for 1981, when a Wadden Sea wide survey was done. From Kamermans *et al.* (2003a) with new information from Kesteloo *et al.* (2004).

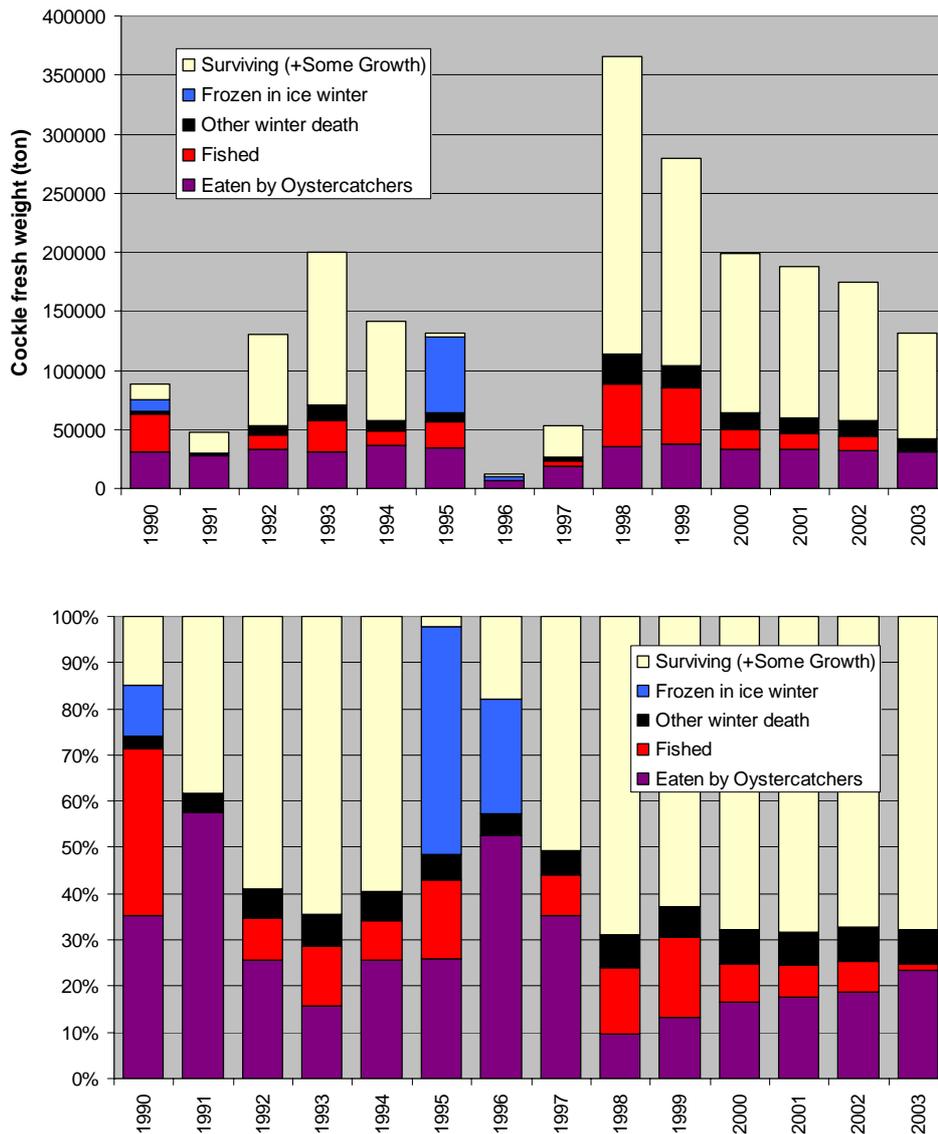


Figure 24: Causes of cockle mortality between early autumn and the following spring in open areas in the Dutch Wadden Sea, estimated for different years. From the data on cockle growth and summer survival in Kamermans et al. (2003b) and the cockle predation and winter mortality estimated in Rappoldt et al. (2003a), the total fresh weight of cockles present in early autumn can be assigned to the various causes of mortality. (a) Mortality of cockles expressed as tons fresh weight adding up to the total loss of fresh weight between September and May. (b) Mortality causes as a fraction of the total loss of fresh weight between September and May.

In the model of the oystercatcher various mortality factors for cockles were calculated separately. Total mortality in the model did not include juvenile cockles, hence predation on cockle spat by knots and gulls was not included. Furthermore, mortality was only calculated for the winter period; this may explain the lower values than observed in the field on an annual basis. Figure 24 gives a quantitative estimate of the various causes of mortality for each winter in the period 1990-2003. In the open areas of the Wadden Sea on average about 27% of the cockle fresh weight present at the end of September is predated by oystercatchers during the course of winter, about 11% is fished, about 6% dies in winter by causes other than predation

and on average about 6% freezes in ice winters. The remaining 49% of the total fresh weight in September was still alive in May at the end of the winter.

In the closed areas of the Wadden Sea the cockle densities have been relatively large, and the contribution of predation to cockle mortality is smaller (14%) than in the open areas. We also calculated 2% mortality from fishery, because it was not possible to produce a perfect match between the areas on which we did the model calculations and the areas that were actually open and closed for fishery. As a result of the lower mortality from bird predation and fishery, a greater proportion of the stock survived until May: 64%.

When fishing a cockle bed, the fishing gear does not disturb the entire area of the seabed. The percentage that is actually touched by the fishing gear varies between on average 30-40% of the fished area (Table 4). For the central parts of a particular fished cockle bed, the percentage that is actually touched by the dredge may on occasion exceed 90% (Ens *et al.*, 2004). The tracks are fished in a more or less random way, overlapping more and more until the density of remaining cockles is so small that further fishing becomes unprofitable (Figure 25). The sediment that is sieved out by the fishing gear is partly deposited outside of the tracks, covering the remaining cockles with an extra layer of sand and bringing them more or less out of reach of the fishing gear. That is the reason why cockle beds may be fished two or three times with some days or weeks in between, giving the remaining cockles the opportunity to re-establish their position in the upper sediment layer.

Table 3 presents information on the absolute areas of cockle beds, the fishing area (including all quadrants with a fishing intensity exceeding 2%) and the area actually touched by the dredge. This information is then related to relevant surface areas in Table 4. The area touched by the dredge relative to the fishing area, for instance, expresses the intensity of fishing in the areas where fishing took place (average value 31%). The area touched by dredge relative to the mudflat area (average 1.2%) sets an order of magnitude for possible effects on average Wadden Sea sea bed properties. The fishing area as a fraction of the cockle bed area was 57% for cockle beds in the open areas. The data on surface area of cockle beds in Table 3 and Table 4 refer to mappings of cockle beds by the fishermen (Kamermaans *et al.*, 2003a). An alternative method is to use the RIVO surveys and classify the total area with cockles in densities over 50/m² as cockle beds (Figure 26). The fished area is shown in black for the different years. Also shown are the beds in open and closed areas. In 1994 all beds in open areas have been fished, and in 1995 almost all beds in open areas. In the other years fished areas varied between 10 and 50% of all open beds. Another source of information are calculations on the overlap in fishing areas between years. From 1992 to 2001, a cumulative 19% of the mudflat area was fished at least once (Kamermaans *et al.*, 2003c). Most of this area was fished only once (9%), or twice (5%). The remaining 5% was fished between 3 and 7 times. Together, these different types of information suggest that most existing cockle beds in open areas will have been fished at least once since 1993.

In the part of the Wadden Sea which is permanently under water, cockle fishing gear annually touched around 0.7% of the area of the seabed (Table 5).

Table 3: The surface area covered by cockle beds, according to surveys by the fishermen, in the littoral zone of the Dutch Wadden Sea. The fishing area is the area where fishing has occurred. It comprises all quadrants of ca. 2 ha with an area touched by the dredge exceeding 2%. Based on data from Kamermans et al. (2003c) and Kamermans et al. (2003b).

Year	cockle beds (ha)	Beds in open area (ha)	Fishing area (ha)	Touched by dredge (ha)
1992			2026	852
1993	11514	8588	5387	1630
1994	5294	2447	5220	1688
1995	7927	4258	9174	2424
1996	345	132	0	0
1997	4888	2545	0	0
1998	20834	16030	5629	1616
1999	15282	10464	6191	2183
2000	11537	7023	7499	2137
2001	15610	10963	6136	1704
Average	10359	6939	4726	1423

Table 4 The surface area actually touched by the dredge and the fishing area (Table 3) expressed as a percentage relative to various relevant reference areas. In the calculation of average values, percentages exceeding 100 were set to 100.

Year	Touched by dredge as a percentage				Fishing area as a percentage		
	of fishing area (%)	of cockle bed area (%)	of open cockle bed area (%)	of mudflat area (%)	of cockle bed area (%)	of open cockle bed area (%)	of mudflat area (%)
1992	42			0.7			1.6
1993	30	14	19	1.3	47	63	4.3
1994	32	32	69	1.4	99	(213)	4.2
1995	26	31	57	2.0	(116)	(215)	7.4
1996		0	0	0.0	0	0	0.0
1997		0	0	0.0	0	0	0.0
1998	29	8	10	1.3	27	35	4.5
1999	35	14	21	1.8	41	59	5.0
2000	28	14	30	1.7	48	(107)	6.1
2001	28	11	16	1.4	37	56	5.0
Average	31	14	25	1.2	46	57	3.8



Figure 25: Tracks on the mud flats after suction dredging for cockles. In the centre of the picture is a small mussel bed. According the fishing plan, no fishing for cockles takes place on mussel beds. Photo Jaap de Vlas.

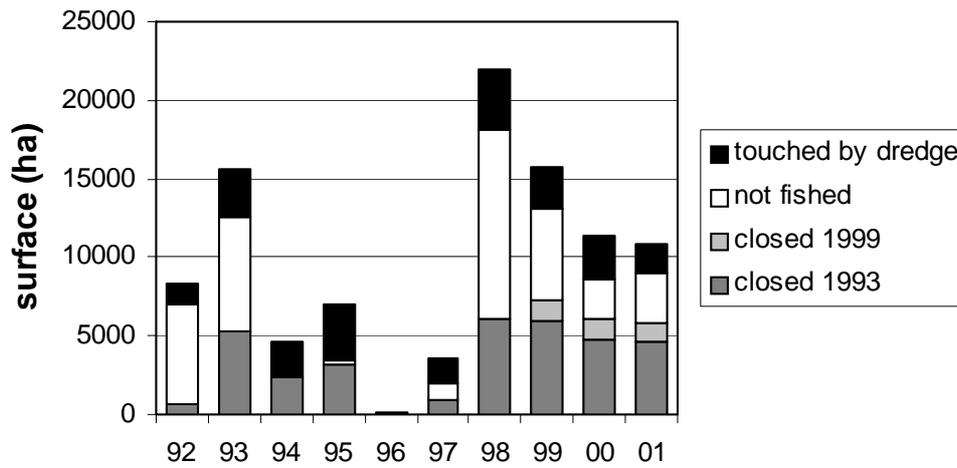


Figure 26: Cockle bed surface (defined as areas with cockle densities of at least 50 cockles per m^2) in open and closed areas with fished area (touched by dredge) in black. From Kamermans et al. (2003c).

Table 5: Area fished per year in the sublittoral zone of the Dutch Wadden Sea. The fished area is the area actually touched by the dredge. The fishing area comprises all quadrants of ca. 2 ha with a fished area exceeding 2%. For both fished area and fishing area the absolute values (in ha) are given and the values expressed as a percentage of the total surface area of the sublittoral zone. From Kamermans *et al.* (2003c).

Year	Fished area cockle fishery		Fishing area cockle fishery	
	sublittoral (%)	sublittoral (ha)	Sublittoral (%)	sublittoral (ha)
1992	0.4	493	1.4	1648
1993	1.2	1448	1.9	4731
1994	0.5	549	0.9	2234
1995	0.9	1088	2.0	4895
1996	0.0	0	0.0	0
1997	1.3	1579	1.6	4053
1998	1.9	2194	2.7	6640
1999	0.4	465	0.8	1916
2000	0.5	636	1.3	3138
2001	0.1	116	0.2	616
Average	0.7	857	1.3	2987

3.3 Effects on the sea bed

It is clear that mechanised cockle fishing will lead to a loss of silt in the short term. In a monitoring area along the Groningen coast the effect of fishing could still be measured six months later (Figure 27) in an area where silt accumulated in the course of the years. This trend was only temporarily interrupted. The differences, when combined for five plots in the same area, were statistically significant until a year after fishery (Figure 28; Zwarts *et al.*, 2004). Fishery tracks in the same area were detectable on aerial photographs up to one year after fishing in 2002, which is in accordance with the sediment data. On a flat near Schiermonnikoog, fishery tracks were still visible two years after fishing (Figure 29). On other locations, fishery tracks disappeared within a year, but no systematic study was undertaken of the rate with which tracks disappeared.

Whether there are still measurable differences in the long term depends among other things on available quantities of silt, wave action, storms and churning by benthic fauna. An experiment south of the island of Ameland (Ens *et al.*, 2004) showed silt losses by cockle fishery of about 15% to about 50%, followed by recovery within half a year after fishing (Figure 30). Judged by the silt content of the sediment, the Ameland location represents a more dynamic situation than the tidal flats of the monitoring location along the Groningen coast (Zwarts *et al.*, 2004).

An example of a stabilizing effect of the benthic fauna is provided by an unfished part of a cockle bed south of the island of Schiermonnikoog, where tubes of *Lanice conchilega* stabilized the sediment during at least 1,5 year, whereas sediment loss was visible in the water-filled fishing tracks around that plot (Figure 29).

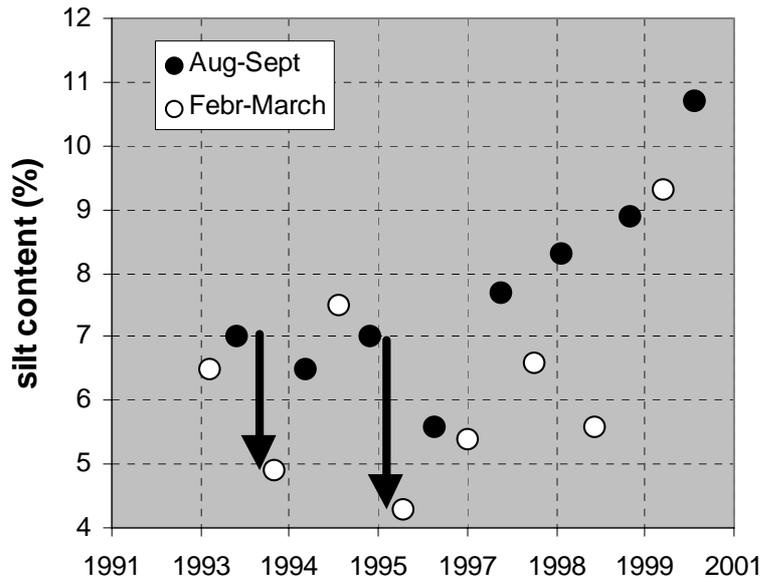


Figure 27: Silt content of plot 47.0 near the mainland coast. Open dots: silt content in spring; closed dots: silt content in autumn. The arrows indicate fishery shortly after the autumn observations.

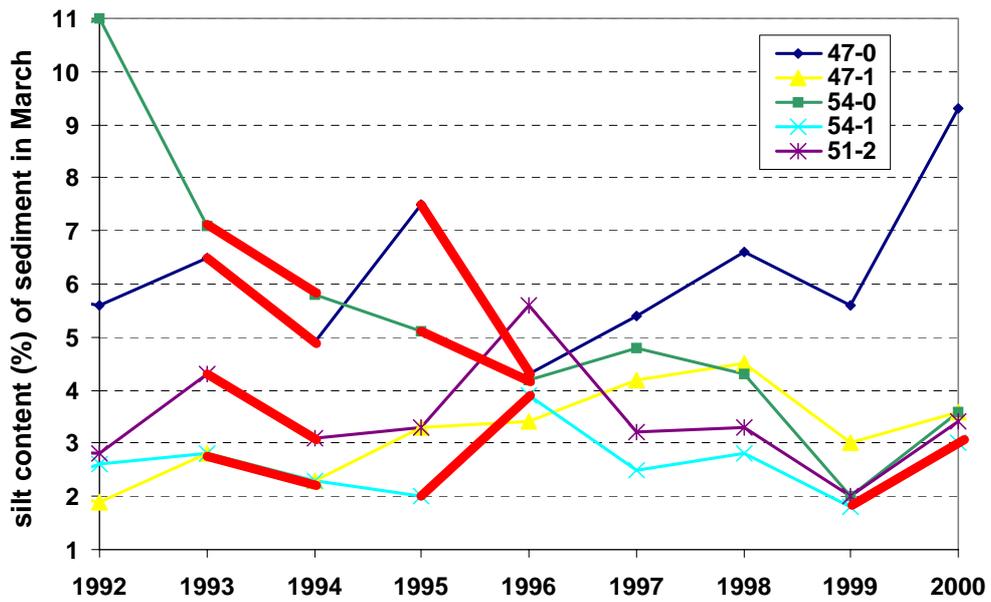


Figure 28: The silt content in March, from 1992 and 2000 at five locations along the mainland coast. The connecting lines are red if cockle fishery had taken place during the period between two sampling data. From Zwarts et al. (2004).



Figure 29: Tracks of cockle fishing that were still visible many months after fishing. The square at the centre of both pictures was open to hand gatherers, but closed to suction dredges. *Lanice* survived in the central square and on the unfished ridges. The area was fished in autumn 1999. The photo on the left was taken by Jaap de Vlas on 26 May 2000. The photo on the right was taken by Sophie Brasseur in July 2001, almost 2 years after fishing took place.

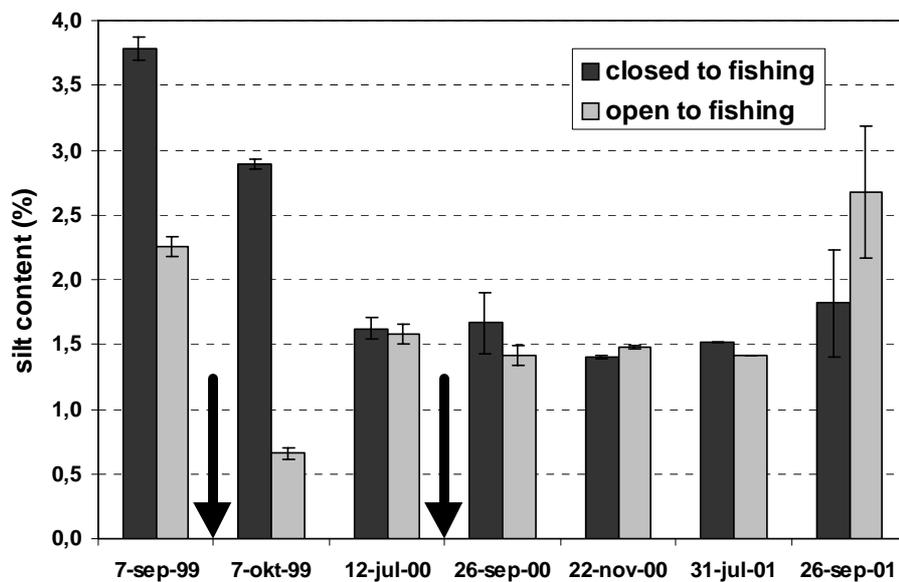


Figure 30: The silt content (mean and SE) at a location south of Ameland, separated for the area closed to fishing (dark grey) and open to fishing (light grey). The arrows indicate intensive fishery; between 7 September and 7 October 1999 and between 12 July and 26 September 2000. From Zwarts *et al.* (2004).

According to Dernie *et al.* (2003) the recovery time of the sediment is closely correlated to the silt content of the sediment and to the recovery time of the benthic fauna. As demonstrated by Zwarts *et al.* (2004) cockle fishery is carried out in sandy as well as more muddy sediment, with a tendency to more silty areas during the period after 1990. The benthic fauna in these areas is relatively rich.

To determine whether there is a large-scale long-term effect, Zwarts *et al.* (2004) made an analysis of the sediment development in the whole Wadden Sea since the first sediment studies started in 1950. In general, the tidal flats became more sandy in nearly all offshore intertidal areas in the western half of the Dutch Wadden Sea (>2-4 km from the coast). The eastern part remained more or less the same, but the tidal flats along the mainland borders became more silty. As shown in Figure 31a, conspicuous accumulation of silt can be observed north of the harbours of Harlingen and Delfzijl, near to the locations where sediment dredged from these harbours is disposed. Comparison with the locations where cockle fishery took place during the period 1993 – 2003 learns that fishery was concentrated in areas with increasing silt contents (Figure 31b).

Mean values of the silt content before 1990 were compared with data collected in the period 1997 – 2002 in open and closed areas as a whole. The overall result is an increase in silt contents in fished areas of 10.5% and an increase in unfished areas of 19.4% (Table 6). However, these increases need a correction because the samples that have been collected since 1993 were just from the top 5-10 cm of the sediment, causing outcomes that were about 15-20% higher than during earlier surveys when sediment samples were taken with a depth of 20 cm. Taking this into account, the silt content of open areas decreased by 5-10%, whereas the silt content of closed (unfished) areas was stable or increased a little bit (increase 0-5%). The statistical analysis of these data indicates a significant difference ($p < 0,05$). However, the closed areas are not randomly chosen so the outcome could be influenced by their position. A new analysis attempting to compensate for this shortcoming yielded the same trend, but without statistical significance.

Table 6: Changes in silt content of the top layer of the sediment in areas open and closed for fishery. From Zwarts *et al.* (2004).

		Silt content in the 1950s	Silt content after 1992	Number of samples	Increase (%)
Open	mean	2.49	3.16	2650	10.58
	SD	2.11	3.32		2.38
Closed	mean	2.44	3.37	691	18.97
	SD	1.55	2.85		1.99

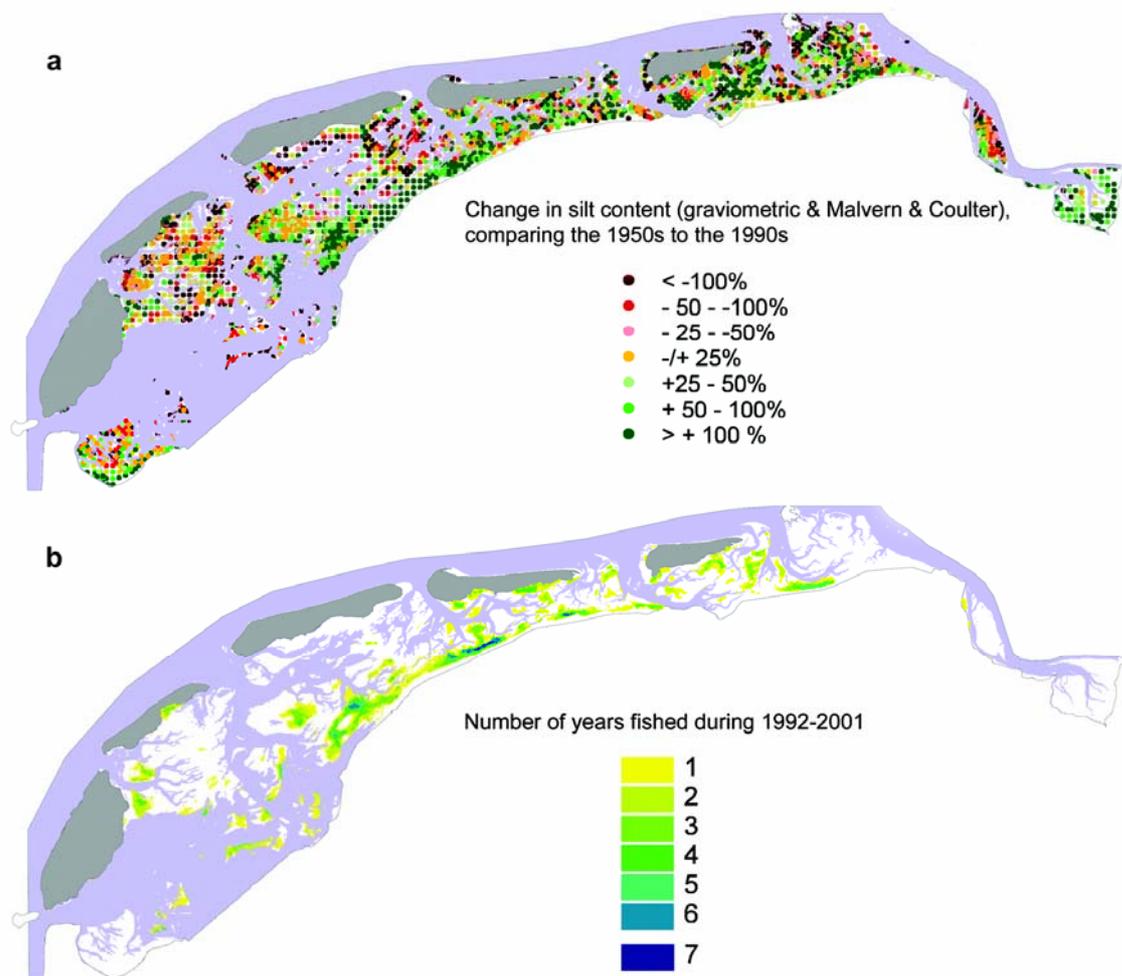


Figure 31: (a) Changes in the silt content of the top 5 cm of the sediment, comparing the 1950s with the 1990s Zwarts *et al.* (2004), (b) The number of years that a given area was fished for cockles in the years 1992-2001 as determined from the black box data (Kamermans *et al.*, 2003c; Zwarts *et al.*, 2004).

3.4 Effects on the cockle stock and cockle distribution

3.4.1 Cockle stock

Cockle stocks in the Wadden Sea are highly dynamic, primarily due to great variability in spatfall between years and occasional mass mortalities in severe winters (Figure 23). Large spatfalls occurred in 1979, 1987, 1992, 1996, 1997 and 2003, amounting to a good spatfall every 5 years (Zwarts *et al.*, 2004; Kesteloo *et al.* 2004). The large spatfall of 1996 did not show up in the RIVO surveys, because most cockles died in the severe winter of 1996/1997. Thus, good recruitment, where the cockles reach a fishable size, occurred on average every 6 years. Figure 32a shows the stock of juvenile cockles in open and closed areas and Figure 32b of adult cockles, all based on spring surveys. The stock of juveniles is always higher in open areas, which is not surprising, given that the open area covers 69% of the total tidal flat area, compared to 26% for the areas closed in 1993 and an additional 5% for areas closed

in 1999. Despite this difference in surface area, the stock of adult cockles was higher in the closed areas from 1995 onwards.

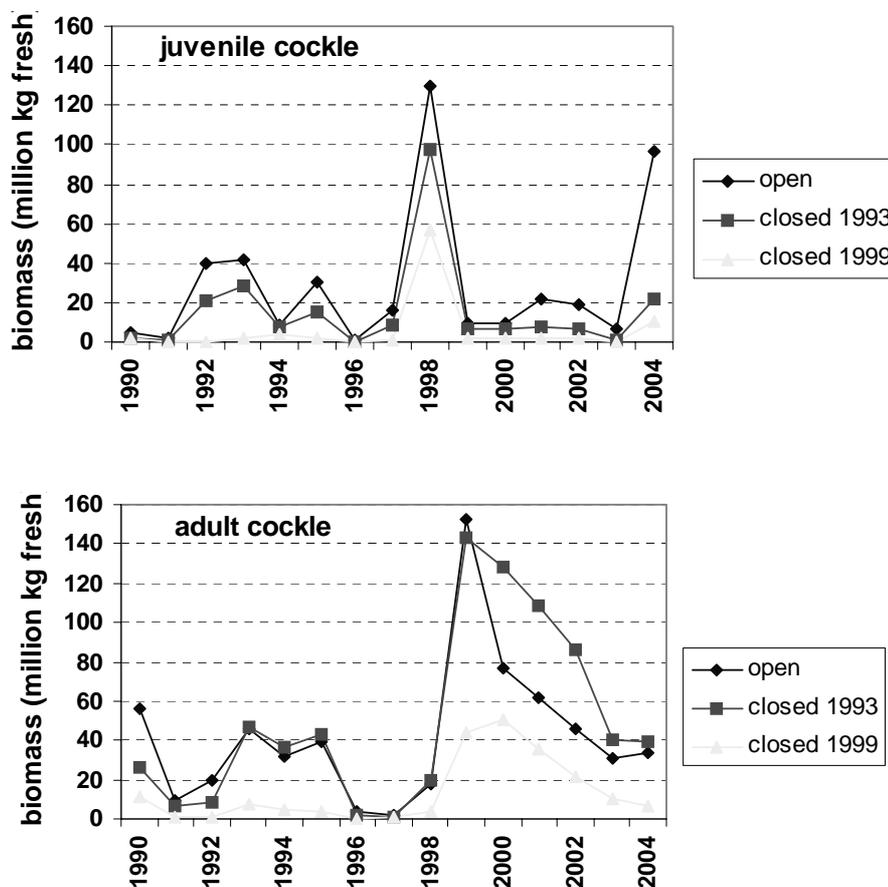


Figure 32: Stocks of (a) juvenile and (b) adult cockles in the Wadden Sea, separated for areas open to fishery, areas permanently closed in 1993 and areas closed in 1999, comprising respectively 70%, 25% and 5% of the tidal flat area. From Kamermans *et al.* (2003a) with data from recent years added (Kesteloo *et al.* 2004)..

In areas open for cockle fisheries the biomass densities of cockles was always lower than in closed areas (Figure 33). This difference was increased after closure, which can be explained as follows. First, fishery only occurs in the open areas and the harvest as fraction of the stock in the open areas was estimated on the basis of model calculations at 11% per year. Second, additional mortality due to fishery will have contributed to the difference in density of adult cockles through increased mortality of cockle spat and undersized older cockles in the fished areas. This mortality is estimated at 10-50% according to de Vlas (1982), Franklin & Pickett (1978) and references in Dare *et al.* (2004). Third, according to our model calculations, oystercatchers exerted a significant predation pressure on cockles. The results suggest that predation pressure on cockles was considerably higher in the areas open for fishery. Finally, more cockle spat developed annually per square metre in the closed areas in the first 8 years after closure (Figure 34).

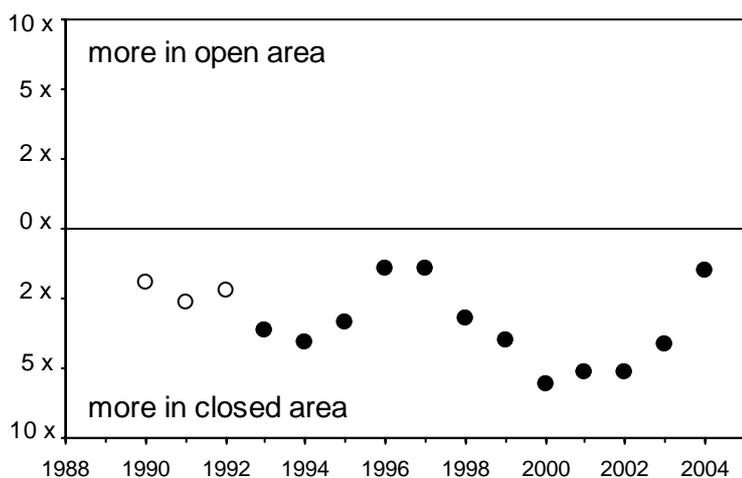


Figure 33: Comparison of the biomass density of cockles (all year classes combined) in areas open and closed for fishing. From Kamermans *et al.* (2003a) with data from recent years added (Kesteloo *et al.*, 2004). For each year, the logarithm of the ratio of density in the open areas divided by the density in the closed areas is plotted. The years indicated with an open dot are before the permanent closure in 1993 (see footnote 5). A *t*-test allowing for unequal variances indicated that the difference in biomass density between open and closed areas was higher after closure: $t = -2.7$, $df=12.7$, $P=0.02$, 2-tailed.

A remarkable feature of Figure 34 is that the 4 years with higher recruitment in the open areas are the last 4 years of the study period. The shift from higher recruitment in the closed areas to higher recruitment in the open areas is statistically significant.

We hypothesize that this pattern in cockle recruitment is the result of two processes. Better spatfall in closed areas may be due to better local conditions in comparison with open areas and this can be a direct or an indirect effect of fishery, as put forward by Piersma *et al.* (2001). This spatfall contributes to higher cockle stocks in closed areas. Fishery does not harvest adults or damages undersized cockles in closed areas, so abundance increases and differences between open and closed areas increase. Eventually, spatfall is hampered by high adult densities, through competition for space or by filtration of larvae by adults (Andre *et al.*, 1993). Beukema & Cadée (1999) also observed a significant negative effect of high cockle stocks on subsequent recruitment on the Balgzand, as did Dare *et al.* (2004) in the Wash.

We tested the fishery impact hypothesis by analysing the magnitude of the difference in recruitment in relation to fishery effort (Kamermans *et al.*, 2003a). The impact of fishery was tested on spatfall as estimated in autumn, i.e. 1 year after fishery, and we observed a significant negative effect in the Wadden Sea (and no effect in the Oosterschelde estuary, see chapter 8). If we included a larger dataset based on spring surveys there was no relation between the density of juvenile cockles and fishery effort in one year or two years before spatfall. Also accumulative effects could not be demonstrated. We conclude that fishery impact alone cannot explain the difference in juvenile densities as observed in the first period after closure and it remains unclear what other factors may have played a role. As described in section 1.5.9.2, we have no evidence for structural differences between open and closed areas before closure but the data are scarce.

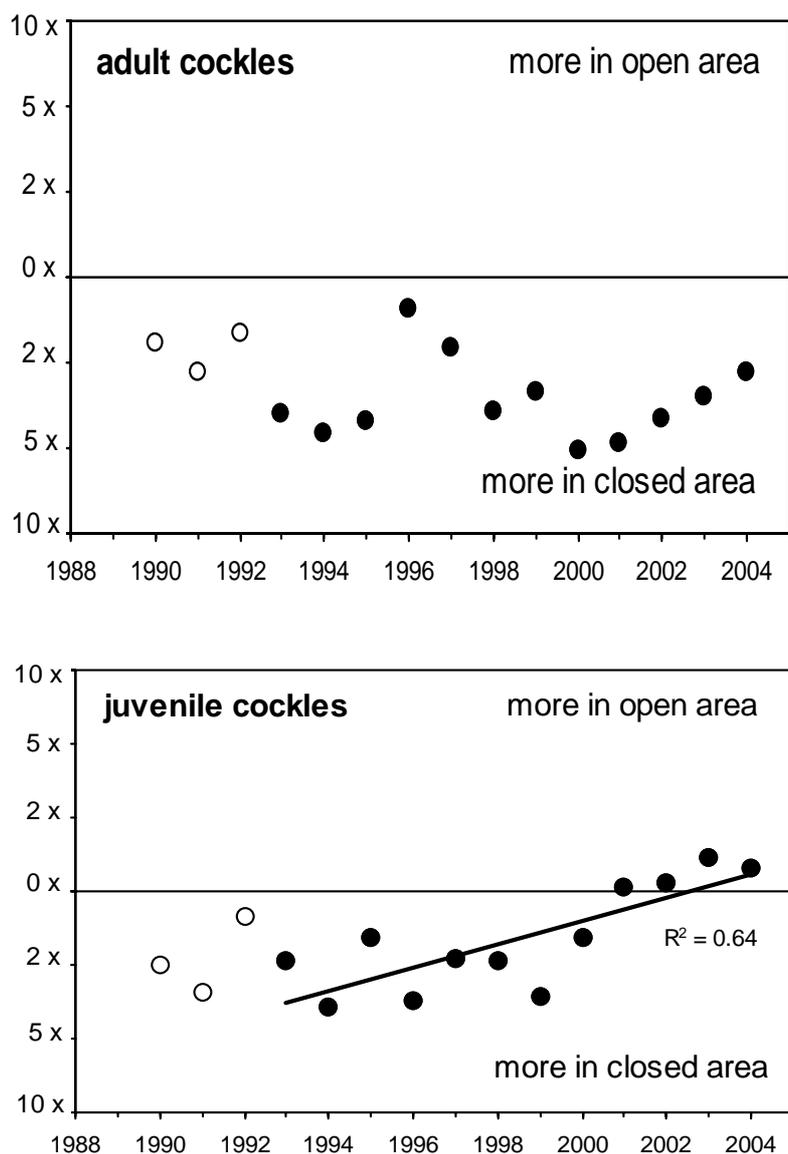


Figure 34 Comparison of the density of cockles in areas open and closed for fishing for (a) adult cockles and (b) juvenile cockles. For each year, the logarithm of the ratio of density in the open areas divided by the density in the closed areas is plotted. From Kamermans et al. (2003a) with recent data added (Kesteloo et al. 2004).

To test the hypothesis that cockle stocks have a negative influence on recruitment, we plotted the stock of cockles of nearly 1 year old (our best estimate of the spatfall) against the total cockle stock in the previous year, for both open and closed areas (Figure 35). We excluded the spatfall of 1996, because we know that nearly all cockles of this large spatfall were killed in the severe winter of 1996/97, so they did not show up in the spring survey of 1997. In both open and closed areas, recruitment was reduced when cockle stocks were high.

In conclusion, during the years of our study, cockle fishery resulted in on average smaller and younger stocks of cockles in the areas open to cockle fishery.

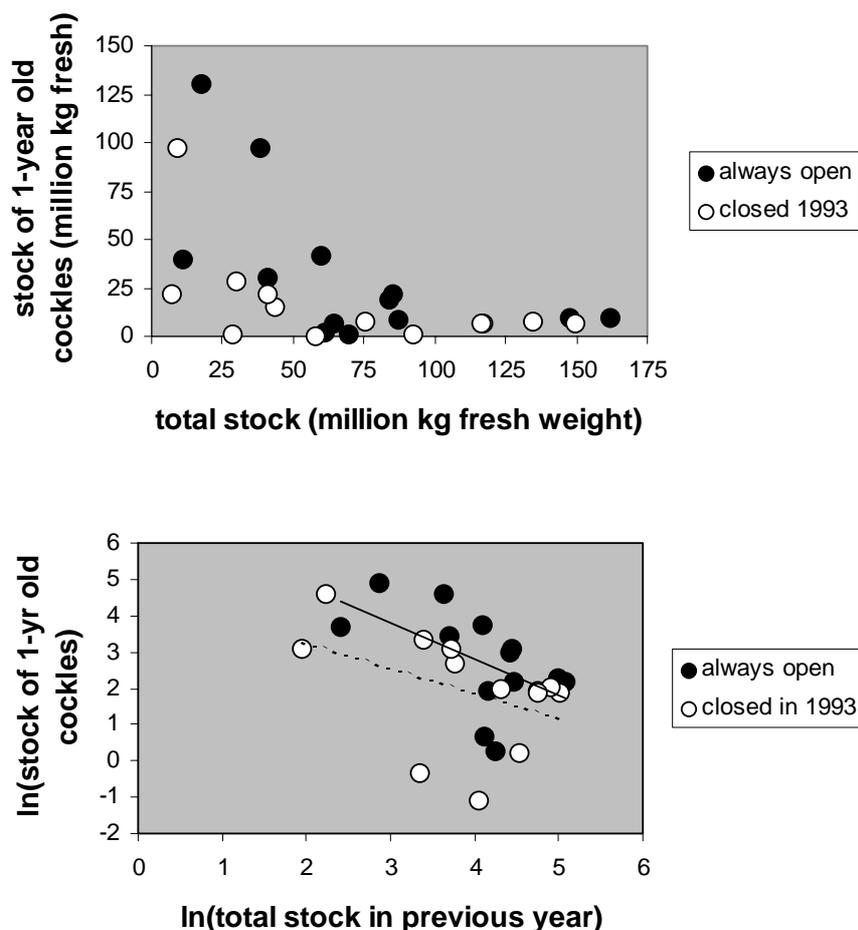


Figure 35: (a) Density of 1-year old cockles plotted against the stock of cockles in the previous year, separated for areas open and closed for cockle fishery. (b) Same plot as in (a) except that the logarithms are taken to allow statistical analysis. Closed areas (SN93): $r=-0.43$, $N=13$, $P=0.07$, 1-tailed. Open areas: $r=-0.52$, $N=13$, $P<0.05$, 1-tailed. Data from Kamermans et al. (2003a), complemented with recent data from the RIVO-surveys (Kesteloo et al. 2004).

3.4.2 Cockle distribution

Apart from influencing the abundance of cockles, cockle fishery may also affect the distribution of cockles. We expect fishery to concentrate on beds with high densities of large cockles low in the tidal zone. This is because (1) high cockle densities yield many cockles per unit fishing effort, (2) large cockles are more valuable and (3) areas low in the tidal zone are easiest to fish and most often available to the boats. Cockles grow well on low-lying sandy tidal flats and grow relatively slowly on higher muddy areas near the mainland coast (Jensen, 1992). Thus, the expectation is that after a good spatfall cockles will be fished first from low-lying more sandy areas and only later from high-lying muddy areas. For the good spatfall of 1997, the prediction is borne out with respect to the silt content of the sediment of the beds, because in open areas, remaining cockle beds were increasingly found in muddy areas, in

contrast to the beds in closed areas (Zwarts *et al.*, 2004; Figure 36). However, the prediction is not borne out with respect to the height of the remaining cockle beds, because in both open and closed areas remaining cockle beds were increasingly found high in the tidal zone (Zwarts *et al.*, 2004; Figure 37).

How can this be explained? It should be kept in mind that some new beds will have developed from the relative small spatfalls after 1997. Thus, the changing distribution of cockle beds following the large spatfall of 1997 will not only depend on the depletion of this large spatfall, but also on the location of new spatfalls, although to a lesser extent. If new and small spatfalls primarily occurred high in the tidal zone, this may explain the (unexpected) upward trend for the closed areas in the graph relating height of the beds to the number of years after the large spatfall of 1997 (Figure 37). In fact, when recruitment of cockles is poor, it occurs primarily high in the tidal zone (Beukema & Dekker, 2004).

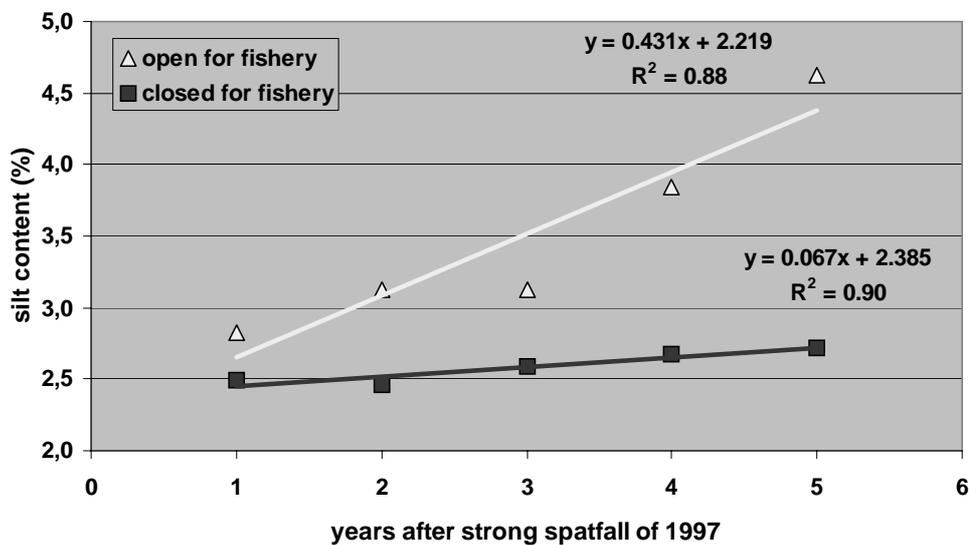


Figure 36: Silt content (%) of top layer in areas where cockle beds were found, plotted against the number of years since the strong year class of 1997, for areas open and closed for fishing. From Zwarts *et al.* (2004).

Selective mortality, due to predation or fishery, may cause changes in the distribution of a single year class of cockles as it grows older. Over a longer time scale, the distribution of cockles may change as a result of changes in recruitment with respect to height and silt content. There is clear evidence for such a change in distribution on a longer time scale. In the 1980s, many beds were present in the middle of the Wadden Sea, somewhere between the mainland coast and the islands (Figure 38). In the 1990s, most beds were present along the boundaries of the Wadden Sea, mainly near the mainland coast but near the Wadden Sea islands as well. The distribution maps are from the fishermen and it is possible that cockle beds in less profitable muddy areas were not mapped as well in the 1980s, compared to the 1990s. However, the absence (or disappearance) of beds in the centre of the Wadden Sea in the 1990s cannot be caused by changes in monitoring because in the 1990s all relevant concentrations have been mapped by thorough monitoring. The shift in location of spatfall to higher positions in the tidal zone is demonstrated in Figure 39,

for the main recruitment years 1979, 1987, 1992 and 1997 (Zwarts *et al.*, 2004). The change in the position of the beds after each of the large spatfalls is due to the processes of selective mortality (and some new recruitment) described previously. As expected, the beds from the recruitments in 1987, 1992 and 1997 showed a shift to higher elevations. Remarkably, the beds of the large recruitment of 1979 stayed more or less in place.

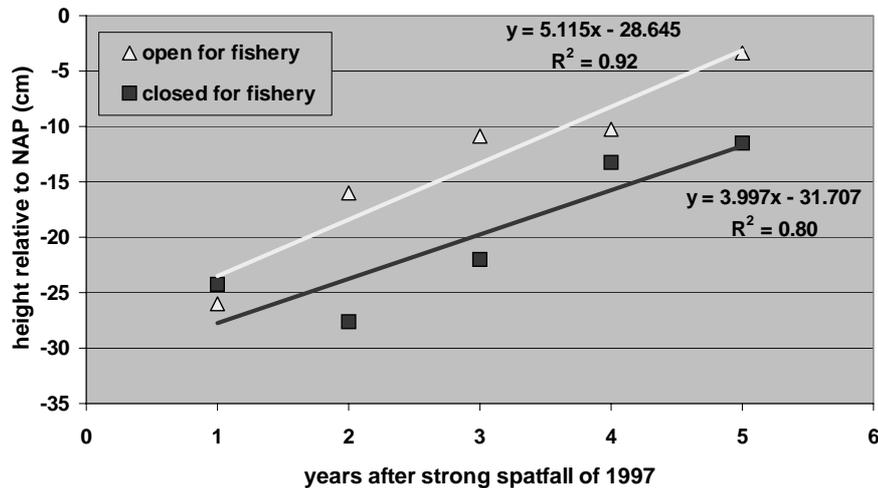


Figure 37: Height of cockle beds in the tidal zone against the number of years since the strong year class of 1997, separated between cockles in areas open and closed for fishing. From Zwarts *et al.* (2004).

The distribution maps in Figure 38 suggest that the shift of cockle beds to higher elevations was not as pronounced in the large closed areas of the Balgzand and Terschelling, both closed from 1990 onwards, and the Rottumeroog-Rottumerplaat area, which was closed in 1988, 1989, partly in 1990 and from 1990 onwards. Frequency diagrams support the observation that the shift to higher elevations was more pronounced in the open areas than in the closed areas (Figure 40; Zwarts *et al.*, 2004). However, this shift was not equally strong in the closed areas in comparison with the open areas. As can be seen in Figure 38, the beds mainly disappeared from the middle of the Wadden Sea in the entire area between Texel and Schiermonnikoog. These flats were open for fishery, except the small enclave of the Piet Scheveplaat between Ameland and the mainland coast. The large closed area south of the islands Rottumeroog and Rottumerplaat showed no systematic shift. The distribution mainly changed in respect to the tidal height of the flats; the lower, generally more sandy central areas, which were open to fishery, lost their cockle beds. The change in distribution with respect to height, summarized for all closed and open areas, is given in Figure 40. The distribution also changed in the closed areas, but less pronounced compared to the open areas. This change in the closed areas was taken into account when the difference between open and closed areas was analysed. The additional, fishery-related change was significant ($P < 0.001$).

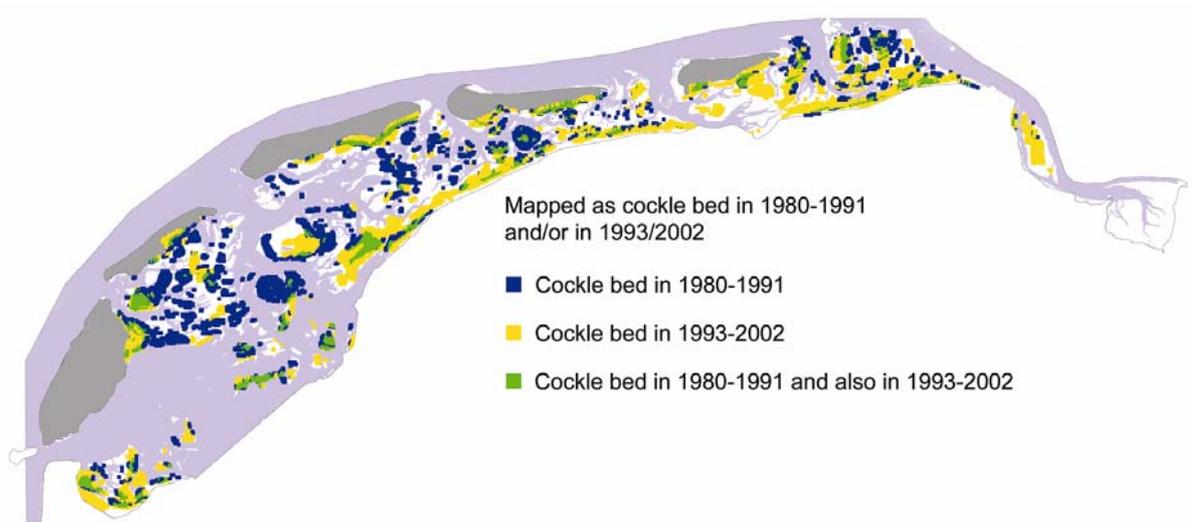


Figure 38: Location of cockle beds in the Wadden Sea in different periods. Based on maps drawn in the field by the fishermen in spring each year. From Zwarts et al. (2004).

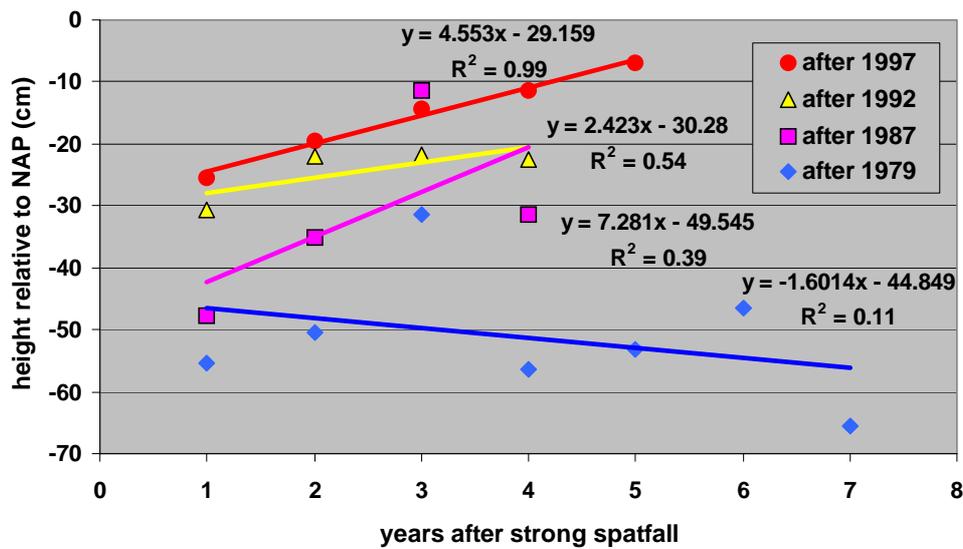


Figure 39: Location of cockle beds with respect to height as a function of the number of years since a good spatfall. From Zwarts et al. (2004).

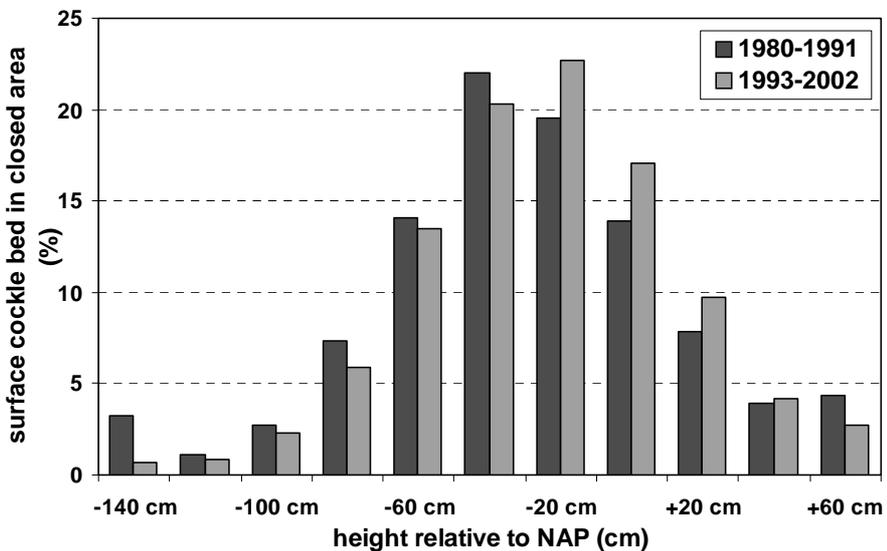
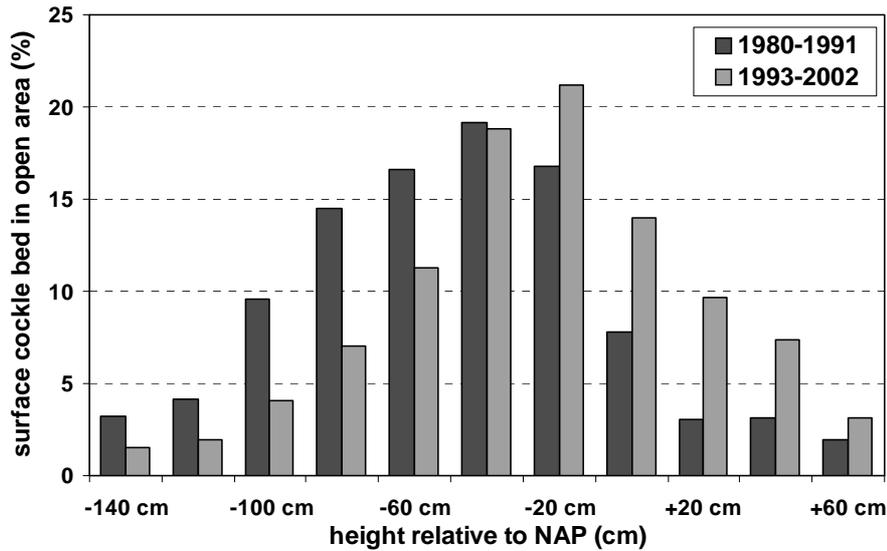


Figure 40: Height of cockle beds as percentage of the total area of beds in the years 1980-1991 and 1993-2002, based on the data in Zwarts et al. (2004).

3.5 Short-term and medium-term effects on non-target benthic species

A direct effect of mechanised cockle fishing is that all benthic fauna which live just beneath the surface is washed out at sites where the cockle dredge disturbs the seabed. The knife at the front of the dredge is set at a depth of 3 cm. Apparently, the sediment is washed out to a depth of at least 4-5 cm, corresponding to the underside of mature cockles in the sediment. The fishing tracks overlap and cross each other, but each track will be filled partly with the washed-out sediment that escapes through the bottom bars of the fishing gear. A next crossing (Figure 41) will increase the total depth. Evidence for increased depth is that these extra crossings cause increased

bycatch of benthic fauna, as demonstrated by (de Vlas, 1982), like mature *Macoma* individuals that live in this sediment zone. Consequently, the mortality of benthic animals is mainly restricted to species that dwell in the upper layer, or are present with body parts that cannot regenerate. Mortality figures, as measured over fished cockle beds as-a-whole, for fishing intensities that removed some tens of percents up to more than 90% of the cockles are given in Table 7. There is no indication from this table that new fishing gear and fishing techniques have reduced mortality of non-target benthic fauna. Comparable mortality figures have been observed in other studies on suction dredging for cockles, both in the Netherlands (Hiddink, 2003) and in the United Kingdom (Hall & Harding, 1997; Ferns *et al.*, 2000). The losses observed in Table 7 were followed by recovery during the year after fishing, due to new generations of small organisms. The effect will last until immigrants and/or new generations have taken over completely and will be especially marked for long-lived sedentary species.

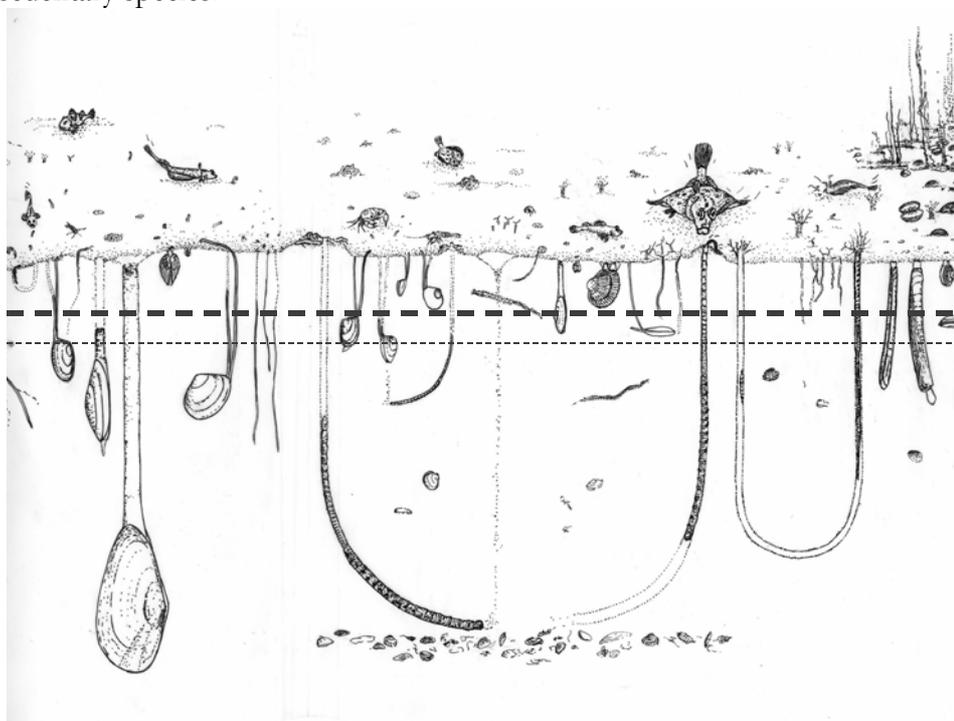


Figure 41: Schematic representation of the benthic fauna living in and on the sediment and the depth to which suction dredge penetrates the sediment. The dotted lines indicate the approximate fishing depths in initial (not overlapping) tracks and in tracks that overlap with others. Adapted from de Vlas (1985).

Several authors have advanced the hypothesis that disturbance of the bottom, as happens in mechanised cockle fishing, could cause an increase in the numbers of worms in the fished sites, at the expense of the numbers of shellfish (Reise, 1982; DAYTON *et al.*, 1995). Examination of the benthic fauna on fished and unfished locations with cockles (Leopold *et al.*, 2003a) provided no evidence for a general increase of worms. Two shellfish species were clearly negatively affected by cockle fishery, apart from the cockles themselves: (scattered) mussels and *Macoma* disappeared from the fished sites, although for *Macoma* a decline due to fishery could not always be established for all years (Figure 42, Figure 43). At higher densities of cockles and fishing effort, the fished areas showed similar or lower population levels

of the large worms *Lanice* and *Arenicola*, instead of the predicted increase. No effect was observed on the smaller *Scoloplos armiger* (a bristleworm). In the case of the still smaller worms, such as spionidae and nematodes, more fishing actually equated to fewer worms. Yet, one large worm species, the ragworm *Nereis diversicolor* was more abundant on medium to intensively fished cockle beds than in unfished conditions. As it happens, ragworms are probably the most important source of food for many worm-feeding bird species (Leopold *et al.*, 2003a). In a geographically more restricted study in the western Wadden Sea Kraan *et al.* (2004) found evidence that shellfish decreased in the fished sites, whereas worms increased, compared to nearby unfished sites.

Table 7: Mortality of benthic organisms on cockle beds, observed within some weeks after fishery on a number of fished cockle beds in the Wadden Sea and the Oosterschelde in 1979 and 1980 (de Vlas, 1982) and one cockle bed south of Ameland fished in 1999 and 2000 (Ens *et al.*, 2004). In the study of Ens *et al.* (2004) no distinction was made between spat and adults of *Macoma*; in one year an increase of 25% was calculated for *Heteromastus* directly after fishing.

	Study de Vlas (1982)	Study Ens <i>et al.</i> (2004)
<i>Cerastoderma</i> , spat	10%-50%	No data
<i>Macoma</i> , spat	5%-30%	} 45%-50%
<i>Macoma</i> , adult	0%-25%	
<i>Mya</i> , spat	0%-60%	No data
<i>Mya</i> , adult	0%	No data
<i>Hydrobia</i>	0%-1%	No data
<i>Corophium</i>	Some	No data
<i>Nereis</i>	0%-20%	30%-55%
<i>Nephtys</i>	5%-40%	No data
<i>Scoloplos</i>	5%-30%	60%-100%
<i>Heteromastus</i>	??-50%	?? – 25%
<i>Lanice</i>	0%-5%	55-70%
<i>Arenicola</i>	0%	No data

Cockle shells can serve as a substratum for mussel spat. For this reason a reduction in subsequent spatfall of mussels was anticipated on cockle beds where cockle fishing had taken place. Several observations exist of a negative impact of cockle fishing on mussel spat on a small scale (Hiddink, 2003; de Vlas, 1982) and photograph in Brinkman *et al.* (2003c), in addition to one observation of mussel spatfall on both the fished and the unfished part of a cockle bed (Ens *et al.*, 2004). However, in the extensive EVA II study of Brinkman *et al.* (2003c) covering the entire Wadden Sea, no clear pattern emerged when the spatfall of mussels was related to cockle fishery in the previous autumn at the scale of the Wadden Sea.

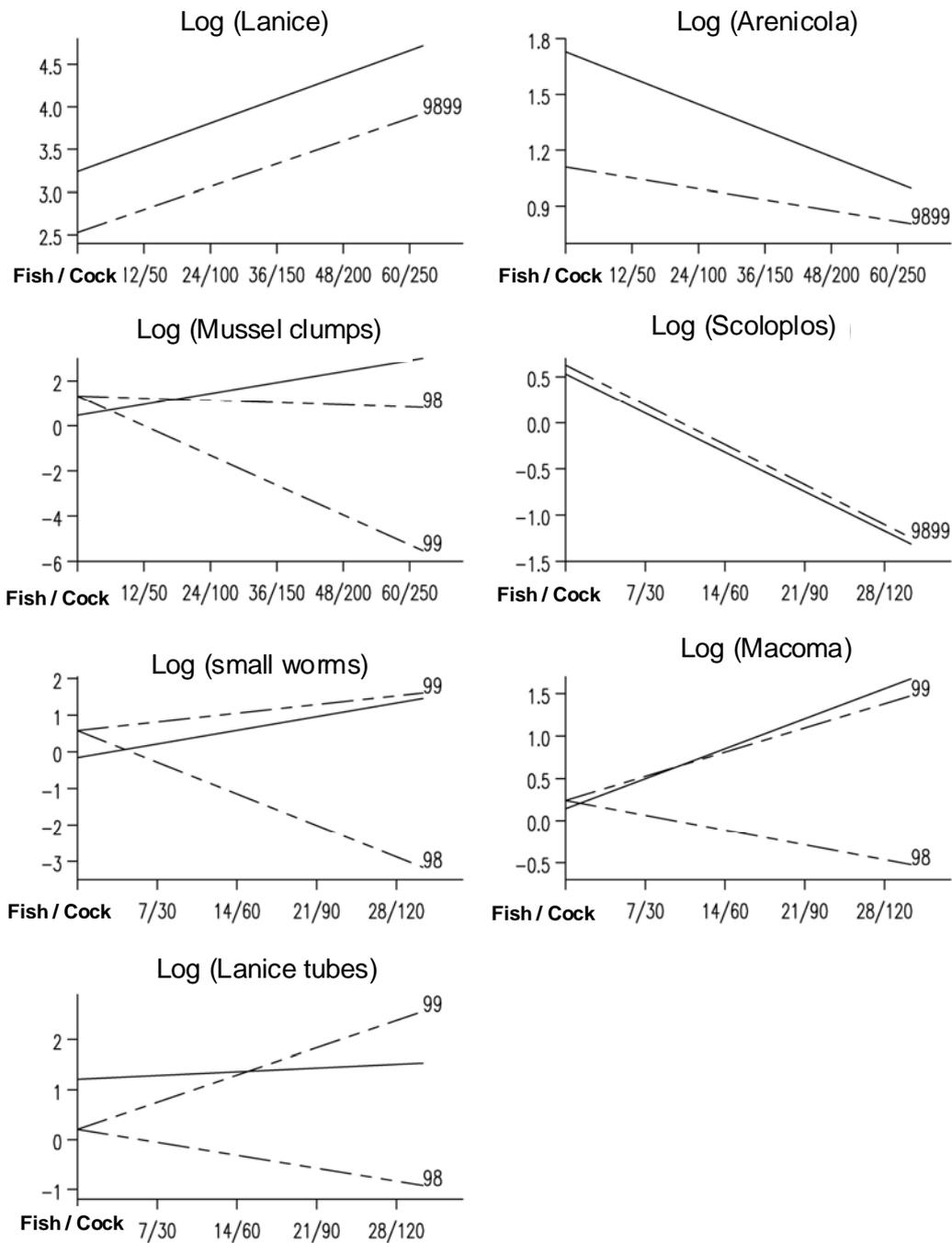


Figure 42: The effect of cockle fishery as determined from the sampling in 2000. For various benthic species the logged density is plotted against the cockle density (number on the right in number of cockles per 0.25 m²) in the closed areas (continuous line) and against the fishing effort (number on the left in number of registrations by the black box in a square measuring 50 by 50 m around the sampling location) in the open areas (interrupted line). The analysis assumes that cockle density can be matched with fishing effort. The numbers near the line indicate the year of fishing – separate lines were drawn when the statistical analysis indicated that the result depended on the year of fishing. From Leopold et al. (2003a).

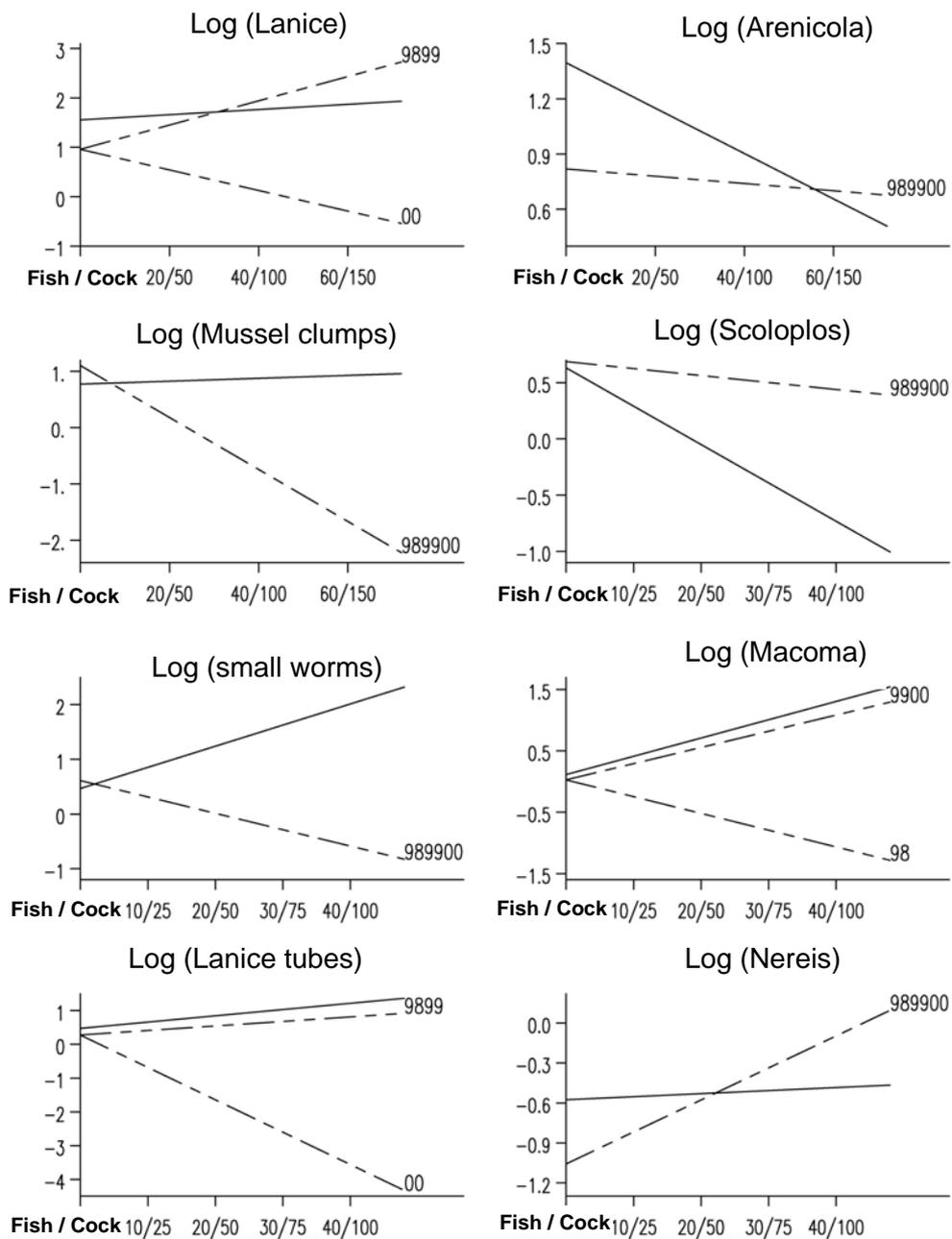


Figure 43: The effect of cockle fishery as determined from the sampling in 2001. For various benthic species the logged density is plotted against the cockle density (number on the right in number of cockles per 0.25 m²) in the closed areas (continuous line) and against the fishing effort (number on the left in number of registrations by the black box in a square measuring 50 by 50 m around the sampling location) in the open areas (interrupted line). The analysis assumes that cockle density can be matched with fishing effort. The numbers near the line indicate the year of fishing – separate lines were drawn when the statistical analysis indicated that the result depended on the year of fishing. From (Leopold et al. (2003a).

3.6 Effects on benthic fauna in a subtidal area

The EVA II studies on the effects of cockle fishery have focused on cockle fishing on the tidal flats, both in the Wadden Sea and in the Oosterschelde. The reason being that sublittoral stocks of cockles are minor compared to the littoral stocks. However, in 2002, the effects of hydraulic dredging for cockles on the sediment structure, the non-target species and the under-sized cockles associated with a subtidal cockle bed have been experimentally investigated in the northern part of the Voordelta (SW Netherlands) (Craeymeersch & Hummel, 2004).

Changes in sediment particle size composition and infaunal community were examined. Sediment composition was not significantly different among control and treatment plots before and 7 months after fishing. At most of the stations there was an increase in silt content, up to more than 30%. There were large temporal and spatial differences in the benthic community structure and densities of the numerically dominant species. The temporal changes in the density of cockles, tellins and sand gapers were not different in the treatment and control plots, both 2 weeks and 7 months after fishing. At a few sampling locations characterized by a high silt content (>46.5%) the diversity appeared to be lower than statistically expected. There was a significant negative relationship between total number of polychaetes and fishing activities. There is no evidence that fishing activities affected species' interactions. Further statistical analysis showed that the amount of variation in the species data purely related to fishing activities was lower than 6%. The authors therefore concluded that there were no substantial effects of fishing activities on the sediment structure and the infaunal community (Craeymeersch & Hummel, 2004).

3.7 Protection of seagrass beds

Communities of common seagrass (*Zostera marina*) and dwarf seagrass (*Zostera noltii*) in the Dutch Wadden Sea were reduced to a few scattered remnants around the 1930s (den Hartog & Polderman, 1975; Philippart *et al.*, 2003; Philippart, 1994) and showed little recovery since. Like mussel beds, seagrass beds (Figure 44) harbour a rich community of life. Policy is aimed at restoration of the seagrass beds (Anonymous, 1990). For this reason most of the areas in which seagrass grew in 1993 are included in the closed areas for mechanical shellfish fishery. The fishing plans of the shellfish sector (Productschap Vis, 2000) ensure that new seagrass beds known to the sector will not be fished. Habitat maps (de Jonge & de Jong, 1999) indicate that there are also other areas along the edges of the Wadden Sea which could be suitable for seagrass (Figure 45).



Figure 44: The two species of seagrass that occur in the Wadden Sea: (a) Common seagrass *Zostera marina* (Photo www.zeegras.nl), (b) Dwarf seagrass *Zostera noltii*. Photo Jaap de Vlas.

During the evaluation period, common seagrass gained ground in 2000 in the closed area west of the Eemshaven and south of Rottumerplaat, as well as in the open area south of Schiermonnikoog. In the Terschelling harbour basin, however, common seagrass further declined. Dwarf seagrass increased slightly during the evaluation period in both closed and open areas (Essink *et al.*, 2003).

Regarding common seagrass, too little data are available to allow any conclusion on cockle fishing preventing establishment of seagrass beds after 1993. Along the North Groningen coast, however, dwarf seagrass managed to colonise a single fairly large area of intertidal flats between 1996 and 1999 when there was absence of fishing for cockles (Essink *et al.*, 2003). After this area was fished again since 1999, distribution of dwarf seagrass showed a gradual retreat, coinciding with progressing coverage of cockle fishing. In 2002, hardly any dwarf seagrass was left in the area open for cockle fishery, i.e. outside the brushwood groyne lined sedimentation fields, where cockle fishery is not allowed. The total area lost was about 60 ha, mostly consisting of small separate patches of dwarf seagrass (Figure 46). This loss confirms observations in other areas that cockle fishery is detrimental to seagrass beds (de Jonge & de Jong, 1992; de Jong & Meulstee, 1989; Groeneweg, 2002b; Philippart, 1994). Results of professional surveys, e.g. (Groeneweg, 2002a; Groeneweg, 2002b; Groeneweg, 2001), coming available later, have not been communicated well in time before the fishing season. Some recovery was observed during the summer of 2003, when about one third of the damaged area contained sea grass plants again (Groeneweg, 2003).

Fishing for cockles in the area shown in Figure 46 occurred because the presence of dwarf seagrass was not well known to the fishermen. Moreover, young plants and small separate patches are difficult to discern at the time of surveys on foot carried out by the fishermen themselves. Thus there is a risk that newly established beds in the open areas will not be discovered in time.

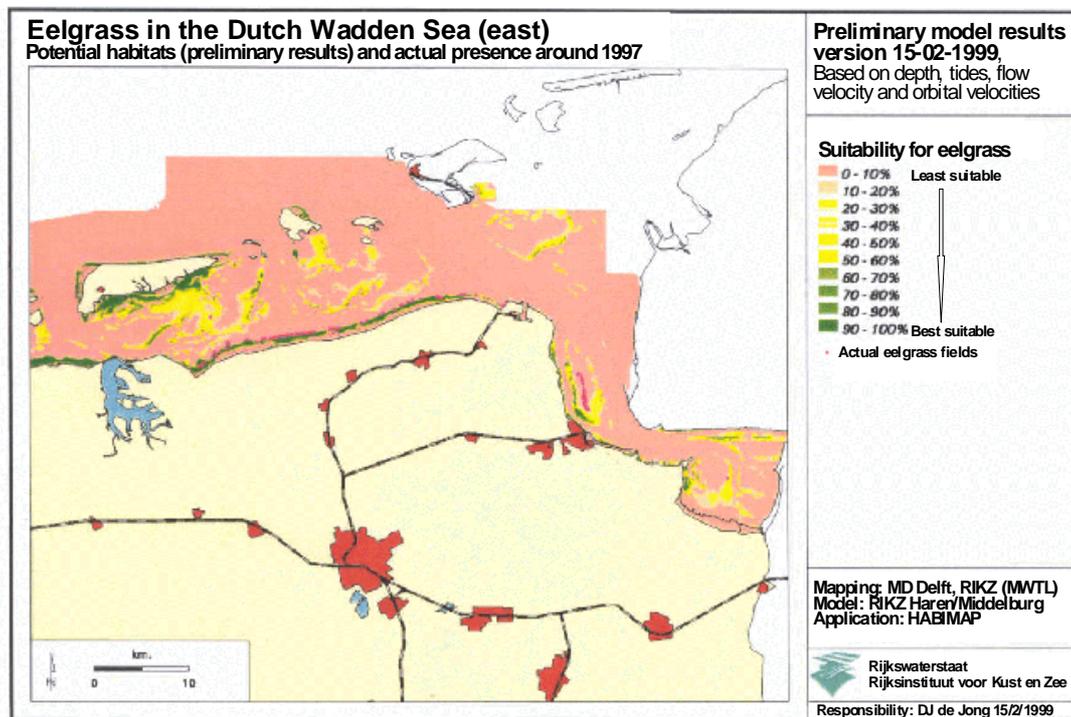
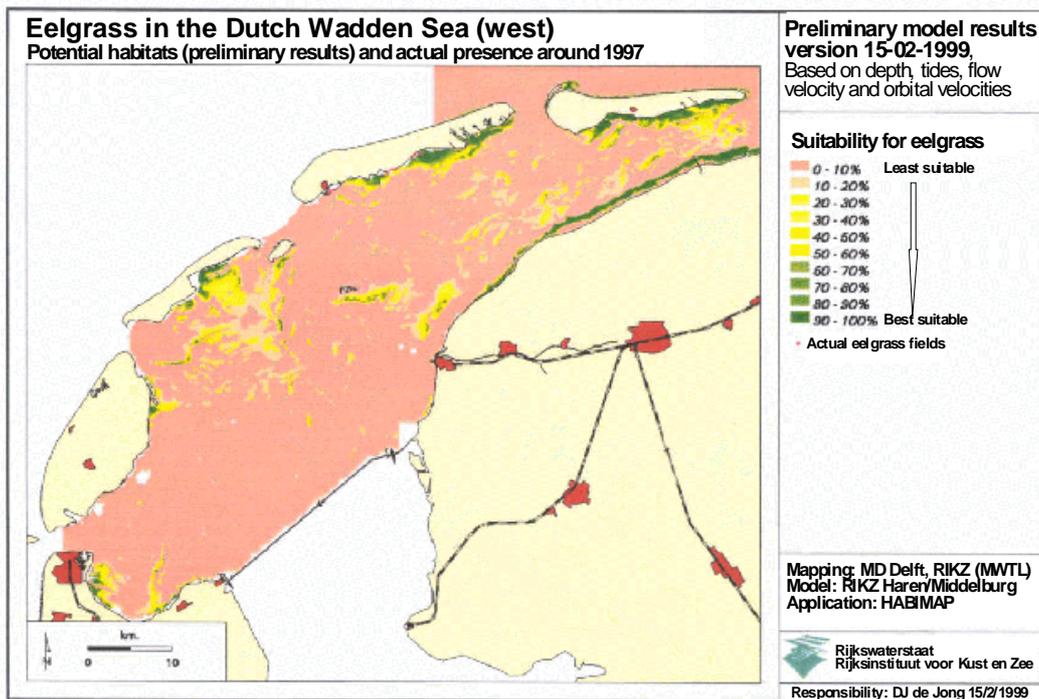


Figure 45: Map of potential seagrass habitat. From de Jonge & de Jong (1999).

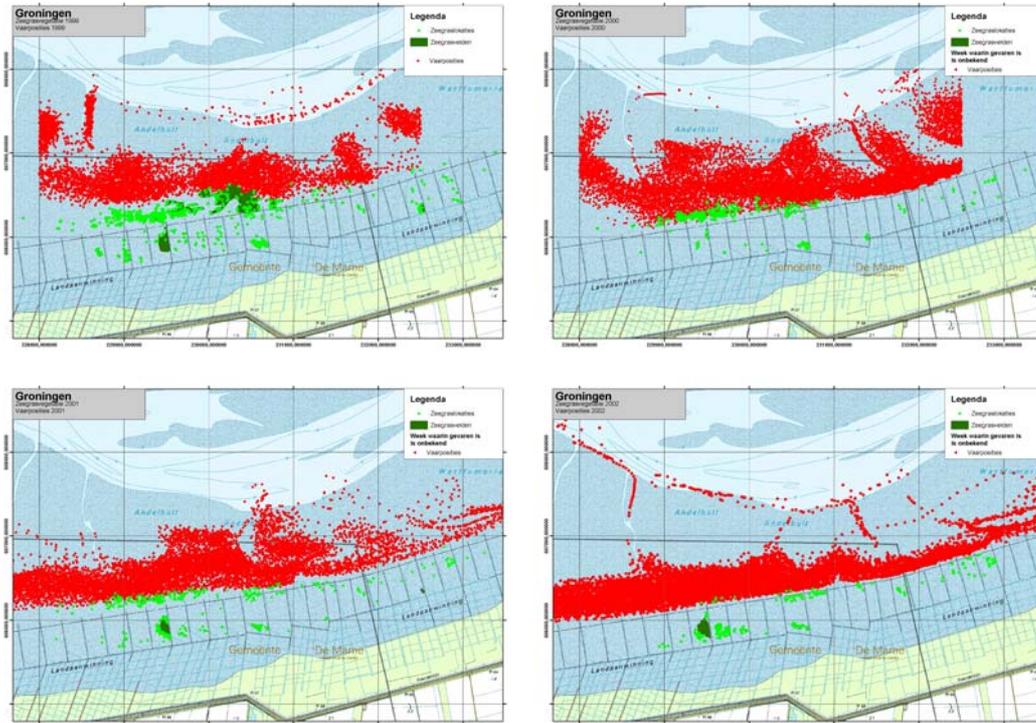


Figure 46: Recording of the position of a cockle boat during fishing (red) and of dwarf seagrass (*Zostera noltii*; green) on the mud flats outside the land reclamation near the Linthorst Homanpolder, Noord Groningen. (a) 1999, (b) 2000, (c) 2001 en (d) 2002. Source: black box data P.O. Kokkels; seagrass data from (Groeneweg, 2002a; Groeneweg, 2002b; Groeneweg, 2003; Groeneweg, 2001). Drawing from Essink et al. (2003).

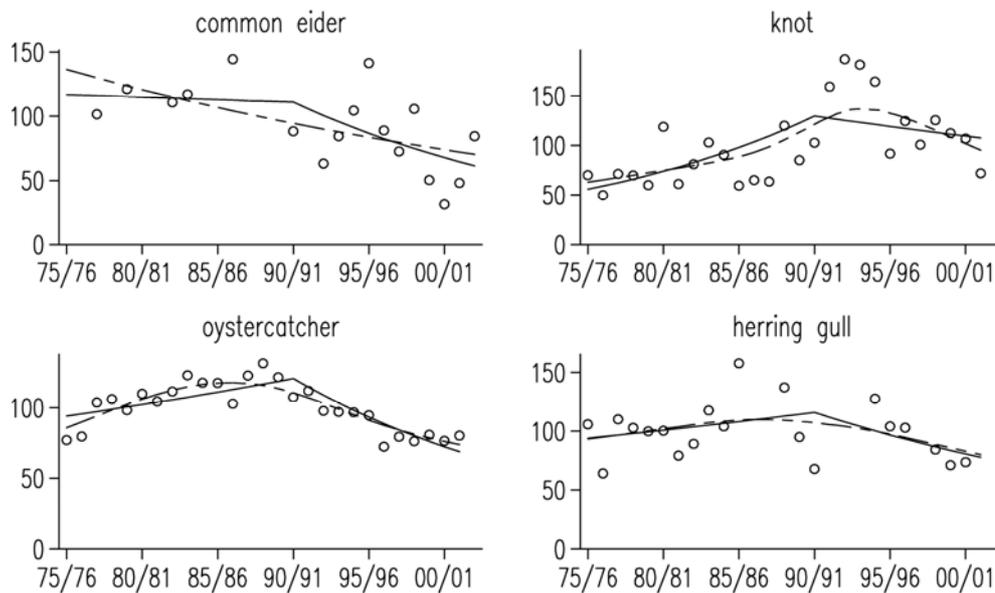


Figure 47: Index of the average number of birds counted in the Wadden Sea against season, for birds feeding on bivalve shellfish. Also shown the spline function for the entire period and for the periods before and after the disappearance of the intertidal mussel beds. A change in trend is significant for oystercatcher and knot. The eider duck is included for comparison, but the data apply to January counts only and the trend is distorted because available counts before 1975 are not included (see text). From Leopold et al. (2003b).

3.8 Effects on birds

A first indication of the effect of cockle fisheries on birds was obtained through comparison of the development of their usage (measured as the number of bird days per year) of areas open and closed for shellfish fishery (Leopold *et al.*, 2003b). These trends must be studied within the trends observed for the Wadden Sea as a whole. For many bird species that feed on the intertidal flats of the Wadden Sea, a change in trend in the annual usage of the flats occurs somewhere at the end of the 1980s, beginning of the 1990s (Figure 47, Figure 48, Figure 49, Figure 50). This corresponds to the disappearance of the intertidal mussel beds. In the graphs we fitted a trend line using splines (Hastie & Tibshirani, 1990) for the entire period, and for the periods before and after the disappearance of the intertidal mussel beds. We subsequently tested whether the change in trend was statistically significant. Changes from a negative trend towards a positive trend outnumber changes from a positive trend towards a negative trend. For species feeding either primarily on worms or shellfish, the greater the percentage shellfish in the diet, the larger the decline during the last ten years (van Roomen *et al.*, 2004). The only species not fitting the trend is the avocet, which feeds on worms, yet showed a decline in recent years. For species that feed primarily on prey other than bivalves or worms (Figure 50), and for species whose diet is a mixture of shellfish, worms and other prey (Figure 49), no simple patterns emerge.

Four species of birds were identified as shellfish eaters: common eider, oystercatcher, herring gull and knot. All these species have declined in recent years, although the onset of the decline varies between the species (Figure 47). Of these, the common eider and the oystercatcher feed on large shellfish, whereas knot and herring gull feed on small shellfish. Since common eiders depend primarily on the subtidal areas for their food supply, we did not investigate the effect of closing intertidal areas. In contrast to waders, several counts of eiders covering the entire Wadden Sea are available for the period before 1975. We did not include these counts in (Figure 47) to facilitate comparison with the other bird species. However, including these counts makes clear that the suggestion that eiders have continually decreased from 1975 onwards is an artefact of this selection of the data. Eiders have increased during the 1960s, fluctuated in numbers during the 1970s and 1980s, and declined during the 1990s. The recent decline in the Wadden Sea was accompanied by an increase in the number of eiders using the North Sea coastal zone (see Figure 72 in chapter 5), but this increase did not fully compensate for the decline in the Wadden Sea (Ens & Kats, 2004). The interpretation of these changes is discussed in chapter 5, where the policy of food reservation for common eiders is evaluated.

The numbers of oystercatchers declined after about 1990 (Figure 47). The decline in the number of oystercatchers started in the first half of the 1990s. Since the strong and sudden decline due to the severe winter of 1996/1997, no further decline has occurred, nor have numbers recovered. The lowered numbers are largely due to the disappearance of the intertidal mussel beds in 1990 (Smit *et al.*, 1998; Rappoldt *et al.*, 2003a), see also chapter 5. The fact that we did not see a sudden decline in the number of oystercatchers following the rather sudden disappearance of the intertidal

mussel beds is due to the fact that oystercatchers can feed on alternative, less profitable prey. This does lead to a slightly higher mortality rate (Stillman *et al.*, 2000), and perhaps reduced reproduction in summer. Since oystercatchers are long-lived, a slight increase in mortality rate may cause an increasing population to decline (Goss-Custard, 1996). In addition, severe winters may lead to strongly increased mortality and a sudden drop in numbers, as happened in the winter of 1996/97. If feeding conditions during winter are good during subsequent years, the population may recover. If not, the population will remain low. In this respect it is striking that the population did not suffer long from the three severe winters in the period 1984-1987, when mussel beds were present, but has not yet recovered from the two severe winters during the period 1995-1997, when there were few mussel beds.

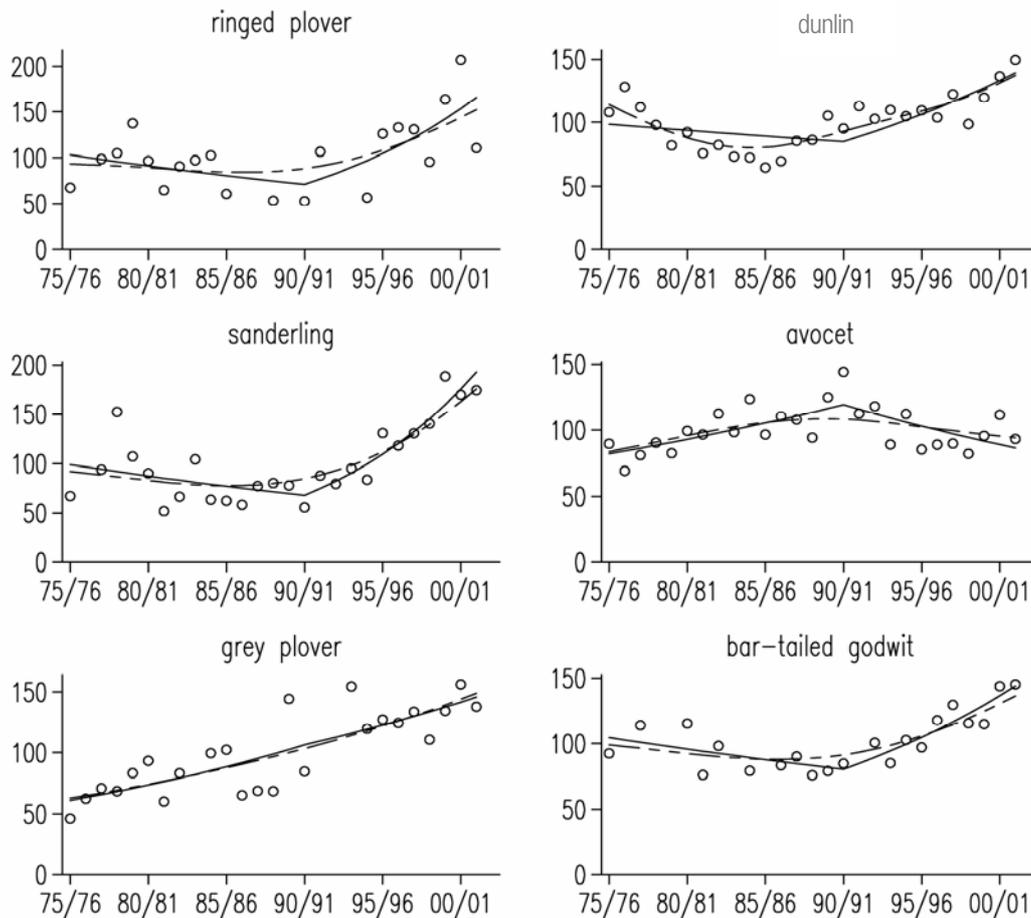


Figure 48: Index of the average number of birds counted in the Wadden Sea against season, for birds feeding on worms. Also shown the spline function for the entire period and for the periods before and after the disappearance of the intertidal mussel beds. The change in trend is significant for avocet, ringed plover, sanderling, dunlin and bar-tailed godwit. From Leopold *et al.* (2003b).

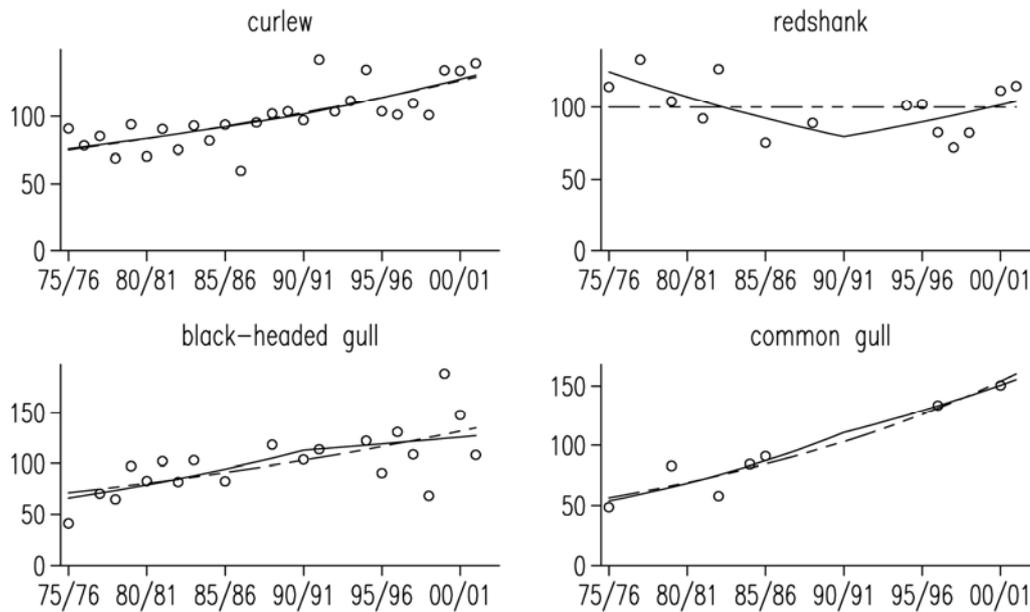


Figure 49: Index of the average number of birds counted in the Wadden Sea against season, for birds feeding on a mixed diet of worms, bivalve shellfish and other prey. Also shown the spline function for the entire period and for the periods before and after the disappearance of the intertidal mussel beds. The change in trend is significant for redshank. From Leopold *et al.* (2003b).

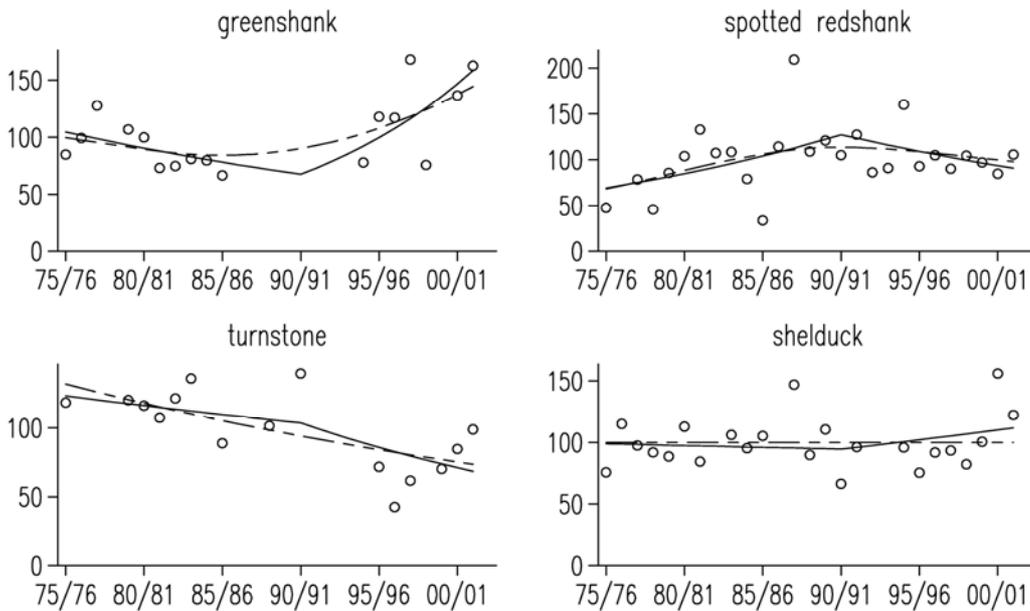


Figure 50: Index of the average number of birds counted in the Wadden Sea against season, for birds feeding primarily on 'other' prey like crustaceans and fish. Also shown the spline function for the entire period and for the periods before and after the disappearance of the intertidal mussel beds. The change in trend is significant for spotted redshank, greenshank and turnstone. From Leopold *et al.* (2003b).

As will be discussed more fully in chapter 5 on food reservation, the carrying capacity for oystercatchers was calculated to be lowered by a number in the order of 15000 birds in the 1990s due to cockle fishery (Rappoldt *et al.*, 2003a). Thus, cockle fishery

also played a role in the decline. However, according to the analysis of Leopold *et al.* (2003b), the decline in oystercatcher numbers was sharper in closed areas for several of the time series that they analysed. In their analysis, they distinguished not only areas that were open or closed to fishery, but also a mixed category, mainly including areas with patches that were closed in 1999. It is clear from Figure 51a that the overall change in numbers described above, is repeated in each of these areas. The data depicted in Figure 51 apply to more years than analyzed by Leopold *et al.* (2003b) and a steeper decline in the closed areas is not obvious. According to the bottom panel of Figure 51, the distribution over the three areas remained roughly the same during the period of decline. How can we explain that oystercatchers did not increasingly utilize the closed areas, despite the fact that cockle fishery did affect the stock of mature cockles in the open areas as predicted (Kamermans *et al.*, 2003a)? Part of the explanation is that the decrease in the number of oystercatchers is primarily due to the disappearance of the intertidal mussel beds (Smit *et al.*, 1998; Rappoldt *et al.*, 2003a). The number of oystercatchers decreased from more than 260.000 in the 1980s to approximately 175.000 at the end of the study period, i.e. a decline of 85.000 birds. The decline in the carrying capacity as a result of cockle fishery is estimated at a number in the order of 15.000 birds (Rappoldt *et al.*, 2003a), which is less than 20% of the overall decline. Before the mussel beds disappeared in 1990, the distribution of oystercatchers in the Wadden Sea was positively correlated with the distribution of mussel beds (Ens *et al.*, 1993). The little evidence that we have suggests that mussel beds were slightly more common in the closed areas before they disappeared (Table 2). Subsequently, the mussel beds returned first in the open areas (Figure 52). Both effects obscure the effect of the decrease in cockle stocks in the closed areas due to fishery. A similar type of argument applies to another prey item, the Baltic tellin. Before the mussel beds disappeared, these clams were probably of little importance as food for oystercatchers during winter, due to their low profitability as a result of high burying depth at that time of year (Zwarts *et al.*, 1996b). During the 1990s, the oystercatchers primarily relied on cockles and Baltic clams according to the model calculations of Rappoldt *et al.* (2003); see also Figure 73 in section 5.2. During the years in this period that Baltic tellins comprised more than 20% of the diet, these shellfish were more common in the open areas (Kamermans *et al.*, 2003a). Finally, feeding in fields during high tide, which oystercatchers do in periods of food shortage (Goss-Custard *et al.*, 1996b), was probably more important in the 1990s than in the 1980s. It is possible that the closed areas offered fewer possibilities to feed in fields during high tide, than the open areas. Whether these explanations suffice, requires calculations with WEBTICS to determine the development of the feeding stress in different subareas of the Wadden Sea.

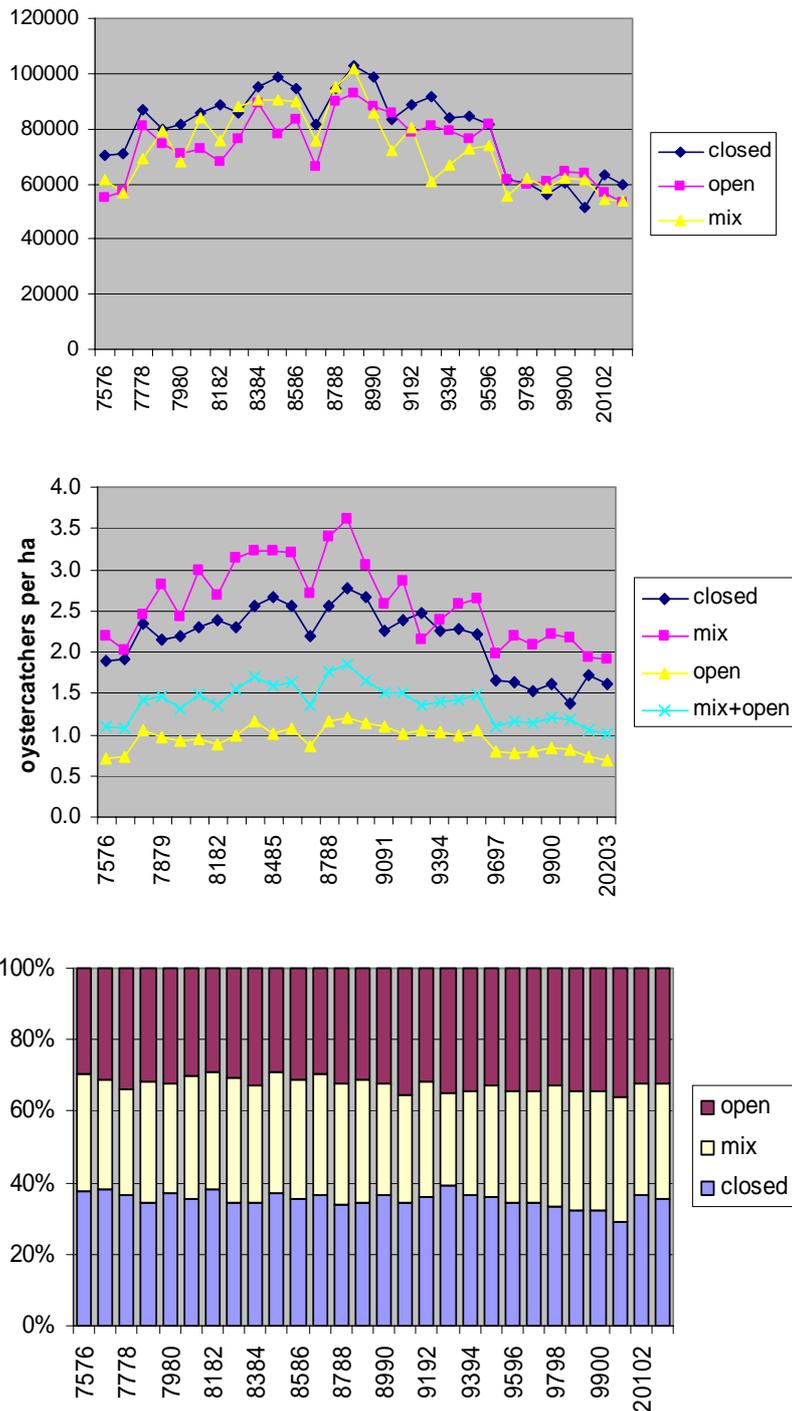


Figure 51: (a) The number of oystercatchers (imputed using integral as well as partial high-tide counts in the period August-January) in areas that were assigned to low-tide feeding areas on the basis of expert judgement (see methods) and classified as open, closed or mix. The data analyzed by Leopold et al. (2003b) were updated with more recent information from SOVON (van Roomen & van Winden, pers. comm.) (b) The same data as in panel a, but now expressed as feeding density by dividing the number counted during high tide by the surface of the assumed feeding area. (c) The same data as in panel a, but expressed as a proportion.

Additional insights were obtained by Verhulst *et al.* (2004). These authors caught oystercatchers in both open and closed areas to investigate the effect of cockle fishing on the condition of oystercatchers. The oystercatchers in the closed areas proved to be in better condition. The authors attribute this to the failure of the oystercatchers to redistribute in response to the changes in the food supply brought about by the cockle fishery. Their argument is supported by the well known site fidelity of oystercatchers (Ens & Cayford, 1996; Verhulst *et al.*, 2003). This does not mean that oystercatchers do not respond to changes in the food supply within their home range. After having been fished for cockles, a study site under Ameland was used less by oystercatchers, compared to a neighbouring control site (Ens *et al.*, 2004). Similarly, when an experimental mussel bed was created, the number of oystercatchers frequenting the area increased (Ens & Alting, 1996). However, in both cases all that probably happened was that individual oystercatchers shifted their use of space within their home range in response to the changes in food supply. In contrast, when the stocks of both mussels and cockles were very low in the Wash, the largest intertidal area in the United Kingdom, the oystercatchers did not move away (i.e. did not choose a new home range), but stayed and experienced high mortality (Atkinson *et al.*, 2003). Verhulst *et al.* (2004) estimate that mortality was increased by 43% in the areas open to cockle fishery. A limitation to the study of Verhulst *et al.* (2004) is that no attempt was made to control for confounding factors. The study had to be treated as an experiment, because for logistical reasons, sample sizes were too small to control for confounding factors.

A final feature of Figure 51 that must be discussed is that the feeding densities that we calculated differed consistently between areas. To obtain the feeding densities, we divided the number counted during high tide by the surface of the presumed feeding areas and it is certain that there are errors in the linking of high tide counts to the low tide feeding areas. Especially in the central part of the western Wadden Sea, the distinguished boundaries are quite arbitrary. Furthermore, birds using a particular feeding area can use different roosts. There are two locations where it is conceivable that considerable numbers of oystercatchers assumed to feed in a closed area on the basis of the location of their roost, do in fact feed in an open area: the eastern part of the Balgzand and the eastern part of Terschelling. Similarly, there are two places where it is conceivable that considerable numbers of birds assumed to feed in an open area, do in fact feed in a closed area: Griend and the Frisian coast south of the Piet Scheveplaat. Given these errors, the safest comparison is between the calculated densities in the closed areas and the rest (i.e. mixed plus open). A possible explanation for the consistently higher calculated feeding densities in the closed areas are the higher height (see section 1.5.9.2), which will allow the oystercatchers to feed for longer. Alternative explanations that need to be investigated are the presence of safe roosts, the distance between these safe roosts and the feeding grounds and the presence of fields where the oystercatchers can feed during high tide.

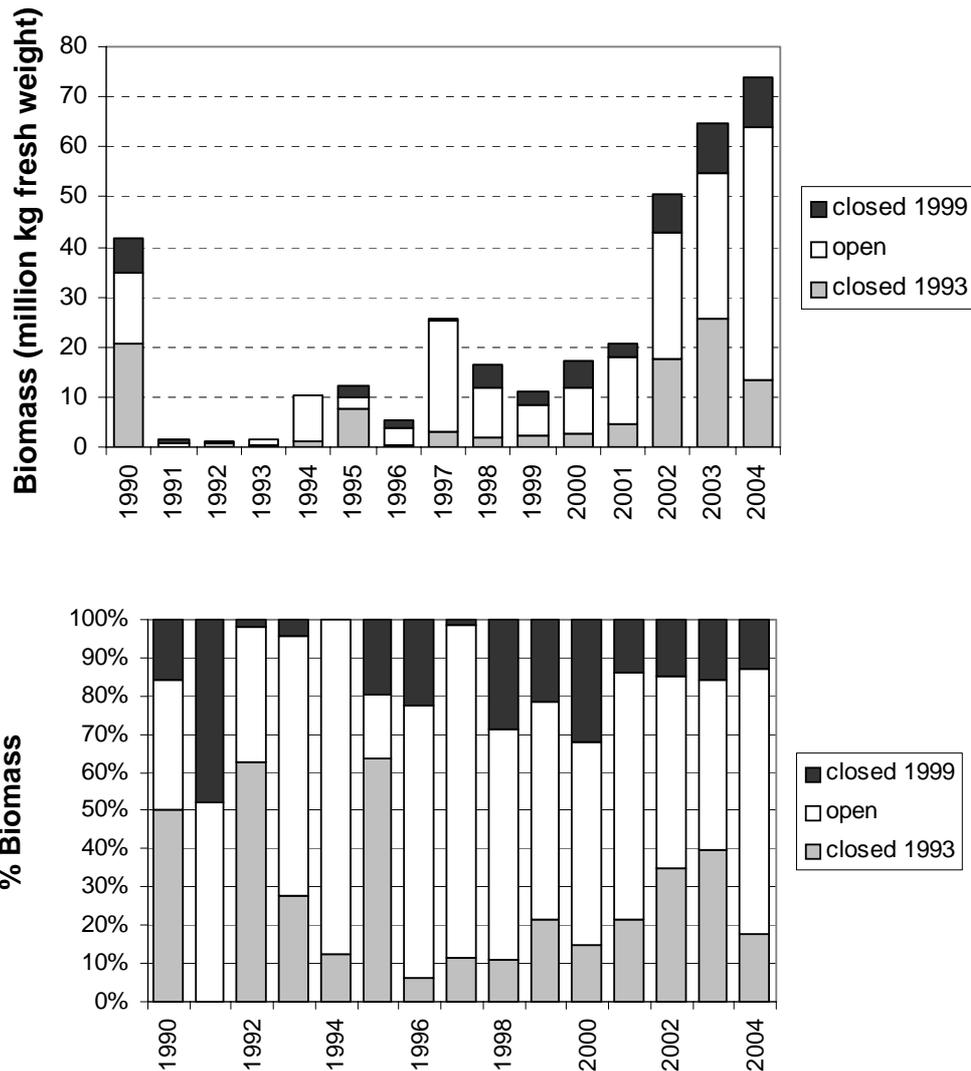


Figure 52: Distribution of mussel beds over areas open and permanently closed for shellfish fishery: (a) total area in ha, (b) percentage area.

According to Figure 47 the annual number of bird days of knots in the Wadden Sea has increased until the early 1990s and subsequently decreased again. Knots roost in only a few very large flocks so that counting errors are not averaged out (Rappoldt et al., 1985). Furthermore, it is possible that in the early days of counting flocks were sometimes missed (Leopold et al., 2003b). Since home ranges of individual knots are very large (800 km² according to Piersma et al. (1993)) and individual knot may even switch between the western part and the eastern part of the Dutch Wadden Sea within the same season (Spaans, unpublished), it is difficult to allocate birds counted during high tide to specific feeding areas. Analysis of changes in numbers with respect to area type (open or closed to fishing) suggest that the increase and subsequent decrease predominantly occurred in the open areas Leopold et al. (2003b). Given the uncertainties in the data, it is not possible to draw clear conclusions on the effect of shellfish fishery from these data.

Another approach is to study the effect of cockle fishery on the food supply of the knot. Knot depend on shellfish which are sufficiently small to be swallowed whole and sufficiently large to be profitable in terms of energy gain per unit handling time. Furthermore, the prey must be within reach (the length of the bill is 35 mm) and the ratio of flesh to shell weight must be high (Zwarts & Blomert, 1992). According to the last criterion, the four common bivalves in the Wadden Sea are ranked as follows: Baltic tellin > soft-shelled clam (*Mya arenaria*) > mussel > cockle. While Baltic tellin are the preferred prey, cockles are also often taken, because more profitable prey are not always available (Piersma *et al.*, 1993; van Gils *et al.*, 2004). In some years, we found evidence for a negative effect of cockle fishery on the density of *Macoma* in fished areas (chapter 3). Hence, cockle fishery may have a negative impact on the food supply of knots. For cockles, (van Gils *et al.*, 2004) present evidence that cockle fishery not only affects the quantity of cockles available, but also the quality of the prey. The more often an area is fished, the lower the quality of cockles in that area, measured as the ratio of flesh weight to shell weight. Local survival of knots whose stomach is of insufficient size to effectively digest thick-shelled cockles is reduced and was estimated to vary between 30% and 60%. This is much lower than the estimates of survival of adults in Britain, which varied between 75% and 85% in the period 1969-1995 (Boyd & Piersma, 2001). The important question is whether the knots with a stomach of insufficient size to digest poor quality cockles moved away from the Wadden Sea, or died.

In contrast to the shellfish-eating birds, the numbers of most species of worm-eating birds increased during the period 1990-2002 (Figure 48). The increase was largely seen in the open areas and to a lesser extent in the closed areas (Leopold *et al.*, 2003b). A possible explanation is that this is linked to the differential presence of mussel beds. The mussel beds initially developed well in the open areas off Ameland and Schiermonnikoog (Figure 52). Many worm-eating birds, such as dunlins, prefer to forage around mussel beds, e.g. Ens *et al.* (2004). An alternative explanation for the increase of the worm-eating birds in the open areas is that as a result of the cockle fishery, worm species became more common in these areas. According to Kraan *et al.* (2004) worms generally increased following cockle fishery. This was not observed by Leopold *et al.* (2003b), except for *Nereis diversicolor*, which is an important prey item for birds feeding on worms.

3.9 Discussion

3.9.1 Hand raking

Nowadays, most cockles are fished with suction dredges, but gathering by hand still occurs. The effects of hand gathering have not been studied. The direct loss of silt by hand raking is probably small, as the sediment is not washed through. Side-effects can be expected due the reduction of cockle biomass and damage to other organisms. In our studies, we have ignored the effects of hand gathering cockles, assuming them to be small in comparison with the effects of mechanical fishery,

because of the less radical intervention with the sediment and the small capacity of the hand gatherers (estimated at about 6% of that of the mechanical cockle fishery).

3.9.2 Recovery after disturbance due to suction dredging

The immediate effects of cockle fishery are undisputed and consist of extraction of marketable cockles, mortality of non-target benthic fauna and washing out of fine sediments. The important question is how quickly the sediment and biota recover from this disturbance. With recovery, we do not mean that the fished area returns to its original state, because unfished areas also continually change in a dynamic and variable ecosystem like the Wadden Sea. Rather, there should no longer be a difference between the affected area and a properly chosen undisturbed control area (Dernie *et al.*, 2003).

A qualitative review of the many possible ways in which dredging and trawling may impact benthic communities is provided by Dayton *et al.* (1995) and Watling & Norse (1998). More recently, Collie *et al.* (2000) undertook a meta-analysis of 39 published studies on the effects of towed bottom-fishing gear on benthic communities. They reached the following conclusions:

1. Intertidal dredging and scallop dredging have the greatest initial effects on benthic biota, while trawling has less effect.
2. Fauna in stable gravel, mud and biogenic habitats are more adversely affected than those in less consolidated coarse sediments.
3. Recovery rate appears most rapid in less physically stable habitats, which are generally inhabited by more opportunistic species.

In general, the results mirror biological intuition, but major gaps in knowledge were also identified. Very recently, Kaiser *et al.* (2004) repeated the meta-analysis with a much larger data-set. Intertidal dredging again comes out as one of the more detrimental fishing activities and recovery rate is estimated at several years.

An alternative approach has been taken by Kaiser in Lenihan & Micheli (2001). The idea is to relate the spatial scale of the disturbance to the temporal scale of recovery: the greater the spatial scale of the disturbance, the longer it takes to recover. Building on this approach Versteegh *et al.* (2004) conclude that the intensity of current cockle fishing in the Wadden Sea may be so high that the system cannot recover. The authors estimate the spatial scale of cockle fishing as the total surface fished in the Dutch Wadden Sea. When they had chosen to estimate the spatial scale as the average size of a cockle bed, they would have obtained a much lower number.

Cockle fishery extracts cockles, leads to mortality among non-target fauna and may have indirect effects. The time of recovery from the direct effects depends on the life span, recruitment and immigration capacity of the benthic organisms. For cockles, which are characterized by an average life span of approximately 5 years (which is less than for *Mya* and *Macoma*, but longer than for most worms), variable recruitment with on average one highly successful recruitment per 6 years and limited mobility, fishery could result in a prolonged effect. The environment in which cockles live is

not very stable, due to the absence of a solid or quiet substrate and due to the non-cushioned influence of air temperatures and storms. But even effects that last for 5 years before they get masked or overruled by natural events are long enough to bring the cockle habitat in a constantly affected state when cockle fishery is continued. Our investigations indicate that this constantly affected state will include years where the recruitment of cockles is higher in the areas open to fishery compared to the areas closed to fishery. When this happens in a year with high recruitment (as was the case in 2003), it is likely that in a number of years the total stock of cockles will be higher in the open areas.

The rate at which fishing tracks disappear may also offer a clue to recovery. Fishing tracks may disappear within some months, as in the experiment described in Ens *et al.* (2004), but remained detectable during more than a year on other places (along the mainland coast and on a location in the middle of other tidal flats, e.g. Figure 29). According to Dernie *et al.* (2003) the recovery time of the sediment is closely correlated to the recovery time of the benthic fauna. They also found that muddy sand takes longer to recover than either sandy or muddy substrates. However, their study applies to small, hand-dug study plots surrounded by large areas of undisturbed mud flats so do not necessarily apply to entire cockle beds fished by cockle boats. The opportunity to study in the Wadden Sea if these relationships also applied to disturbances at a larger spatial scale was not taken.

Cockle fishery leads to a loss of fine sediments directly after dredging. The comparison between areas open to cockle fishery with closed areas suggested a longterm difference, the silt content of the sediment being about 10% lower in the open areas. We hypothesize that the indications we found on the effect of cockle fishery on sediment composition result from two processes:

- (1) Resuspension and tidal transport of silt during fishing. This will initially result in a lower silt content of the fished area. Eventually, silt deposition will restore the old situation
- (2) Removal of cockles will lead to a reduction of the biodeposition capacity, leading to a lower flow of silt towards the bottom. Benthic filter feeders produce a lot of biodeposits as they sieve out silt and other particles from the water column. The non-edible fraction is rejected as pseudofaeces and deposited on the surface of the sediment. The edible fraction is ingested, and the non-digestible part is rejected as faeces that settles on the sediment as well (Smaal *et al.*, 1986; Smaal & Prins, 1993; Dame, 1996). Biodeposits can accumulate on the sediment or through bioturbation be reworked within the sediment, or they can erode and flush away. The fraction that remains in or on the sediment depends on the local hydrographical conditions, and in general mussels create more biodeposits due to their bed structure than cockles. Still cockle beds can also accumulate biodeposits, and it is therefore likely that removal of cockles reduces the capacity to accumulate silt. Restoration of this potential requires new spatfall i.e. restoration of the cockle bed.

The most obvious difference between areas open and closed to cockle fishery in the benthic fauna was the cockle stock itself. Lower cockle stocks in open areas were

primarily caused by the removal of the marketable cockles, but the difference was enhanced by some extra mortality in juvenile cockles as a result of fishing (de Vlas, 1982), increased predation by oystercatchers, and a lower cockle recruitment during the initial period 1993-2000. Other organisms showed changes as well. Leopold *et al.* (2003a) found lower densities of mussels and *Macoma*, as well as *Lanice* and other worms, with *Nereis* as the exception with increased densities on moderately to intensively fished locations. For shellfish, the results of Leopold *et al.* (2003a) agree with the results of Kraan *et al.* (2004). For worms, the results of Leopold *et al.* (2003a) do not agree with the results of Kraan *et al.* (2004), who found that, compared to unfished control areas, worms in general tended to increase following fishery⁶. The research of Leopold *et al.* (2003a) was carried out in the whole Wadden Sea, and was confined to locations with cockle beds, whereas the study of Kraan *et al.* (2004) was executed in the western part of the Wadden Sea, on cockle beds as well as in surrounding areas without cockles. For the time being, we conclude that there is some evidence from the EVA II project that cockle fishery favours ragworms *Nereis diversicolor* at the expense of shellfish, and that there is evidence from other research that worms increase in fished areas. The results from the EVA II project do not support the original suggestion of Reise (1982), but the results of Kraan *et al.* (2004) do. Ragworms are an important prey for worm-feeding birds, so both studies can potentially explain why worm-feeding bird species increased, especially in the areas open to shellfish fishery.

The question that has aroused heated debate is whether the impoverishment of the sediment and benthic shellfish fauna after fishing is self-sustaining, causing longer recovery times than expected from the life span of the organisms involved, as suggested by Piersma & Koolhaas (1997), who called it the negative biodeposition spiral. There is certainly evidence that supports this view. Piersma *et al.* (2001) and Hiddink (2003) showed a reduction in recruitment and survival of cockles and *Macoma* respectively. Kamermans *et al.* (2003a) observed reduced recruitment of cockles in fished areas a year after fishing and between 1993 and 2000, recruitment of cockles was decidedly better in the areas closed for shellfish fishery. The sandy western and central parts of the Wadden Sea remained poor in cockles, so the 'negative biodeposition spiral' proposed by Piersma *et al.* (2001) could hold for the sandy parts of the Wadden Sea. However, the 'negative biodeposition spiral' does not apply everywhere in the Wadden Sea. The difference in recruitment of cockles between areas open and closed for fishery gradually disappeared and at the end of the study period, recruitment was even higher in the open areas. The improved recruitment mainly took place high in the tidal zone: in silty areas along the mainland coast and in the shelter of the Wadden Sea islands. A possible explanation for this shift is that initially, effects as suggested by Piersma *et al.* (2001) led to a reduced recruitment in the open areas. With a build-up of the cockle density in the closed area, negative effects of high cockle stocks on recruitment (see e.g. Dare *et al.*, 2004)

⁶ The results of Kraan *et al.* (2004) would be fully comparable to the results of Leopold *et al.* (2003a), if the worms in the study of Kraan *et al.* (2004) had a negative correlation with cockle density and if, instead of an increase of worms in the fished areas, there was actually a decline of worms in the unfished control areas. According to Piersma (pers. comm.), this was not case.

then pushed the system towards less recruitment in the closed areas and more recruitment in the open areas.

3.9.3 Changes in the distribution of cockles

Cockles have shifted their distribution upwards in the tidal zone, but this shift was more obvious in areas open to cockle fishery if compared to areas closed to fishery (Zwarts *et al.*, 2004). We will first discuss the hypotheses that have been advanced for the general shift of cockles upwards in the tidal zone and then we will discuss why the trend may have been more pronounced in the open areas.

First, the predation hypothesis proposed by Beukema & Dekker (2004). These authors observed in their study on the Balgzand that the centres of distribution not only of cockles, but also of gaper clams and Baltic tellins have shifted into a shoreward direction to higher tidal levels. Superimposed on this general trend they found that in all three species, the infrequent strong cohorts were characterised by distribution centres further offshore than those of weak cohorts. In years with strong cohorts (large spatfall) the animals are found everywhere including the lower areas, while in years with weak cohorts, they are found mainly in higher areas. Both phenomena can be explained by variation in the presence of predators, in this case brown shrimp (*Crangon crangon*). Juvenile shrimp have been very numerous in the Wadden Sea during the last 10 years (Beukema & Dekker, 2004), and they belong to the most effective predators on the lower tidal flats, consuming any edible organism that is small enough to handle. Beukema & Dekker (2004) conclude that 'the declining trends of bivalve recruitment in the Wadden Sea are governed primarily by natural changes, in particular increases in predation pressure on early benthic stages which in turn appear to be largely governed by the warming climate'.

Second, as a result of large scale geomorphological processes low-lying flats may have become more sandy, making the habitat less suitable for recruitment (Beukema & Dekker, 2004). This phenomenon occurs at a large scale in the western part of the Wadden Sea. Large quantities of fine sediments have been trapped since the closure of the Zuiderzee in 1932 in the subtidal areas north of the Afsluitdijk, at least partly at the expense of the silt contents of the tidal flats. At the same time, there is a tendency of increased silt contents in coastal areas, and not in the middle of the Wadden Sea.

Third, low-lying flats may have become more sandy as a result of the disappearance of the mussel beds in 1990. Mussel beds accumulate a lot of silt, thereby enriching the surrounding sediment (Zwarts *et al.* 2004). If this hypothesis holds true, the return of the mussel beds should lead to a return of recruitment of cockles in low-lying sandy areas.

A final possibility is a genetic shift towards cockles that tend to settle higher in the tidal zone, due to selective fishing of low-lying fast-growing cockles (Piersma & Koolhaas, 1997). Testing of this last hypothesis requires genetic information, which

is not collected as part of the monitoring programs. Thus, there are effectively no data available.

The shift of cockles to the higher intertidal was less obvious in areas that were closed for cockle fishery. A possible explanation for this difference between open and closed areas is the effect of cockle fishery on the sediment composition, either directly, or by the enrichment of the sediment by faeces and pseudofaeces produced by the cockles in the unfished areas. Beukema & Dekker (2004) suggested that especially low-lying parts of the intertidal flats, already poor in fine sediments, may be vulnerable to the loss of fine sediments through suction dredging.

The change in cockle distribution has important consequences for the ecosystem (Bakker, 2003). Cockles grow more slowly in high-lying muddy areas (deMontaudouin & Bachelet, 1996; Wanink & Zwarts, 1993; Kamermans, 1993; Kristensen, 1957; Jensen, 1992), and are more susceptible to frost (Kristensen, 1957; Beukema, 1989; Ens, unpublished). Cockles high in the tidal zone will be less accessible to common eiders, but available for longer for oystercatchers, which may be important in periods of heightened tidal levels during period with westerly winds. However, from the point of view of the oystercatcher these poor-growing cockles will be less profitable compared to large cockles with a high flesh content (Zwarts *et al.*, 1996b).

3.10 Conclusions

Effects on seagrass

- Cockle fishing causes damage to existing seagrass beds. Newly settled individual plants cannot easily be detected so the risk of damage on newly developing beds is difficult to avoid in areas open for fishery. There is no evidence that cockle fishing affects the chances of new seagrass beds being established.

Direct effects on sediment and benthos

- Mechanised cockle fishing depletes the silt in the sediment of the mud flat immediately after fishing. Recovery takes some months to more than a year.
- Fishing for cockles leads to a lower cockle stock and, on the sites which are fished, leads to mortality among the benthic fauna running into dozens of percent.

Long-term effects on sediment and benthos

- There are indications for a lowered silt content on tidal flats that had been open to cockle fishery during a longer period. This lower silt content of the fished area can be explained by the low cockle stocks and consequently a reduced production of faeces and pseudofaeces in the open areas. There are other large-scale changes in the silt content which cannot be attributed to fisheries.
- Following closure, a higher proportion of the biomass of adult cockles was to be found in the areas closed to shellfish fishing.

- Less cockle spat developed in the open areas than in the closed areas until 2000. The difference has steadily decreased and spat fall is now slightly higher in the open areas.
- Successful recruitment of cockles occurs to a lesser extent than in the past in the low-lying and sandy parts of the Wadden Sea, especially in areas open to fishery.
- A study by Piersma and co-workers found a reduction of shellfish recruitment, a reduced condition of cockles and a general increase of worm densities after cockle fishery. Their study was carried out in the predominantly sandy parts of the western Dutch Wadden Sea
- Our study of fished and unfished cockle beds throughout the Dutch Wadden Sea observed a reduction of a number of benthic organisms on fished cockle beds, with the exception of the worm *Nereis diversicolor*, which increased after fishery.

Effects on birds

- Over the last ten years the numbers of worm-eating birds have increased more sharply in the open areas than in the closed areas.
- Oystercatchers started to slowly decline in numbers after the disappearance of the intertidal mussel beds around 1990. A sudden reduction in numbers occurred during the severe winter of 1996/97.
- No redistribution occurred, i.e. oystercatchers did not become more numerous in the areas that were closed for cockle fishery.
- These patterns in bird numbers may be partly explained by the presence of mussel beds, which initially returned in the open areas.
- The oystercatchers caught in a number of closed areas were in better condition than those caught in a number of open areas, which may be related to high cockle stocks in the closed areas.

4 Ecological impacts of mussel fishery and mussel culture in the Wadden Sea

4.1 Development of intertidal mussel beds

Intertidal mussel beds are an important habitat in the Wadden Sea. They may develop after massive spatfall of mussels in early summer. Such young mussel beds are called 'seed beds' and are preyed upon by gulls, which swallow the young mussels whole (Figure 53). Other bird predators include knots and common eiders. Predation may be so high that the seed bed is completely depleted over the winter (Zwarts & Ens, 1999). According to Nehls & Thiel (1993) high losses of seed beds during winter are primarily due to storm. It is certainly the case that at the scale of the Wadden Sea, mussel beds are less likely to persist at sites with high orbital velocities (Brinkman & Bult, 2003). Mussel seed beds that survive the first couple of years can develop into complex structures that survive decades (Dankers *et al.*, 1989), due to new mussel spat continually settling in between the old mussels. Mature mussel beds carry a diverse benthic epifauna and they enrich the surrounding flats through deposition of pseudofaeces. Bird densities on and around mussel beds are very high (van de Kam *et al.*, 2004). On the beds, oystercatchers prey on the large mussels, whereas many other bird species feed on benthic fauna hiding between the mussels (Figure 54).

Between 1971 and 1982 there was a total area of around 1000 to 6000 hectares of one-year and older intertidal mussel beds in the Wadden Sea, based on interpretation and extrapolation from aerial photographs (Dankers *et al.*, 2003). Van Stralen (2002) gives a qualitative estimate of the stocks of littoral mussels on the basis of observations of fishermen and fishery inspectors during the period 1954-2001. The stocks in the 1976 and 1978, the years on which Dijkema *et al.* (1989) based their estimate of approximately 4000 ha intertidal mussel beds, were characterized as normal. In the sixties and seventies the mussel catch on the eastern flats was around 10 million kilos fresh weight per year. In the late eighties this rose to more than 20 million kilos fresh weight (Figure 55). These extra catches were partly due to the use of cockle fishery vessels, enabling the fishermen to exploit mussel beds high in the tidal zone on watersheds and near the mainland. These beds had been difficult to reach until that time. In the early nineties the intertidal mussel beds almost completely disappeared (Beukema & Cadée, 1996; Dankers & de Vlas, 1992), due to on-going fishing combined with an absence of spat fall (Beukema, 1993) and possibly also storm damage (fishery inspector J. Poelman, pers comm.).

Since 1993 policy has been aimed at the restoration and subsequent conservation of 2000 to 4000 hectares of stable mussel beds. Existing mussel beds are included in the fishing plans for the open areas to protect them from mechanised cockle fishing. In 1994 and 2001 seed mussel fishing was permitted on the intertidal mussel beds. In 2001 it was permitted for research purposes.



*Figure 53: A young mussel bed. The small mussels are preyed upon by large numbers of gulls, mainly Herring Gulls *Larus argentatus*, which swallow the mussels whole. Photo Jaap de Vlas.*



*Figure 54: An old mussel bed, with mussels of many different ages. The large mussels are preyed upon by oystercatchers *Haematopus ostralegus*, while Curlews *Numenius arquata* feed on the shore crabs *Carcinus maenas* in between the mussels. Photo Bruno Ens.*

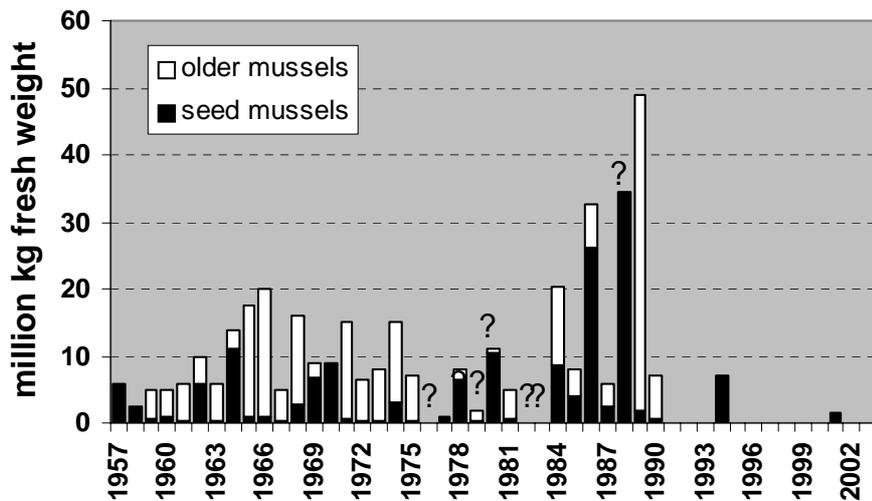


Figure 55: Quantities of mussels fished on the tidal flats of the eastern Wadden Sea. A distinction is made between seed mussels and older mussels. From Dankers *et al.* (2003).

It is however clear that re-formation of the robust and stable structures of the old mussel beds will be a slow process. Good spatfall in the intertidal Wadden Sea area has been observed on average over the last 50 years once in 4 years (Figure 56). In the nineties recovery of mussel bed area started with good spatfall of 2500 ha in 1994 but winter storm losses were high and only 1000 ha remained (Figure 57). It lasted until 2001 when successful spatfall resulted in almost 5000 ha mussel beds of which more than 60% survived the winter period (Figure 58; Steenbergen *et al.*, 2003). Surveys in the spring of 2003 and 2004 show areas of 2000 and 2260 ha respectively (RIVO data). There is a high risk that seed mussel beds will be lost during their first winter. Also older mussel beds can be lost during winter storms (Nehls & Thiel, 1993).

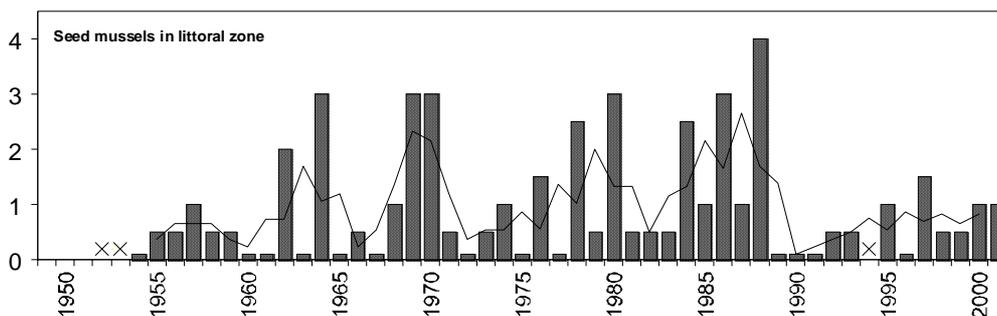


Figure 56: Index of recruitment of mussels as determined in spring (the actual spatfall having occurred the previous year) on the tidal flats in the eastern Wadden Sea, as judged by the fishermen and fishery inspectors. The index is based on semi-quantitative descriptions in historic records (0=absent, 1=local, 2=normal, 3=good, 4=very good). The line indicates the three-year running mean. From van Stralen (2002).

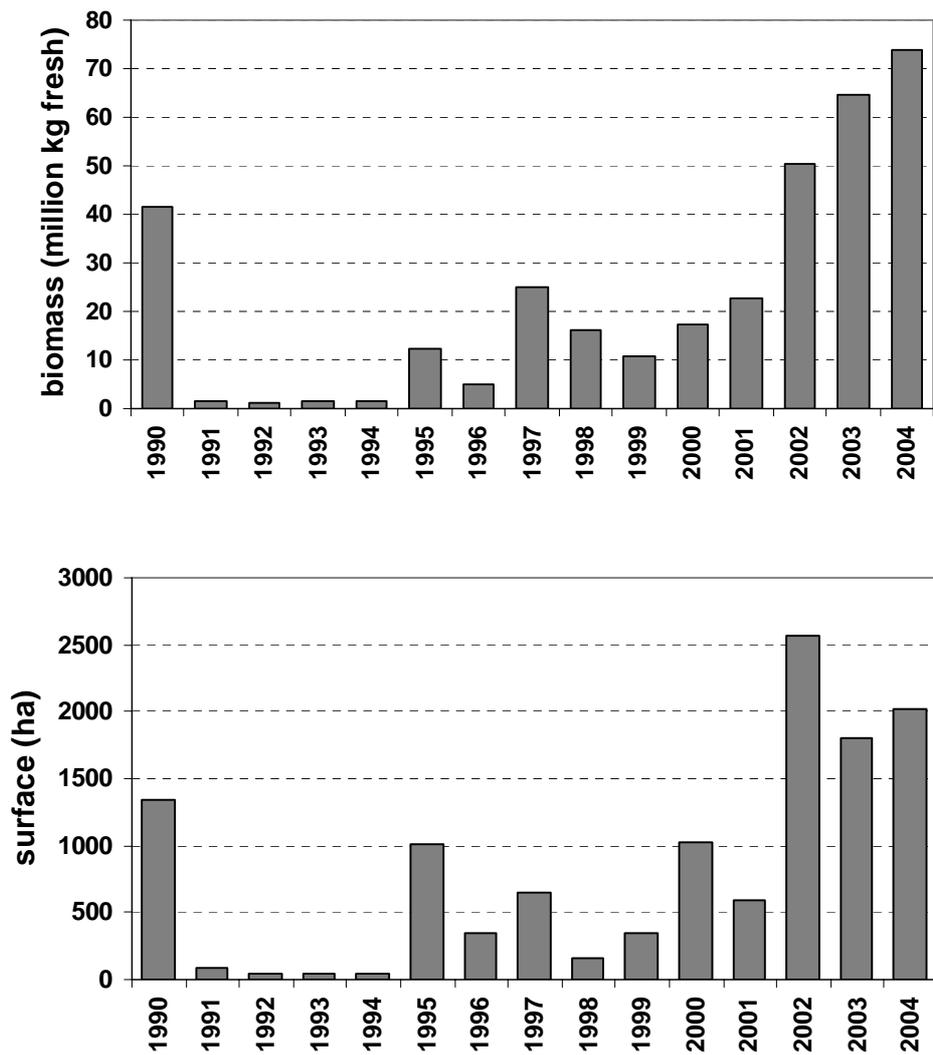


Figure 57: (a) Estimated stock (million kg fresh weight) of mussels on the intertidal flats of the Wadden Sea in spring. From Bult et al. (2003a). (b) Estimated area of mussel beds on the intertidal flats of the Wadden Sea in spring. From Dankers et al. (2003) with new data from RIVO surveys added.

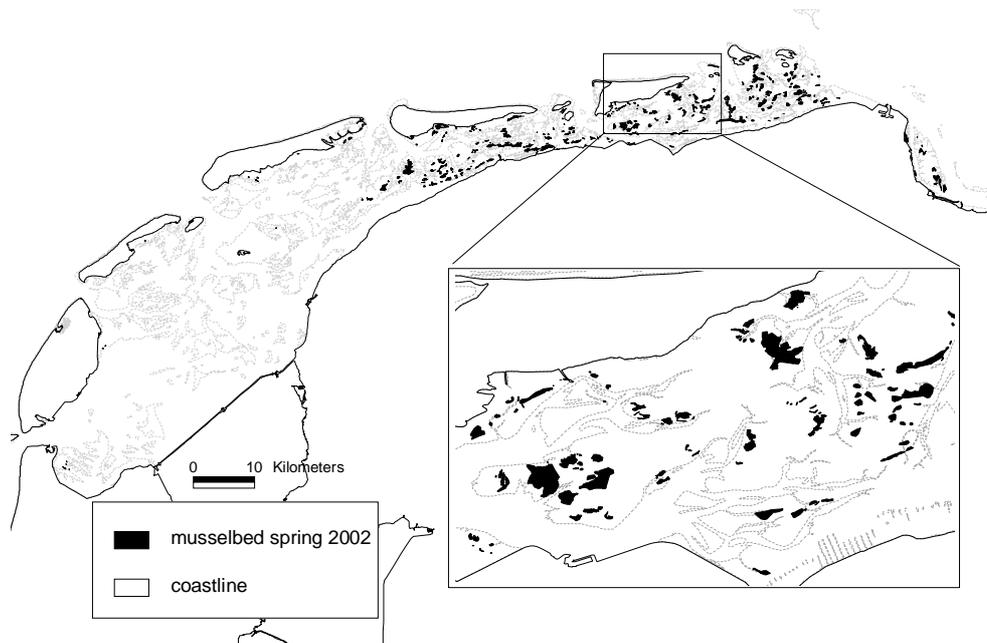


Figure 58: Map showing the location of the intertidal mussel beds in the Wadden Sea in spring 2002.

Also in areas like the Wash and in the German Wadden Sea mussel bed areas show large fluctuations with low values in the nineties. Dare *et al.* (2004) give an extensive description of mussel (and cockle) dynamics in The Wash (UK). They concluded that ‘the most likely cause of the current mussel stock and fisheries problems is the high exploitation rates during the late 1980s and early 1990s combined with the innate variability of mussel spatfall in The Wash. The dependence of spatfall on the presence of adult mussel stocks as a settlement surface means that, once these beds have become depleted, it is difficult for them to re-establish. Establishment of a new mussel bed in The Wash is a rare event. Moreover, environmental conditions in recent years have been unfavourable for mussel spatfall – there have been no cold winters to promote high reproductive output, and there has been a low frequency of the wind conditions that favour larval retention. Natural recovery of mussel stocks is likely to be slow under current stock and environmental conditions.’

In papers by (Herlyn & Millat, 2000; Jaklin *et al.*, 2004; Michaelis *et al.*, 1995; Obert & Michaelis, 1991) it is shown that in the Lower Saxony Wadden sea (Germany) mussel bed area also has shown a sharp decline in the eighties. It accelerated drastically during the early 1990s and reached its lowest point – close to total extinction – in spring 1996. Since records began, the mussel stock had experienced a comparable break down only twice, that was after the extremely severe winter of 1946/47 and after the epidemic mass-mortality in 1951 attributed to the commensalic copepod *Mytilicola intestinalis*.

In order to analyse the situation, a considerable number of scientific activities was initiated. Several of these studies were focussed on fishery effects and bird predation, but also other potentially stock-reducing factors like *Pheocystis globosa* blooms, endoparasites of the mussel and chemical contamination have been investigated.

The result of this evaluation is that during the whole period from 1986 through 2000 only three really strong spatfalls occurred in Niedersachsen, those of the summers 1991, 1994 and 1996. These spatfalls were to a certain degree in line with the 'ice winter rule' which according to a general and long-term experience claims that severe winters with strong ice-formation are followed by summers with particularly strong spatfalls of the mussel and other invertebrates.

According to Jaklin *et al.* (2004) there can be little doubt that the 'mussel crisis' in Niedersachsen with its continuous decline over one decade and its extreme stock minimum in spring 1996 had been a phenomenon beyond the usual population dynamics. It was going along with evidently intensified fishing efforts and with exponentially growing populations of mussel-eating seabirds. But also other incidents have to be considered as the period from the middle of the 1980s to the middle of the 1990s was characterized by a rather accumulated occurrence of exceptional phenomena in the environment of the Niedersachsen coast and adjacent areas, such as: recruitment failure, meteorological effects, persistent chemical compounds, dredging and dumping activities, phytoplankton production and dominance of *Phaeocystis globosa* in the spring blooms, mass development of macroalgae and parasitological infestation (Michaelis *et al.* in prep.).

In Schleswig-Holstein, no systematic studies of the effect of fishery on intertidal mussel beds exist (Nehls & Ruth, 2004). Between 1988 and 1994 the total surface of intertidal mussel beds probably declined from 1500 to 1000 ha according to (Nehls, 2003). In 1994, fishery on intertidal mussel beds was stopped. Since that time, strong spatfalls occurred in 1996 and 1999, which had a big impact on the total surface of intertidal mussel beds (Nehls, 2003). Smaller spatfalls in other years were confined to the existing mussel beds, rejuvenating these beds, but not affecting the total surface, which varied between 600 and 1000 ha during the period 1998-2002 (Nehls, 2003).

It can be concluded that intertidal mussel bed dynamics largely depend on recruitment success and, especially in the past, fishery. In both the German and the Dutch Wadden Sea and the Wash recruitment failure is shown as the major factor that prevents restoration of mussel bed area. The restoration process can be retarded by ongoing fisheries, in combination with a series of other possible factors.

In order to evaluate past policy it was necessary to determine in how far those mussel beds were stable. It is difficult in practice to draw a clear line between stable and unstable beds, and a list of criteria was developed to discriminate relatively stable from other beds (Brinkman *et al.*, 2003a). In addition, criteria were established to facilitate unambiguous charting of the area of mussel beds (Brinkman *et al.*, 2003a).

Until the end of the nineteen nineties the restoration of the mussel beds fell short of expectations. A mussel habitat map was created to support the policy of restoration of the mussel beds (Brinkman & Bult, 2003). This shows the areas with the best chance of recovery of mussel beds (Figure 59). It appeared that those areas that had best chances for mussel spat fall, also had best chances for survival of these newly formed beds, and thus, for the existence of older mussel beds. In 1999 a further

percentage of the most promising areas was closed to fishing on the basis of this map. A further 5% for the cockle fishery and 10% for the mussel fishery were added to the 25% of the Wadden Sea which was already closed to both fisheries.

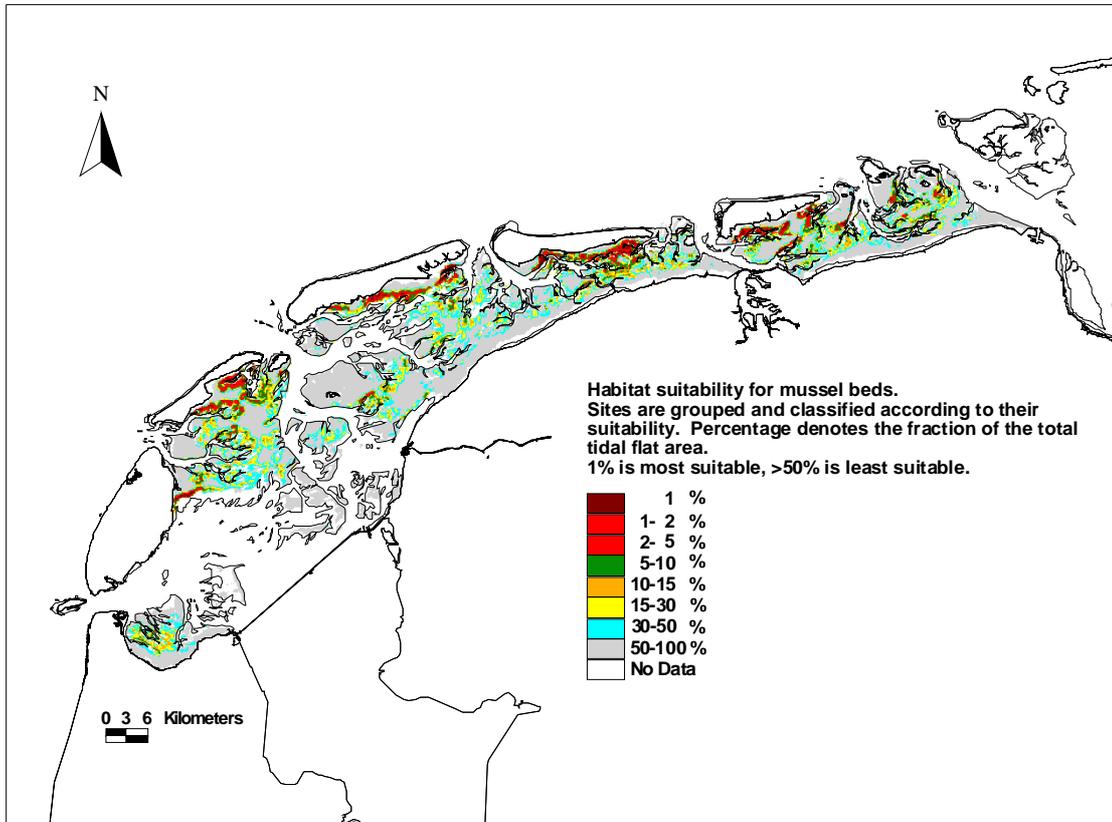


Figure 59: Habitat map indicating the suitability for the development of stable intertidal mussel beds in the Dutch Wadden Sea. From Brinkman & Bult (2003).

The mussel habitat map generally shows the correct areas, but mussel beds can also arise and survive in less favourable areas. According to the map, from 1995 to 2002, 20-40% of the area of mussel beds was situated in the top 10% of favourable areas and 45-75% was in the top 30% of favourable areas (Figure 60). Despite these findings, the question remains as to whether closures were useful for this purpose. The EVA II research established neither a consistent positive nor a consistent negative effect of cockle fishery on the subsequent settlement of mussel spat at the scale of the Wadden Sea (Brinkman *et al.*, 2003c). It is likely that the policy pursued to safeguard mussel beds by means of a system of fishing plans and licences, has contributed to the restoration of the intertidal mussel beds.

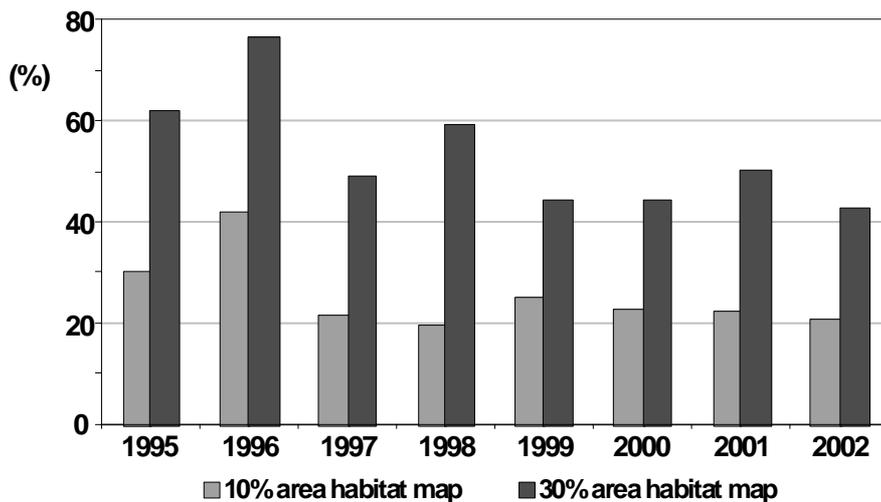


Figure 60: Occurrence of mussel beds (%) in habitat classified as the most suitable 10% and the most suitable 30%. From Dankers *et al.* (2003).

4.2 Testing the 'Jan Louw' hypothesis

Fishermen have long been indicating that a fishery on intertidal seed mussels by thinning out may enhance the stability of the remaining mussel beds. This theory was named after a respected and experienced mussel fisherman and became known as the 'Jan Louw hypothesis'. The rationale of this theory partly stems from the observation that mussel seed beds are often situated on top of a soft and sometimes very thick layer of silt as a result of filtration activities of the mussels and sedimentation processes. This soft layer may decrease the stability of mussel beds as storms and currents are more likely to affect mussel bed structure when mussels get disconnected from the more stable sediments beneath this silt layer. This process of destabilization was described by Seed (1976), but no information exist in the literature as to how this relates to effects of a fishery. For instance, Herlyn & Millat (2000) studied the effects of mussel fishing on intertidal mussel beds by comparing fished and control beds and concluded that fishing negatively affects bed stability (collateral damage). However, fished and control beds in this study may not be comparable as fish locations were selected by fishermen. In general, experimental data on fishery effects are missing and therefore an experiment was carried in 2001 (Smaal *et al.*, 2003).

The experiment consisted of a pairwise test of fishery effects on 10 beds that were partly fished and partly unfished. In addition 11 undisturbed beds in the same area were considered reference sites. The experimental beds were selected based on logistical constraints and suitability for Jan Louw fishing according to the fishermen. Fish and control plots within fished beds were selected randomly. Fishing was done by fishermen using commercial vessels and methods chosen by fishermen. Part of the mussels that were obtained by this fishery was used to test if artificial intertidal mussel beds could be created (0.5 million kg). This was done at 5 locations. The remaining mussels were used on sublittoral mussel culture lots (1 million kg).

Fishing was done in October/November 2001. Cover (%), bed area (ha), and biomass (kg.m⁻²) were measured prior to the fishery (T0, Oct. 2001), directly after the fishery (T1, Dec. 2001) and in June 2002 (T3). Aerial photos were taken during this period as well to support analyses using ground truth data (Figure 61). The harvest was registered by fisheries inspectors of the Dutch Ministry of Agriculture, Nature and Food Quality (LNV). The fishing effort was monitored using black box data (Figure 62).

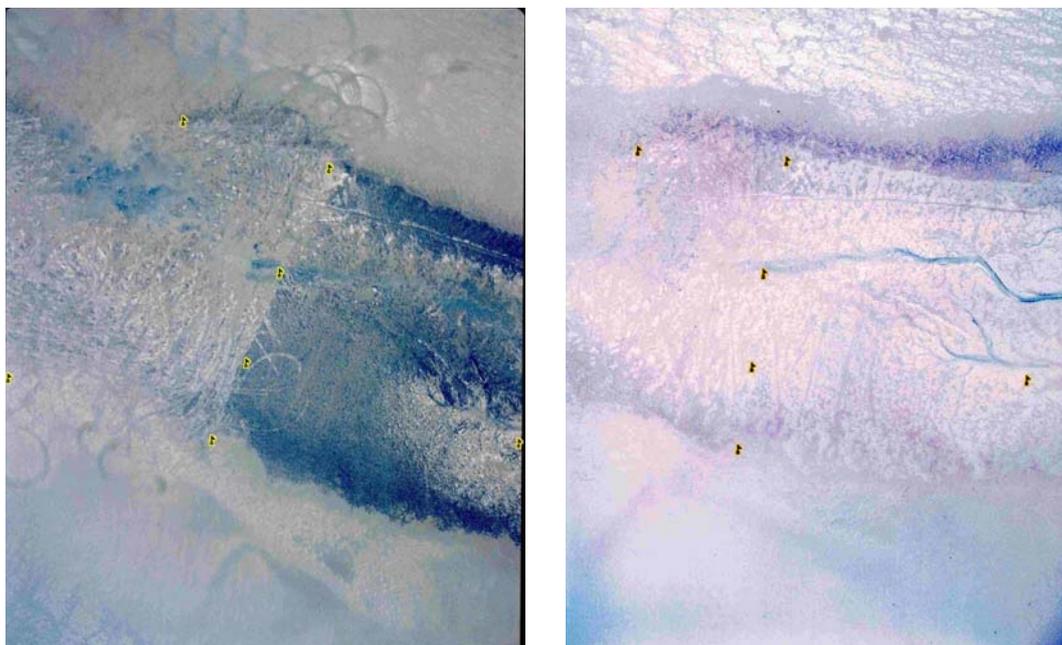


Figure 61: Aerial photographs of a mussel bed subjected to experimental fishing: (a) directly after experimental fishing in autumn, (b) the same mussel bed in the next spring. From Smaal et al. (2003).

Results indicated that the fishery effort varied widely among fish-locations. More effort was directed at beds with higher mussel densities. Mussel bed coverage after fishing was roughly 40% at all fish-locations indicating that Jan Louw fishing leads to a thinning out of mussel densities (Figure 63). Cover and biomass were obviously reduced as a result of fishing (T1). At T2 biomass and bed area at fish and control plots were comparable. There was a slightly higher coverage of fished plots (Figure 64, Figure 65). Bed area reductions at the undisturbed reference banks were comparable to bed area reductions observed at the fish and control plots. It was concluded that no stabilization of mussel beds by Jan Louw fishing had occurred but there was also no sign of extra losses due to fishery. Natural factors played a dominant role in the survival of mussel seed beds.

The mussel bed restoration experiment indicated that 2 out of the 5 artificial mussel beds survived. These 2 beds were situated at locations where (natural) mussel beds were observed previously, indicating that mussel bed restoration is possible on traditional mussel bed locations.

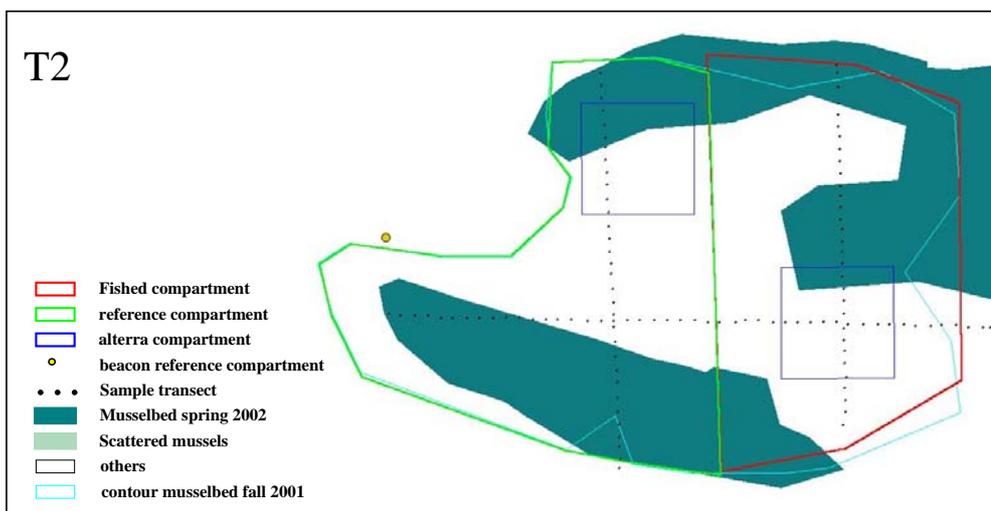
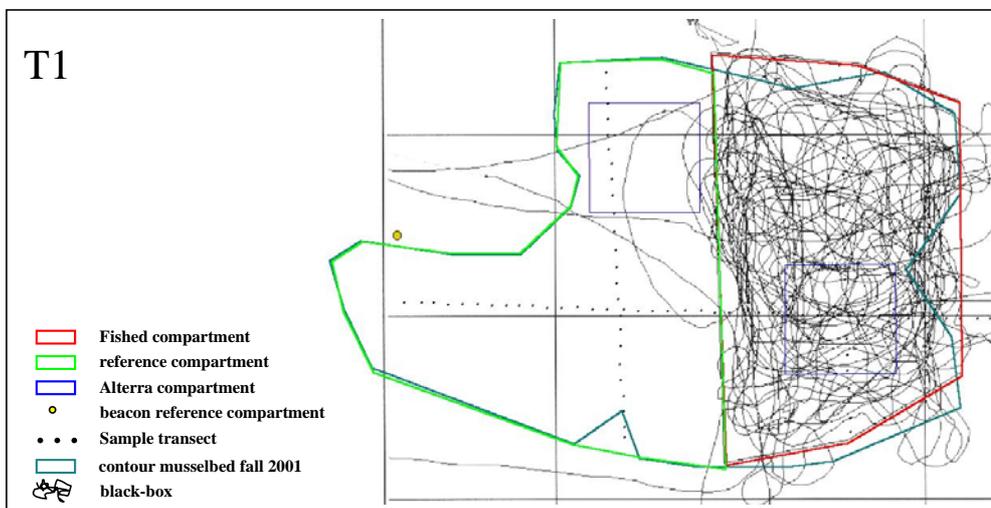


Figure 62: The development a mussel bed (bed 4) which was subjected to experimental mussel fishery. Indicated is the coverage with mussels just before fishery (T0), shortly after fishery (T1) and several months after fishery (T2). From Smaal et al. (2003).

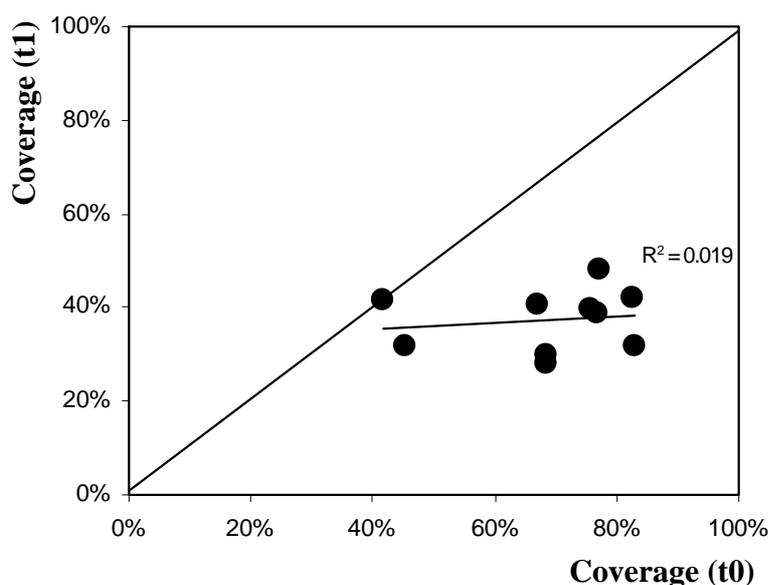


Figure 63: Coverage with mussels of fished plots directly after fishing, plotted against the initial coverage before mussel fishery took place. From Smaal et al. (2003).

Results include a relay of mussels to sublittoral culture lots. Effects on the food situation of birds, in particular oystercatchers and eiders, will depend on the fate of the mussels: bed restoration may benefit oystercatchers; relay to sublittoral culture plots may benefit eiders; relay from littoral mussel beds to sublittoral culture lots may negatively affect the food situation of birds that depend on seed mussels prior to harvesting. The fate of mussels that get destroyed by storms was not extensively studied. Part of them will end up in gullies where they can be consumed by a variety of organisms. Others can be found as conglomerates of mussels attached to each other and to some other shells, scattered over the tidal flat. The study of Zwarts & Drent (1981) suggests that most of these ‘scattered mussels’ are eaten by gulls and oystercatchers.

The relatively better survival of fished plots over the winter (from T1 – T2, Figure 65) may be ascribed to a number of causes including a higher stability of mussel beds due to reduced silt accumulation, a removal of unstable mussels by the fishery prior to other effects and density dependent bird predation. Density dependent bird predation was assumed to be less important than effects of storms and currents because of the large differences in cover and biomass between beds and the similarity of plots within beds that suggest density dependent processes at the local (bed) scale and because bird predation was assumed to lead to an evening-out of densities at larger scales when compared to the more local effects of storms and currents. In addition, bird numbers from the aerial photo’s indicated low bird predation pressure. However, explicit and more detailed observations on bird predation or storm effects were not available. Therefore, the processes that drive winter survival of mussel seed beds need further study.

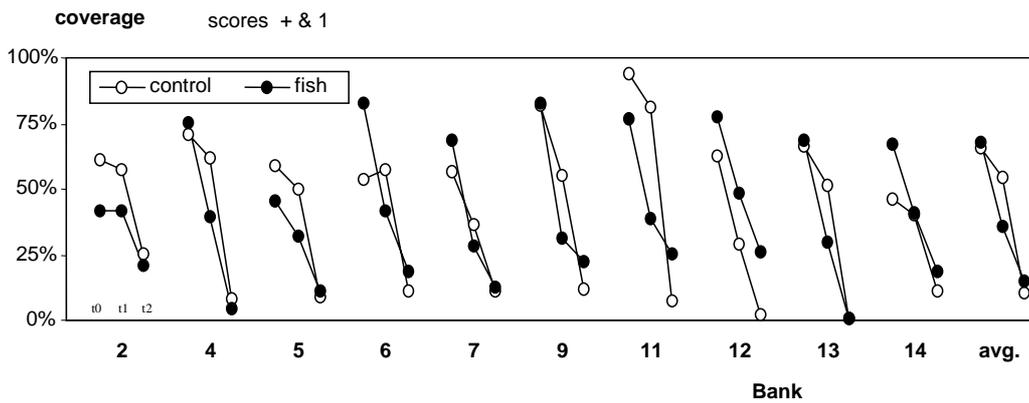


Figure 64: Development of the coverage with mussels (score + and 1 combined) for all 10 experimentally fished mussel seed beds just before fishing (t_0), directly after fishing (t_1), and several months after fishing (t_2), separately for the control and the fished part of the bed. Bed 12 was excluded from the average, because some fishing took place in the control part. From Smaal et al. (2003).

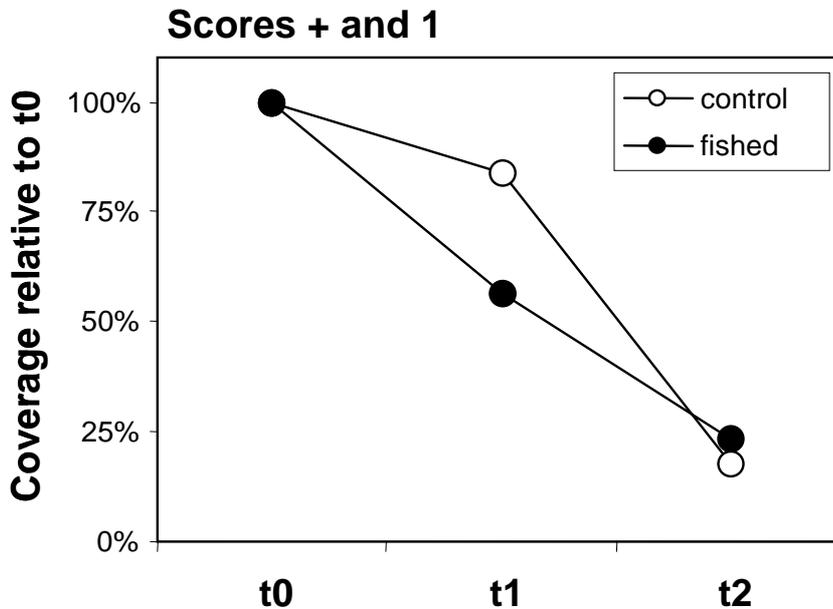
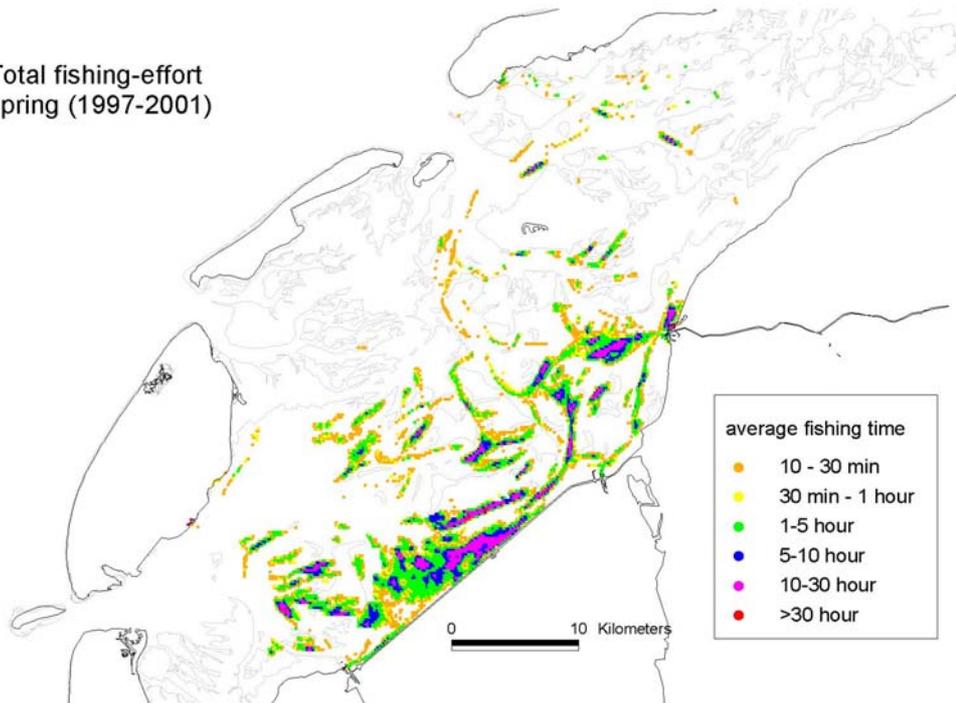


Figure 65: Comparison of the average coverage with mussels of fished and unfished parts of experimentally fished mussel seed beds just before fishing (t_0), directly after fishing (t_1) and several months after fishing (t_2). The coverage at the start of the experiment is set to 100%. From Smaal et al. (2003). Score + and 1 indicate <50% and >50% coverage with mussels respectively.

4.3 Sublittoral mussel stocks and mussel culture

Most of the fishing of wild mussels to stock culture lots occurs in the sublittoral parts of the western Wadden Sea in spring (Figure 66). Some fishing occurs in autumn, in the same general areas.

Total fishing-effort
spring (1997-2001)



Total fishing-effort
fall (1997-2001)

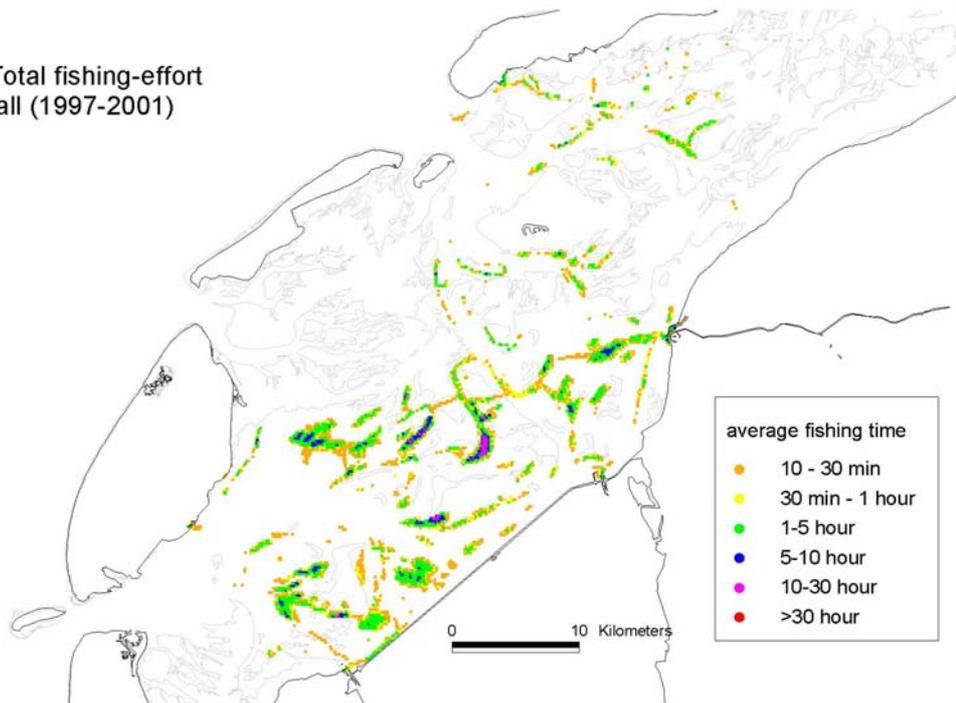


Figure 66: Distribution of the fishery of seed mussels in the western Wadden Sea according to black box data in (a) spring, (b) autumn. From Bult et al. (2003b).

Each year mussels are fished from sublittoral wild stocks in the western Wadden Sea to provide new material for the culture lots in the Wadden Sea and the Oosterschelde. The wild beds are areas with natural recruitment that is successful every two years on average (Figure 67; van Stralen, 2002). The newly settled spat is fished in autumn from relatively unstable sites and transported to culture plots that are located on relatively stable sites. The fraction of wild mussels that is not fished in autumn is normally fished upon in next spring and also brought to the culture plots. Total seed harvest amounted to 31 million kg net fresh weight (approximately 50 million kg gross weight). Total yield at the auction was on average 99.5 million kg over the period 1993-2003. The annual yield came for 37.5% from the Wadden Sea, 42.8% from the Oosterschelde and the rest (19.2%) from Germany (Figure 68).

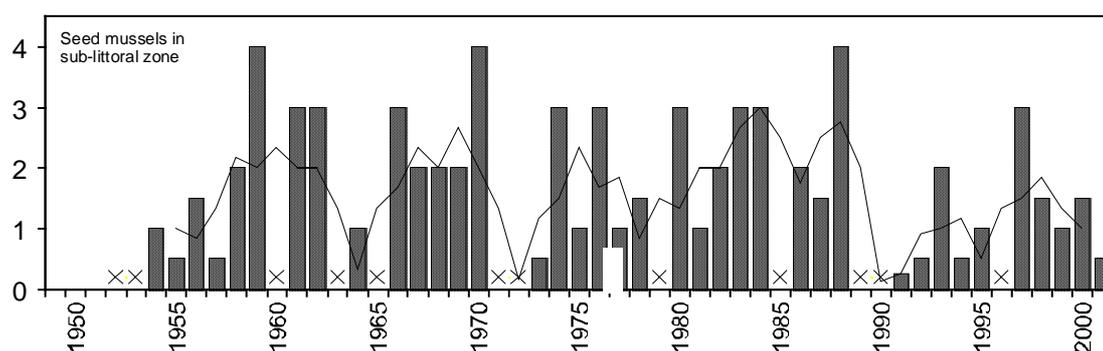


Figure 67: Index of recruitment of mussels in the sublittoral parts of the western Wadden Sea (0=absent, 1=local, 2=normal, 3=good, 4=very good). The index applies to spring, so the recruitment took place in the preceding year. From van Stralen (2002).

In contrast to the period before 1990 hardly any mussel seed fishery occurs on tidal flats anymore. This is due to the disappearance of the intertidal beds, the practical absence of spat fall on the flats in the beginning of the nineties and the fact that the flats were closed to fishing in most years.

The stocks of mussels on the cultivation lots in the Wadden Sea are affected not only by the introduction of seed mussels but also by the transfer of mussels to other lots in the Oosterschelde or to the auction in Yerseke. This loss of biomass is compensated by relatively good growth and survival on the cultivation lots in the Wadden Sea. Better growth and lower mortality on culture plots potentially increases biomass by a factor 2 (Bult *et al.*, 2003b). Corrected for transfer to the Oosterschelde and combined with imports of half-grown mussels from Germany this leads to a tentative estimate of on average 15% more mussel biomass in the sublittoral areas of the Wadden Sea than there would be without mussel cultivation. In addition it should be noticed that better growth results in a good quality (meat content) of cultured versus wild mussels.

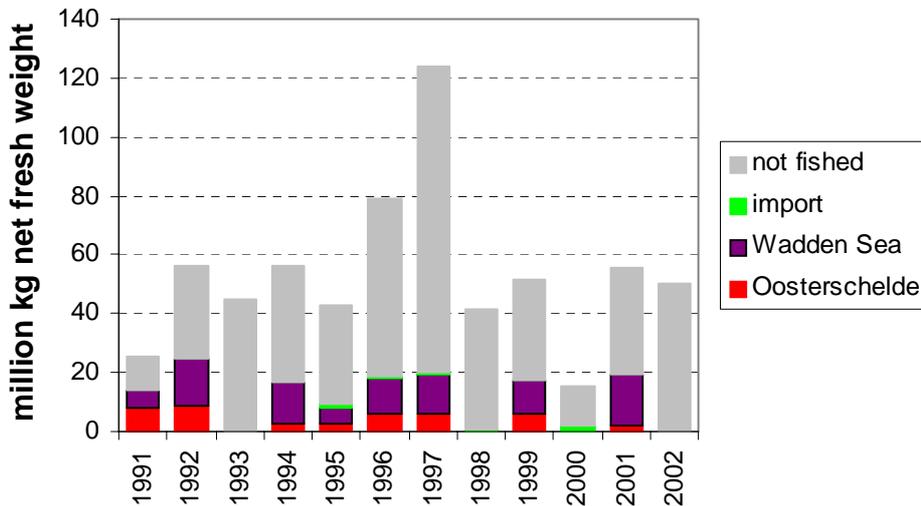
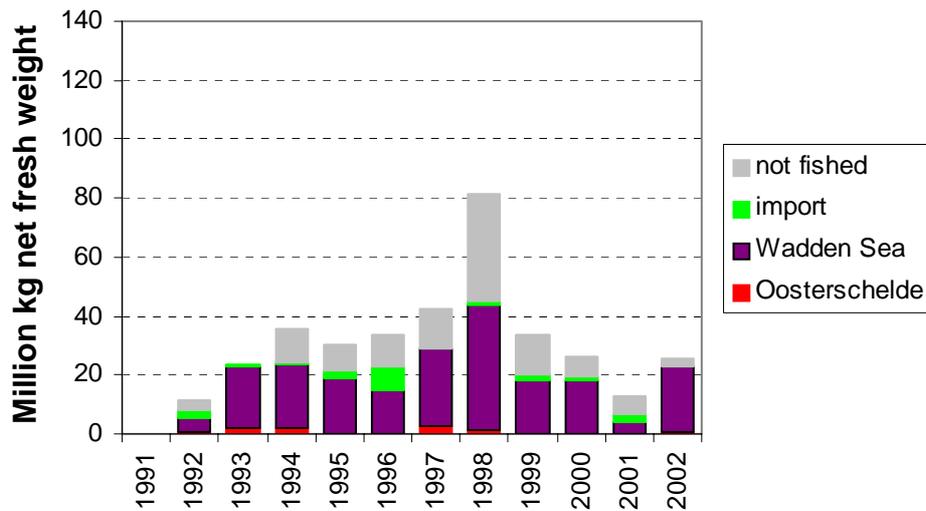


Figure 68: Relocation of wild mussels in the Wadden Sea in (a) spring and (b) autumn. Indicated is whether the mussels were fished and moved to culture lots in the Wadden Sea, fished and moved to culture lots in the Oosterschelde, imported to culture lots in the Wadden Sea or left unfished. From Bult *et al.* (2003b).

The impact of mussel cultivation lots in the Wadden Sea on the total availability of shellfish in the permanently submerged areas - and thus also probably on the shellfish-eating birds - depends on the way they are managed. In the seventies the management of the lots meant that they were well populated with mussels and therefore may have contributed to extra numbers of eider ducks. In the past ten years the paucity of seed mussels resulted in smaller stocks of mussels on the culture lots. Landings of mussels from the Wadden Sea have declined, while landings of mussels from the Oosterschelde have remained more or less constant (Figure 69). Eiders are sometimes chased away from the mussel culture lots, rendering them effectively unavailable. According to Smaal *et al.* (2000) chasing of eiders occurred on 5-7% of the culture lots in the years 1995-1999.

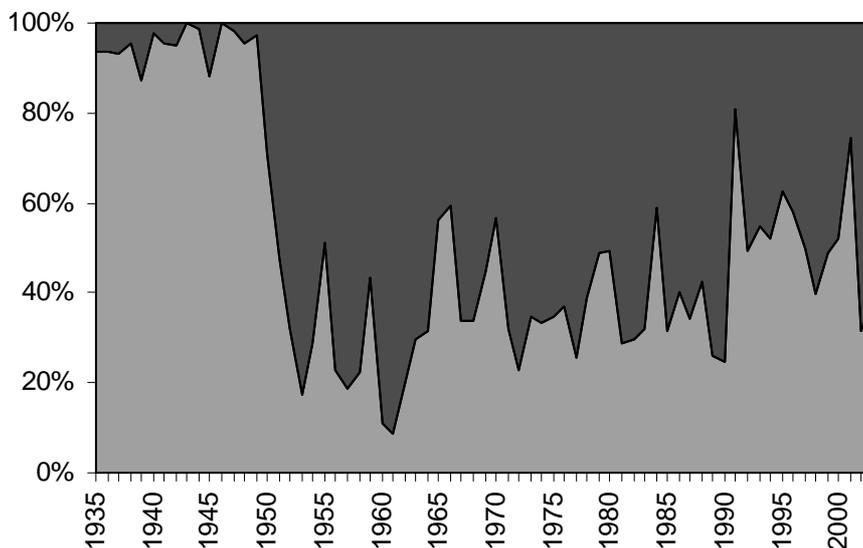
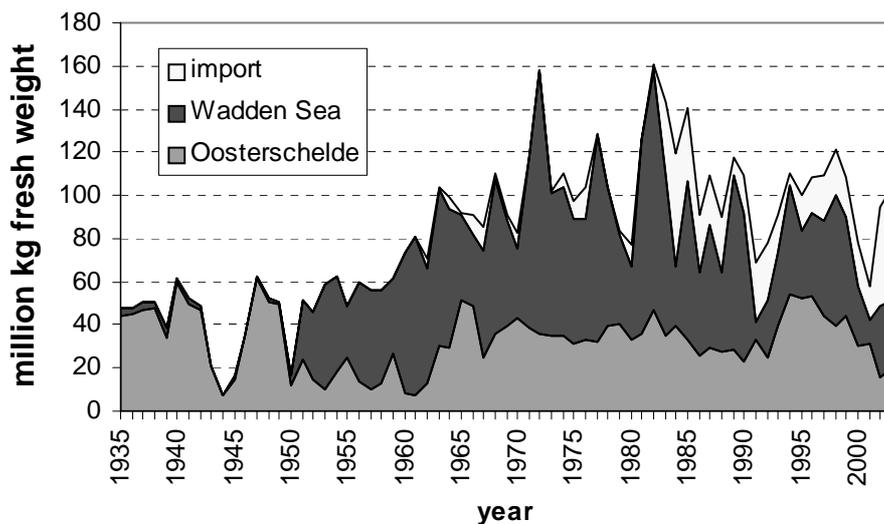


Figure 69: (a) Mussels auctioned at Yerseke (million kg fresh weight), separated for mussels from the Wadden Sea, mussels from the Oosterschelde and mussels imported from elsewhere (mainly Germany). (b) The amount of mussels from the Wadden Sea and from the Oosterschelde as a percentage of the total landings from Dutch coastal waters. From Bult et al. (2003b).

The conclusion is that in an average situation cultivation probably leads to an increase in mussel stocks. But in this case the average does not give the full picture. Every year the mussel farmers move a variable quantity of the mussels from lots in the Wadden Sea to lots in the Oosterschelde. Unfortunately there is still a lack of quantitative data on growing behaviour in lean years compared to rich years. It is therefore still unclear to what extent cultivation impacts on the availability of mussels as food for eider ducks in years of scarcity.

4.4 Discussion

4.4.1 Effect of mussel fishery on littoral mussel beds

The influence of mussel fishery on littoral mussel beds was not directly studied within the EVA II - project, except for fishery on unstable seed beds. The recovery of beds after the loss of almost all beds in 1990, after fishing was stopped, is well documented. The mussel beds in the Dutch part of the Wadden Sea re-established in 1994 but winter storms prevented further development. It lasted until the autumn of 2001 for establishment of approximately 5000 ha mussel seed beds to occur, resulting in 2600 ha in the spring of 2002. This is within the natural range, that was estimated as 1000 to 6000 ha (Dankers *et al.*, 2003), and also within the policy reference value of 2000 – 4000 ha. Thus, it took more than 10 years for mussel bed areas to return to former values.

As shown in Lower Saxony (Herlyn & Millat, 2000) and in the Wash (Dare *et al.*, 2004) loss of mussel beds and slow recovery is not restricted to the Dutch Wadden Sea. Various factors play a role, of which recruitment failure seems most important. This is often related to the absence of cold winters, hence to climate change (Beukema, 1992). In addition, winter storms play a role once seed beds have settled, as these seed beds have an innate instability and can easily be flushed away as observed in winter 1994/95. The absence of existing mussel beds hampers reestablishment of mussel spat as was clearly demonstrated in the Wash, and is also known from the Exe estuary (McGrorty & Goss-Custard, 1995). In Lower Saxony there is evidence that when mussel beds are scarce new seed beds are quite vulnerable to predation, and this is considered as a limiting factor for reestablishment of mussel beds (Jaklin *et al.*, 2004). It is therefore likely that once mussel beds have disappeared, a concert of conditions have to be realised before successful recruitment and maintenance of beds will occur⁷.

In an experimental approach the impact of fishery on seed beds was studied in order to test whether fishery would stabilize the mussel bed (Jan Louw hypothesis), or whether collateral damage would occur as observed by (Herlyn & Millat, 2000). The results showed no increase in stability but also no collateral damage was observed, as the fished plots and the control plots did not show differences in most parameters 9 month after fishery (Smaal *et al.*, 2003).

⁷ According to (Lenihan & Micheli 2001) the time scale of recovery is related to the spatial scale of disturbance. This idea was elaborated by (Versteegh *et al.* 2004). (Dijkema *et al.* 1989) mapped 129 mussel beds with a total surface of about 4000 ha, yielding 31 ha per mussel bed. According to graph 2B in (Versteegh *et al.* 2004) a surface of 31 ha corresponds to a minimal recovery time of 3 years and a surface of 4000 ha corresponds to a minimal recovery time of 9 years.

4.4.2 Impact of mussel fishing in the subtidal zone on associated epifauna

Effects of mussel fishing on associated epifauna and benthic communities in the subtidal zone were not studied within the EVAII project because the Sea and Coastal Fisheries policy did not specify targets on these matters for the sublittoral zone. During the study period, sublittoral mussel stocks became part of the policy of food reservation and we increasingly realized how little we knew of the effects of mussel fishery and mussel culture in the subtidal. A study on the effect of mussel fishery and mussel cultivation on subtidal mussel stocks was subsequently initiated (Bult *et al.*, 2003b). However, we did not specifically study the effects of mussel fishery and mussel culture on biodiversity, so it seems fit to pay some attention to this issue in this discussion. We expect that mussel farming will lead to subtidal mussel stocks that consist of relatively younger mussels when compared to a situation without mussel fishing. In addition, fishing pressure may favour epifauna that have a shorter life history or higher mobility. However, little quantitative information is available from the literature to support these more general inferences that allow for a prediction of the overall impact of mussel fishing on associated epifauna in the situation of the Dutch Wadden Sea.

Buhs & Reise (1997) observed a high abundance and diversity of epibenthic fauna in channels of the Wadden Sea of Schleswig-Holstein where mussels were present. A decline of nearly 50% of all epifaunal species over the last 100 years, in particular slow moving and sessile species, was attributed to fishery disturbances including oyster, shrimp and mussel fishing. They hypothesized that mussel fishery will promote mussel abundance at the cost of other epifauna, as mussels are harvested before a richer epifaunal assemblage is completed. However, it remains difficult to translate these inferences to the net effect of mussel farming on species diversity and epifauna in the Dutch Wadden Sea. Mussels are not just removed but relocated to culture plots. Assuming that mussel beds are characterized by increased numbers of epifaunal species then the net effect of mussel culture will consist of a reduction of epifauna at the fishing locations and an increase at the culture locations. From this, the net effect of mussel fishing/culture may not be as negative as suggested by the study of Buhs & Reise (1997) which did not focus on the effects at culture lots including a potential increase of the total mussel stocks by mussel farming or separate between effects of oyster, shrimp or mussel fishing.

More than 150 species of algae and invertebrates live associated with mussel beds (Saier, 2002; Dittman, 1990; Buschbaum & Saier, 2001), with marked differences between intertidal and subtidal mussel (Saier, 2002; Buschbaum & Saier, 2003). While some species occur in both tidal zones, many are limited to either intertidal or subtidal sites. From this, marked differences exist between epifaunal communities of intertidal and subtidal mussel beds. For example, green and brown algae and periwinkles (*L. littorea*) are abundant on intertidal mussels while many red algae, hydrozoans, bryozoans and whelks (*Buccinum undatum*) are mainly restricted to subtidal mussel beds (Buschbaum & Saier, 2003). The most detailed study on these differences is a study by Saier (2002), who observed a higher diversity, species density

and total species numbers in subtidal mussel beds when compared to littoral mussel beds. Abundances of juvenile periwinkles (*Littorina littorea*) and crabs (*Carcinus maenas*) were higher in intertidal mussel beds. Many less dominant species were more abundant in subtidal mussel beds, including sea stars, polychaetes, anthozoans, and limpets. Nudibranchs and sea urchins were limited to subtidal beds. From this, she concluded that protective measures for mussel beds against the effects of mussel fishery should be extended from the intertidal to the subtidal zone (cf. Saier, 2002). However, effects of mussel fishing on biodiversity and species numbers were not studied in terms of a comparison of fished versus untouched mussel beds or culture beds versus wild beds and because of this, the impact of fishing and the effects of such protective measures remain unclear.

We expect a shift in epibenthic species towards species with a shorter life-history and higher mobility when comparing samples from wild mussel bed locations with samples from culture lots or wild mussel banks that experience a high fishing pressure. However, a more detailed and quantitative assessment of the total effect of mussel farming/fishing on biodiversity in the Dutch Wadden Sea is difficult to make for lack of comparative information from untouched mussel beds, fished beds and culture locations. Because of this, we advise to collect such data, preferably within the context of an experimental set up and in cooperation with the fishery.

4.4.3 Decline of mussel production in the Dutch coastal zone

The production of Dutch mussels from mussel culture lots declined after the seventies and eighties. A number of causes may have attributed to this decline (cf. Ens, 2003), including a reduction of the production potential due to a decline in nutrient levels and effects of prolonged fishing by the cockle and mussel fishery. Certainly, the period after 1990 was characterized by a less abundant mussel seed production, especially in the intertidal zone. Moreover, the 1993 Shellfishery Policy severely limited access to available mussel seed in the intertidal zone. These two causes are certain contributors to the decline in the Dutch mussel production from mussel culture lots. However, it remains unclear why mussel seed production after 1990 was less than before. One possible cause is the decline in frequency of severe winters, which are often followed by high recruitment (Beukema, 1992). We did not show effects of (sublittoral) mussel fishing on mussel seed production and fishing for mussel seed does occur in roughly the same areas year after year. However available data for such analyses were limited and from this, fishery effects cannot be excluded. Results from studies done at the Wash (Dare *et al.*, 2004) conclude that dredging per se appears not to inhibit settlement since spatfall occurred on dredged (intertidal) beds up until the late 1980's. However, it was hypothesized that recovery or re-establishment of mussel beds could become more difficult if dredging reduces bed area and physical structure as substrate for settlement of spat.

4.5 Conclusions

- From 1990 to 1994 there were practically no mussel beds in the Wadden Sea. Since 1995 there has been a gradual recovery to 2000 to 2500 ha in the period 2002-2004. The recovery has been brought about by protection of the newly recruited mussel beds by licensing policy and fishing plans.
- The hypothesis that fishing of seed mussel beds is good for the development of the beds, by increasing stability, could not be confirmed in an experiment. However, nor did controlled fishing lead to extra losses of young mussel beds.
- It is tentatively estimated that during the 1990s, mussel culture on average increased subtidal mussel stocks in the Dutch Wadden Sea by 15%. However, due to lack of data, it cannot be excluded that during years of scarcity, transport of mussels from culture lots in the Wadden Sea to culture lots in the Oosterschelde was increased, thereby increasing the food shortage for the common eiders.
- Compared to the 1980s, production of mussels was lower in the 1990s, which is related to a reduced availability of mussel seed.

5 Evaluating the policy of food reservation for the Wadden Sea

5.1 Introduction

Many birds prey on shellfish, but only two species consume the large shellfish that are also targeted by fishermen: the oystercatcher *Haematopus ostralegus* and the common eider *Somateria mollissima* (Figure 70). Due to their high food demands (as a result of their large size) in combination with their large numbers, the total biomass consumption of these two species far exceeds the biomass consumption of other birds (Smit *et al.*, 1998).



Figure 70: The two major bird predators of large shellfish in the Dutch Wadden Sea. (a) The oystercatcher *Haematopus ostralegus*. (b) The common eider *Somateria mollissima*. Photo Jan van de Kam.

Policy takes the nineteen eighties as the reference point. There were then some 260000 wintering oystercatchers⁸ and 130000 wintering eider ducks. Since then the numbers of shellfish-eating birds has declined. Oystercatchers showed a marked decrease during the severe winter of 1996/97 (Figure 71). Since then, numbers have remained low at around 175000. The number of eider ducks declined to 100000 birds, tens of thousands of which migrated to the North Sea (Figure 72). During the years 2000-2002 there were only 40000 eiders in the Wadden Sea, but in 2003 there were more than 80000.

⁸ At the time of the introduction of the Sea and Coastal Fisheries Policy, the number of oystercatchers was thought to be lower. These numbers were based on the report by (Zegers & Kwint 1992). The reported maximum was about 237.000 birds in October, declining during the winter season to about 200.000 in December, 145.000 in February and 65.000 in April. New statistical treatment of the data, with imputing for missing data, yields a value of 260.000 oystercatchers between September and March for the reference period 1980-1990 (calculations by SOVON published in (Rappoldt *et al.* 2003a)).

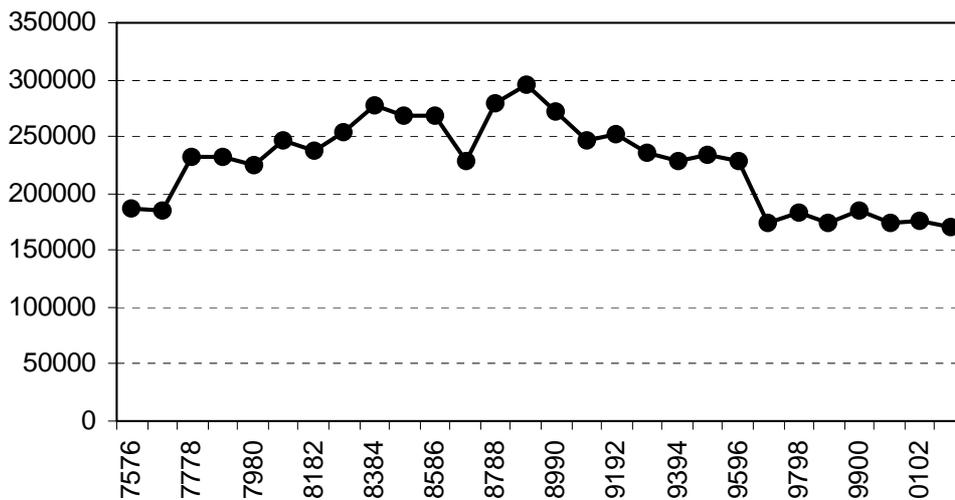


Figure 71: Number of oystercatchers wintering in the Dutch Wadden Sea (averaged per year from August until March) for the winter of 1975/76 to the winter of 2002/03. Missing counts were imputed; see Leopold *et al.* (2003b). Recent data added from SOVON (van Roomen & van Winden, pers. comm.).

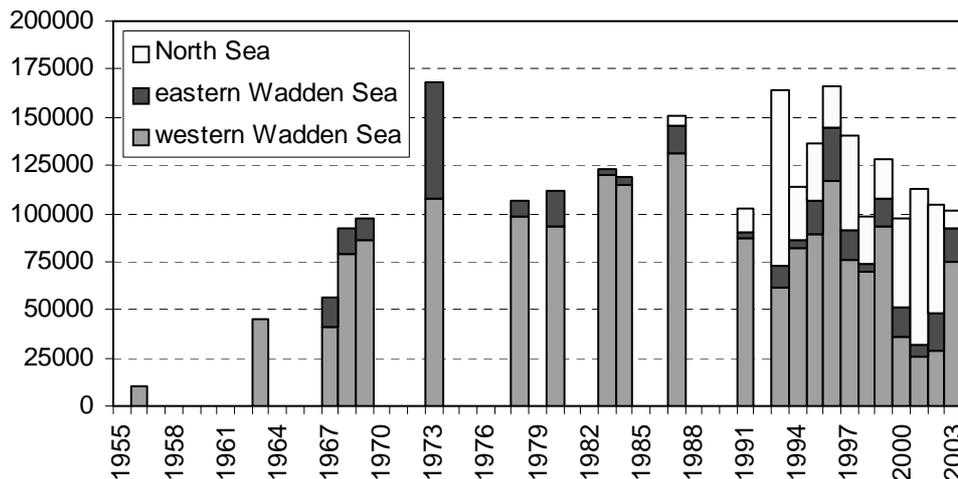


Figure 72: Midwinter counts for common eiders (mostly January) in the Wadden Sea (separated in the eastern and the western part) and the adjacent North Sea coastal zone. Data before 1993 from literature (see Ens & Kats, 2004). Data after 1993 from RIKZ and Alterra.

Analysis of the declining numbers requires an evaluation of the availability of shellfish compared with the reference period, because the policy is based on reservation of shellfish as food for the birds. In several years there was high mortality among oystercatchers and eider ducks. For oystercatchers this was largely due to the harsh winters. If the mud flats freeze, the birds cannot reach the food they contain (Camphuysen *et al.*, 1996; Hulscher, 1989; Goss-Custard *et al.*, 1996b; Ens, 2003). The effect of food shortage only becomes apparent, when the strong effect of severe winter weather is corrected for (Camphuysen *et al.*, 1996; Zwarts *et al.*, 1996c). For eider ducks, high mortality is associated with a shortage of suitable sublittoral

mussels (Ens *et al.*, 2002; Ens & Kats, 2004). At times eider ducks suffered from parasitic infections, but these played a secondary role at most.

To counter the decline in the numbers of shellfish-eating birds, a food reservation policy has been pursued since 1993 for shellfish-eating birds such as oystercatchers and eider ducks. Food reservation means that sufficient shellfish must remain for these birds after fishing. Policy must prevent birds, particularly in lean years, from suffering extra food shortages because of shellfish fishing. The basis for the food reservation policy was the numbers of shellfish-eating birds in the Wadden Sea from 1980-1990, combined with the food requirement per bird. The current food reservation policy was unable to prevent a food shortage for reference numbers of shellfish-eating birds as far as influenced by fishery. For the purposes of the food reservation policy, estimates are required of the shellfish stocks available to birds at the beginning of the winter. Since 1990 a quantitative survey of shellfish stocks has been carried out in the spring. The results are extrapolated to the autumn. The EVA II research has shown that the actual quantity was overestimated by an average of 38% (Kamermans *et al.*, 2003b). The greatest overestimates were made in cockle-rich years, since no account was taken of poorer growth in these years. In lean years the estimates were nearer to the mark. Since 2003 the original estimates have been corrected.

5.2 Oystercatchers

Before the intertidal mussel beds disappeared in 1990, it was estimated that over half of the oystercatchers in the Wadden Sea lived on mussels (Smit *et al.*, 1998). In fact, two independent estimates are involved. Since new insights lead to slight alterations of the original calculations of Smit *et al.* (1998), we repeat the calculations here. The first estimate starts from the distribution map of mussel beds in the Wadden Sea in 1978 (Dijkema *et al.*, 1989). From this map, Ens *et al.* (1993) estimated the total area of intertidal mussel beds in the Dutch Wadden Sea at 4120 ha. This figure is within the estimated range of mussel bed areas in the 1960s and 1970s (Dankers *et al.*, 1989; Dankers *et al.*, 2003). The low tide feeding density of oystercatchers on mussel beds can be estimated at 35 oystercatchers per ha (Zwarts & Drent, 1981; Ens & Cayford, 1996). For the 1980s we estimate the population of oystercatchers wintering in the Dutch Wadden Sea at 260000. From the above we calculate that 55% of the oystercatchers may have fed on the intertidal mussel beds. The second estimate starts with the benthos survey of the entire Dutch Wadden Sea by Beukema (1976) in the 1970s, which yielded 6.2 gram AFDM per m² of mussel meat, equivalent to 30 million kg of wet flesh (Dankers, 1993). Oystercatchers annually consume 25% to 40% (Zwarts & Drent, 1981) of this standing stock, amounting to 7.5 to 12.0 million kg flesh. Smit *et al.* (1998) estimate the annual consumption of the oystercatcher population at 15.4 million kg flesh. Considering a mussel consumption of 7.5 to 12.0 million kg, approximately 50-80% of the food must have consisted of mussels. This range includes the first estimate of 55%.

Mussel beds represented a stable source of food for oystercatchers. This applies far less to cockles, which are the next best alternative (Zwarts *et al.*, 1996a; Zwarts *et al.*, 1996b). The quantity of successful cockle recruitment in the Wadden Sea region is after all very unpredictable: cockle stocks fluctuate by a factor of more than ten between years. Model calculations show that the cockles were by far the most important prey in the period 1990-2001 (Figure 73). Most years cockles made up 40-70% of the oystercatchers' diet. Baltic clams generally took second place, at 20-30%. During this period, mussels contributed little to the diet. In the majority of years this was simply due to the scarcity of mussels, but in some years the model may have underestimated the contribution of mussels to the diet. As described in section 3.8, we consider the disappearance of the intertidal mussel beds as the primary reason for the decline in the number of oystercatchers.

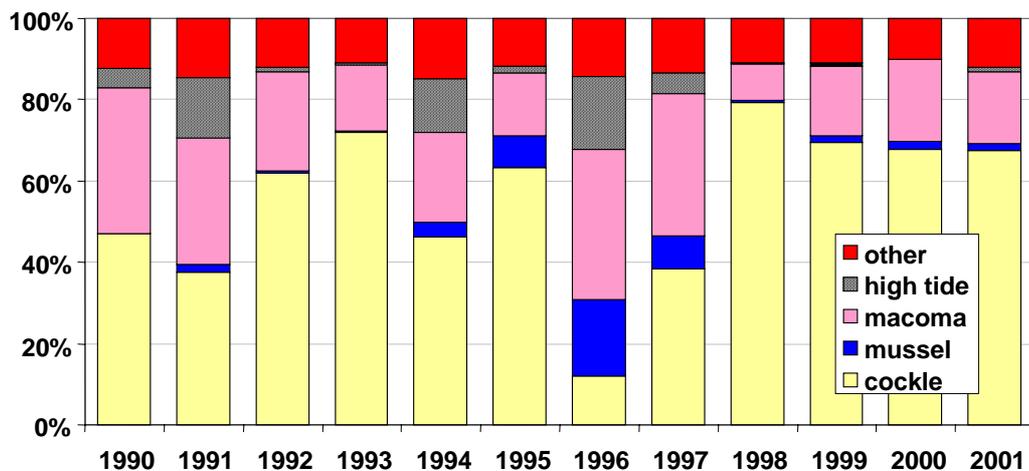


Figure 73: Calculated contribution of cockles and other prey to the diet of oystercatchers in the Wadden Sea in different years. The year 1990 applies to the winter season 1990/1991. From Rappoldt *et al.* (2003a).

While it is important to know the cause of the decline in the number of oystercatchers, the primary aim of this chapter is to evaluate the policy of food reservation and the underlying calculations. Since 1993 the food reservation policy has been largely based on the physiological food requirement of the oystercatchers⁹. This is the amount of flesh an oystercatcher needs to consume in the course of the winter in order to stay in good condition: around 65 kilos of flesh per winter. This approach assumes that every bird will succeed in catching the full hundred percent of the available quantity of shellfish. In practice, if the shellfish density is too low, the birds are unable to harvest them. Even at high densities they can only harvest a limited amount of shellfish since they will at some point get in each other's way. Some of the shellfish are also too small to count as food. Furthermore, the estimate of the total quantity of flesh weight is made in September, whereas shellfish actually lose weight in the course of the winter. Some die off before the birds can eat them. For all these reasons, the ecological food requirement must be taken as the basis for

⁹ The statement that the food reservation was largely based on the physiological food requirement relates to the fact that one aspect of the ecological food requirement was in fact taken into account. In reserving cockles for oystercatchers a minimum density of 50 cockles per m² was used. However, interference at high oystercatcher densities, limited feeding time, loss of shellfish condition during the course of winter etc. were not taken into account.

the food reservation policy to prevent a food shortage for the birds. We have defined the ecological food requirement as the quantity of food which must be available within the ecosystem per bird at the start of the winter, so that the bird can provide for its physiological need for food.

For common eiders, we estimated the ecological food requirement from a plot of mortality against food supply (see Figure 79 in section 5.3). Common eiders do not suffer high mortality in severe winters, but oystercatchers do, making it difficult to employ the same method for oystercatchers (Ens, 2003; Camphuysen *et al.*, 1996; Hulscher, 1989; Goss-Custard *et al.*, 1996b).

A second method to estimate the ecological food requirement is to plot the tendency of the population of oystercatchers to increase or decrease the next year, against the food supply. As expected, the population tended to increase when the food supply was high, but the correlation was not significant (Figure 74; see legend for statistical details). Return rates below 1 indicate a declining population. From this graph, one would estimate an ecological food requirement of about 250 kg cockle flesh per bird.

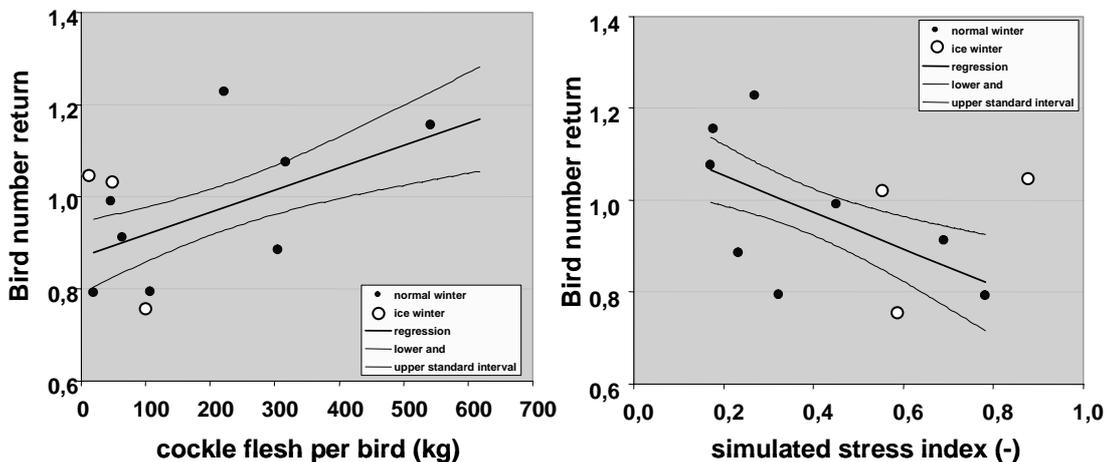


Figure 74: (a) The return of the number of oystercatchers in the next year as function of the non-fished cockle stock in September (after Rappoldt *et al.*, 2003a), Figure 2.5B). Values below and above 1 indicate a decreasing and increasing number of birds respectively. The regression line describes the average return after a normal winter ($P=0.10$; type-II error of 0.69 for a significance level of 0.05). The curves give the standard confidence interval (Draper & Smith, 1981) for values read from the regression line. (b) The return of the number of oystercatchers in the next year as function of the simulated stress index for that winter (after Rappoldt *et al.*, 2003a), Figure 3.26). Values below and above 1 indicate a decreasing and increasing number of birds respectively. The regression line describes the average return after a normal winter ($P=0.13$; type-II error of 0.75 for a significance level of 0.05). The curves give the standard confidence interval (Draper & Smith, 1981) for values read from the regression line.

The return rate as defined by Rappoldt *et al.* (2003a) is the combined effect of immigration (of young birds produced that season and older birds from elsewhere), emigration and mortality¹⁰. The idea is that return rate will be low when the food

¹⁰ (Rappoldt *et al.* 2003a) defines the 'return rate' T_i as follows:

$$T_i = 1 + \ln\left(\frac{a_{i+1}}{a_i}\right),$$

where a_i and a_{i+1} are the number of oystercatchers in year i and $i+1$ respectively

supply, expressed as amount of food per bird, is poor. Whether or not we will observe the predicted positive correlation between return rate and amount of food per bird depends on the time scale over which the local population becomes adjusted to a lowered or increased food supply. If the population becomes adjusted within a single winter, we will not observe a significant correlation between return rate and food supply. In that case, the return rate will not depend on the mismatch between the number of birds and the food supply in the current year, but on the difference between the food stock in the current year and the next year. If, on the other hand, adjustment takes many years, as seems to be the case for the oystercatchers in the Dutch Wadden Sea, we may not observe a correlation either. The slow response of the oystercatchers in the Dutch Wadden Sea may be explained by the fact that they comprise more than half of the continental European population (Goss-Custard *et al.*, 1996a). Thus, changes in the Wadden Sea population will be largely determined by natality and mortality, instead of immigration and emigration. Both natality and mortality are low in the long-lived oystercatcher, so adjustment will be slow, except when extreme events cause high mortality. Thus, the absence of a significant correlation cannot be taken as evidence that the population does not respond to changes in the size of the food stock.

Uncertainty in the estimates of the population size, related to imputing, poses an additional problem. The estimated trend in the total number of wintering oystercatchers is quite robust to the precise details of imputing. However, return rate depends on the difference in numbers between two consecutive years. Since oystercatchers population numbers generally change slowly over the years, this difference is generally small. As a result, small differences in the estimated total number of oystercatchers, which do not matter for the overall trend, can have a big effect on the estimated return rate. According to recent insights it is better to impute missing data on the basis of individual counting sites and not first clustering these counting sites into larger units (Soldaat *et al.*, 2004). Preliminary calculations indicate that return rate is quite sensitive to the method of imputing and that the new method adopted by SOVON leads to poorer correlations for the Dutch Wadden Sea than the correlation depicted in Figure 74¹¹.

Given the uncertainties surrounding the estimate of return rate for the Dutch Wadden Sea, it was necessary to invest most effort in developing a model describing how oystercatchers deplete a given food stock and whether they are stressed for food in the process. A short description of the model, including the most important parameters and assumptions is provided in section 1.5.7. For a detailed account we refer to (Rappoldt *et al.*, 2003d). The amount of food stress calculated with the model increases with a decreasing food supply. In addition, and as expected, the return rate

¹¹ The problems with estimating return rate in the Dutch Wadden Sea do not apply to the Oosterschelde. First, the entire Oosterschelde is counted every month, so the extent of imputing needed is small compared to the Wadden Sea. Second, the Oosterschelde is much smaller, so changes in numbers between years may depend more on immigration and emigration than mortality and reproduction. Thus, adjustment to a changed food supply may occur on a shorter time scale compared to the Wadden Sea. This may explain why the relationship between return rate on the one hand and food supply and food stress on the other hand is much tighter for the Oosterschelde than for the Wadden Sea.

is high when the food stress is low (Figure 74; see legend for statistical details). On the whole, the model calculations are consistent with the correlational analysis in Figure 74. The correlations in Figure 74 are not significant, but the statistical power is low as well. Similar correlations for the Oosterschelde are significant (see Figure 100 and Rappoldt *et al.*, 2003b), providing additional support for our estimate of the critical level of food stress, which, if exceeded, will lead to a declining population. For each combination of oystercatcher numbers, food supply and weather conditions, the model predicts the extent to which the oystercatchers are stressed for food. In combination with the critical stress level, the ecological food requirement can be calculated. The model calculations indicate that, in the absence of mussel beds, 200 kilos of cockle flesh would have to be available per oystercatcher in September. This corresponds to around 3.1 times the physiological food requirement of the birds from September to March inclusive. The error in this estimate of the ecological food requirement is difficult to determine accurately, but could amount to some dozens of kilos. For more details on the derivation of the ecological food supply and the associated margin of error from the model calculations, we refer to Rappoldt *et al.* (2003a).

A possible source of error in the derivation of the ecological food supply is that the decline in the oystercatcher population, manifested in the low return rate in some years, is not due to the poor food supply in winter, but to a deterioration of the conditions on the breeding grounds. Reproduction of oystercatchers has declined (Hulscher & Verhulst, 2003; Ens *et al.*, 2003a). While poor reproduction may be due to poor conditions in the breeding area, there could also be a link to the wintering areas, through the condition with which the birds arrive from the wintering area on the breeding grounds. Thus, food shortage in the Wadden Sea in winter may lead to poor reproduction in summer. In line with this suggestion is the sharp decline observed in oystercatcher populations which depend on the Wadden Sea and other tidal areas throughout the year, such as the breeding populations on Texel and Schiermonnikoog (Ens *et al.*, 2003a). These populations are not affected by changes in agricultural practices, increases in the number of foxes etc., but only by the situation in the Wadden Sea. Interestingly, on Schiermonnikoog the decline in reproductive success coincided with a decline in the proportion of breeders with a pure diet of shellfish (Verhulst, pers. comm.).

Our study has focussed on the relationship between birds and shellfish stocks and no attempt was made to construct a comprehensive population model of the oystercatcher, including the many other factors that may influence the population dynamics of this species. Such a population model is needed for quantitative predictions on the effect of changes in shellfish stock and other factors on the observed and future trends in the oystercatcher population (Goss-Custard *et al.*, 1996a).

Our analysis is supported by research findings in France and Great Britain, summarized by (Goss-Custard *et al.*, 2003). Table 8 lists the estimates of the physiological and ecological food requirement that are now available. Goss-Custard *et al.* (2003) employ a different model, which predicts mortality instead of food stress

(Stillman *et al.*, 2000). They arrive at an estimate for the ecological food requirement by plotting mortality against food supply. According to their definitions, the ecological food requirement is the food supply at which the mortality is 0.5% above the background mortality rate. When food supply is reduced, mortality increases. Despite these differences, the estimates agree well. The physiological food requirement of oystercatchers wintering in France and Britain is somewhat lower, because temperatures are higher and oystercatchers put on less fat as insurance against periods of frost. This does not necessarily translate into lower ecological food requirements: for oystercatchers feeding on cockles, our estimates fall within the range of 105 to 232 kg cockle flesh per bird per winter estimated by Goss-Custard *et al.* (2003).

Table 8: Estimates of the physiological food requirement and the ecological food requirement of oystercatchers (in kg wet flesh per bird) for different study locations with either mussels, or cockles as the main winter food. Also indicated the ratio between the ecological food requirement and the physiological food requirement. The kg AFDM estimates of Goss-Custard *et al.* (2003) were transformed to kg wet flesh, assuming that 1 kg wet flesh corresponded to 1 kg AFDM (Beukema & Cadée, 1997).

Study location	prey species	Physiological food requirement	Ecological food requirement	Ratio	Source
Exe estuary	mussel	41	321	7.7	(Goss-Custard <i>et al.</i> , 2003)
Bangor flats	mussel	41	263	6.4	(Goss-Custard <i>et al.</i> , 2003)
Burry Inlet	cockle	41	232	5.6	(Goss-Custard <i>et al.</i> , 2003)
Wash	cockle	42	105	2.5	(Goss-Custard <i>et al.</i> , 2003)
Baie de Somme	cockle	35	174	5.0	(Goss-Custard <i>et al.</i> , 2003)
Wadden Sea	cockle	65	200	3.1	(Rappoldt <i>et al.</i> , 2003a)
Oosterschelde	cockle	60	150	2.5	(Rappoldt <i>et al.</i> , 2003b)

If the target figure of 260000 oystercatchers remains the same, around 52 million kilos of cockle flesh would have to be available in the absence of mussel beds. If there were 4000 hectares of mussel beds, around 25 to 30 million kilos of cockle flesh would have to be reserved for the oystercatchers (Figure 75). The said 52 million kilos rarely occurred in the Wadden Sea during the research period. Continuation of the current food reservation policy might lead to a further decline in the numbers of oystercatchers - assuming that the cockle stocks and the absence of intertidal mussel beds in the nineties are representative of the future.

In order to assess options for achieving the reference numbers of birds, it is important to estimate how carrying capacity will develop. An estimate of carrying capacity with a large margin for error indicates that the current number of 170000 oystercatchers could fall to around 130000 if there were no mussel beds. Without the restoration of intertidal mussel beds in the Wadden Sea the target figures for oystercatchers will not be reached.

Without cockle fishing, the estimated carrying capacity for oystercatchers would be in the order of 15000 higher (Rappoldt *et al.* 2003a).

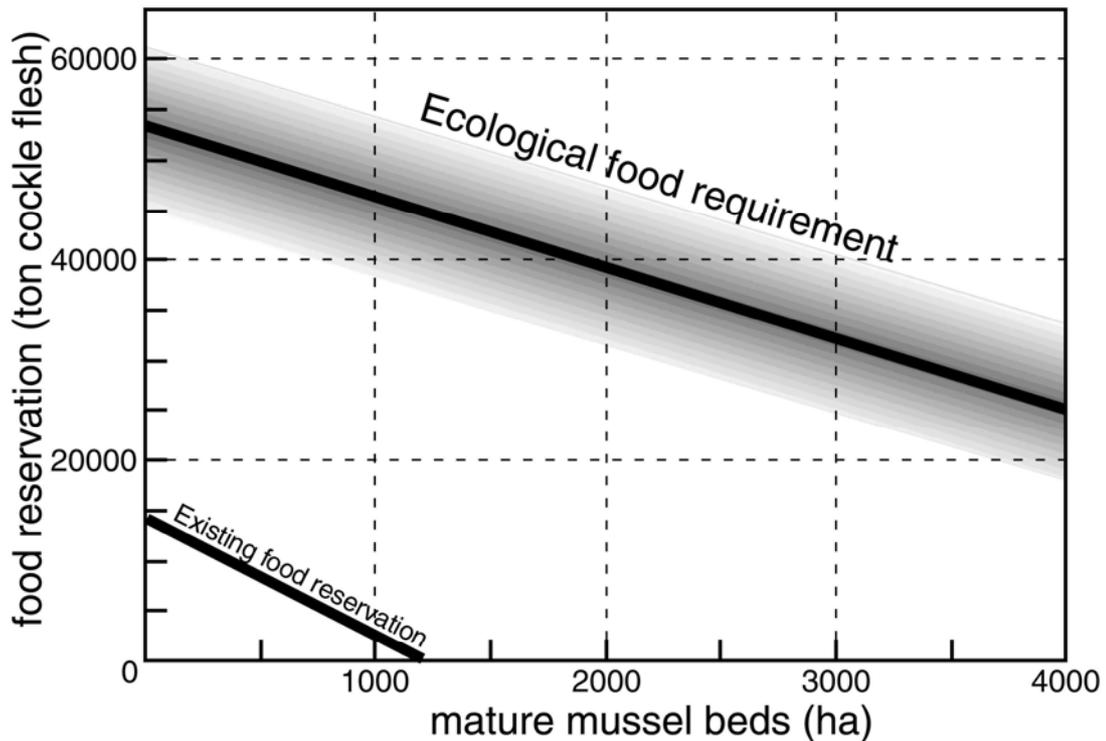


Figure 75: Amount of cockle flesh (million kg) that has to be present in autumn for a given area of mature mussel beds (ha) so that the reference number of oystercatchers (260000) will not suffer from food shortage. From Rappoldt *et al.* (2003a).

Our model calculations evaluating the policy of food reservation apply to a single winter season. However, cockle fishing reduces cockle stocks in subsequent years. This even applies to years in which there were still sufficient stocks after fishing for oystercatchers, eider ducks and other shellfish-eaters such as gulls. Tentative calculations for the Wadden Sea indicate that the decline in stocks due to fishing does not equate 1:1 with the reduction in stock in subsequent years (Rappoldt *et al.*, 2003a). If ten kilos of cockles are removed by fishing, this translates in the following year into a reduction of about seven kilos. The reduction is not ten kilos, as one might expect, because natural die-off and growth influence the ultimate effect. This percentage (70%) only applies if the fishing is not followed by a harsh winter. A harsh winter leads to high mortality among cockles, but this is generally followed by a good spat fall (Beukema, 1982; Beukema *et al.*, 1993). If fishing continues for several successive years and at the same time there is no new spat fall of cockles, the reduction of the stocks by fishing leads to food shortages for the shellfish eaters at an earlier date than would otherwise have occurred. The results of the model calculations are presented in Figure 76. The effect is clear for the strong year class of 1997. It should be noticed though that reduction of the adult stock by fishery seems to have a positive effect on recruitment. The overall cumulative impact of fishery therefore requires more extensive model calculations than presently available.

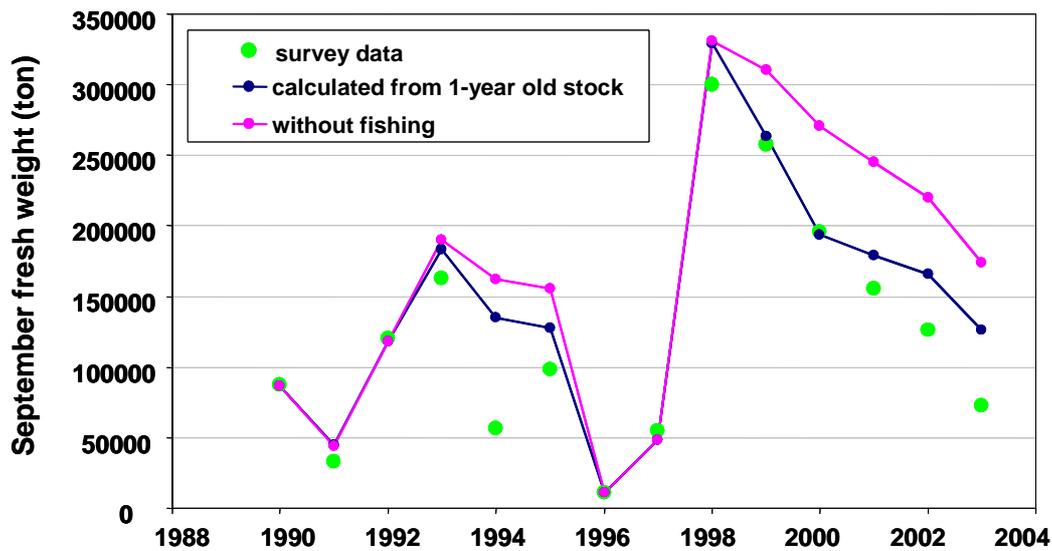


Figure 76 The cockle stock in September for open areas in the Wadden Sea calculated from the amounts of one year old cockles in May (without using the information on older cockles) in combination with the data on cockle growth and summer survival in Kamermans *et al.* (2003b), and the cockle predation and winter mortality estimated in Rappoldt *et al.* (2003a), for the older year classes. For September each year the sum of the various year classes, presented both with and without fishery, is compared with the September stock derived from the complete spring survey.

5.3 Common eiders

The food reservation policy implemented in 1993 assumed that the cultivation of mussels and associated seed fishing would not entail great changes for eider ducks (LNV, 1993a). The assumption was that the mussels were transplanted largely within the system. For this reason there was no food reservation policy for the sublittoral areas. Since 2000, following the high eider duck mortality in 1999 (Camphuysen *et al.*, 2002) and a subsequent evaluation of the policy of food reservation by Ens (2000), 8.6 million kilos of flesh have been reserved in the sublittoral areas of the Wadden Sea and the North Sea coastal zone (LNV, 2000). This quantity is based on the physiological rather than the ecological food requirement. Even after the introduction of this new policy, there was still mass mortality among eider ducks in 2000 and 2001 (Figure 77; Ens *et al.*, 2002).

Model calculations show that the net energy yield of different types of prey decreases with increasing shell thickness, decreasing flesh content and increasing diving depth (Brinkman *et al.*, 2003b). This means that sublittoral mussels are the most attractive prey for the eider ducks (Figure 78). Experiments with eider ducks in captivity confirm this preference (Bustnes & Erikstad, 1990; Bustnes, 1998; Ens & Kats, 2004). The mussels which are permanently underwater have a far thinner shell and a higher flesh weight than the mussels on the flats. After mussels, in decreasing order of preference, eider ducks will eat the following shellfish: littoral cockles, sublittoral cockles and *Spisula* (Ens & Kats, 2004).

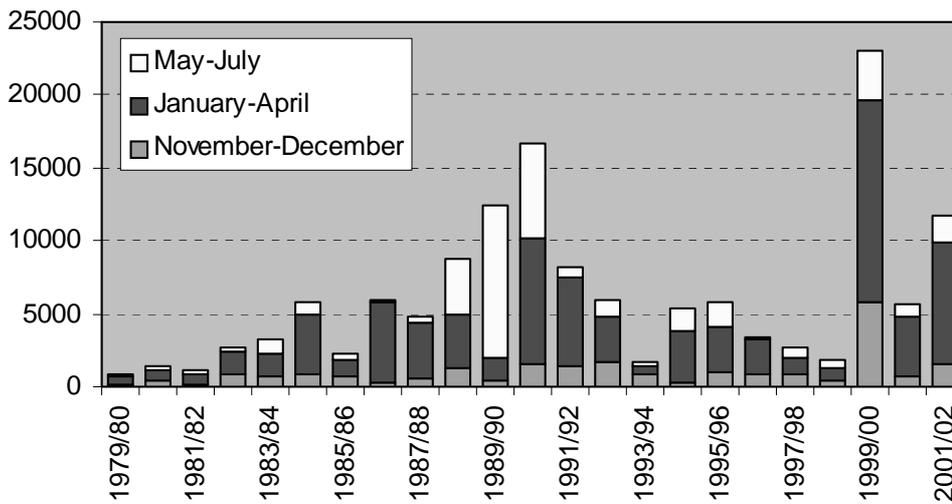
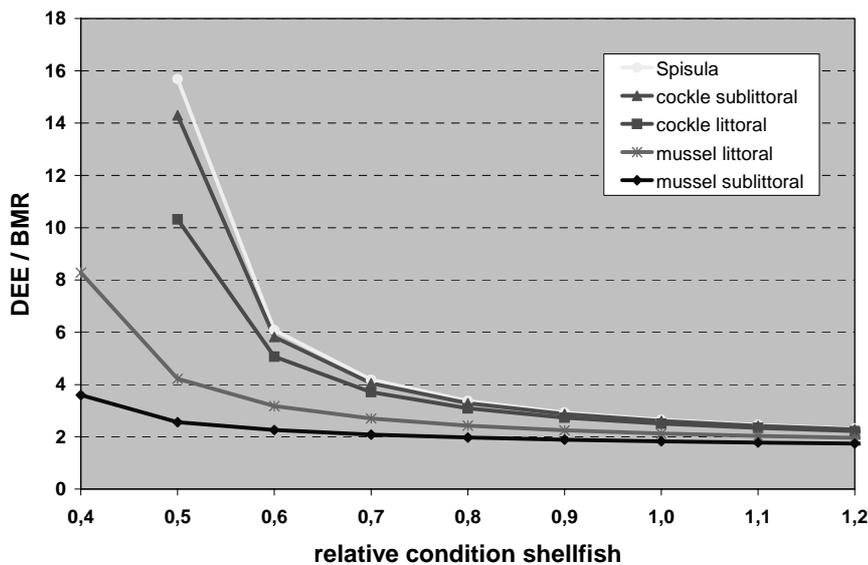


Figure 77: Estimated number of common eiders found dead on the Dutch coasts north of IJmuiden per winter,



separated for three periods (November-December, January-April, May-July). From Ens & Kats (2004).

Figure 78: Daily energy need of a common eider (expressed as multiple of BMR), calculated with the model of (Brinkman et al., 2003b) as a function of the condition of various shellfish species (maximum condition in an average year is set to 1). From Ens & Kats (2004).

For eider ducks the ecological food requirement can only be derived from the relationship between food supply and mortality (Figure 79). In this graph, mortality is expressed as the number of dead eiders per km beach. This choice was made, to maximize both the number of data points as well as the reliability of each individual data point (Ens & Kats, 2004). The current reference number for eider ducks is 130000. To prevent an increased risk of mortality at this population level there would

have to be around 60 million kilos fresh weight of half-grown and mature sublittoral mussels available on 1 January (Figure 79). Estimates show that such stocks were generally available between 1970 and 1990, but in the last ten years these levels have only been reached five times. It must be admitted that this estimate of the ecological food requirement contains several arbitrary choices. Instead of looking when the probability of a mass mortality starts to increase, one could decide which risk of a mass mortality occurring is acceptable. Table 9 lists the values one gets when this risk is chosen as 50%. Even more important is the fact that what one considers a mass mortality is arbitrary. When more eiders must die before we speak of a mass mortality, it is clear that the food stocks at which this mortality will occur, will be lower. Finally, it is clear that the relationship between mortality and mussel stock, although significant, is not very tight. Thus, other factors also play an important role in the mortality of the common eiders.

We lack the knowledge to infer the population consequences of a particular mortality level. What we know is that the common eiders breeding and wintering in the Netherlands are part of the Baltic/Wadden Sea flyway population (Rose & Scott, 1994). The status of this population has recently been described by Desholm *et al.* (2002). Between 1940 and 1991 this flyway population showed a strong increase, but between 1991 and 2002 there appears to have been a sharp decline from an estimated 1200000 to 760000 animals. The majority of these birds winter in Denmark and complete counts of Denmark are infrequent. The estimated decline is due to a single low count in 2000. However, scientists attached to NERI are convinced that the count can be trusted (Fox, pers. comm.). The total number of ducks wintering in the international Wadden Sea varied between 200000 and 300000, which is about 25% of the Baltic/Wadden Sea population. More than half of the birds wintering in the Wadden Sea, winter in the Dutch part, but we have no quantitative information on the extent of exchange over large distances within the Wadden Sea, or on the extent of exchange between the Wadden Sea and the Baltic Sea during winter. Hunting of common eiders is not allowed in the Netherlands, but permitted in Finland and Sweden, where most eiders of the flyway population breed. Hunting pressure is especially high in Denmark, where the annual hunting bag declined from 160000 in the 1980s to 90000 at the end of the 1990s (Desholm *et al.*, 2002). In recent years, bird cholera has caused high mortality in some Danish breeding colonies, but it is not known if birds from Danish colonies regularly spend the winter in the Dutch Wadden Sea. Nothing is known of the presence of absence of site fidelity between years of common eiders wintering in the Dutch Wadden Sea. Our only information on site fidelity is from females ringed on the nest in the Netherlands. Such females are found dead close to their ringing site, both in summer and winter (Swennen, 1991).

Table 9: Critical values derived from Figure 79 on the stock of littoral mussels present on 31 December (in million kg fresh weight) at which the probability of a mass mortality among common eiders steeply increases, or reaches 50%. Critical values are derived for the stock of mature sublittoral mussels as well as all sublittoral mussels.

	Strong increase in the risk of a mass mortality	Probability of a mass mortality exceeds 50%
Stock of mature sublittoral mussels	about 60	33
Total stock sublittoral mussels	about 90	64

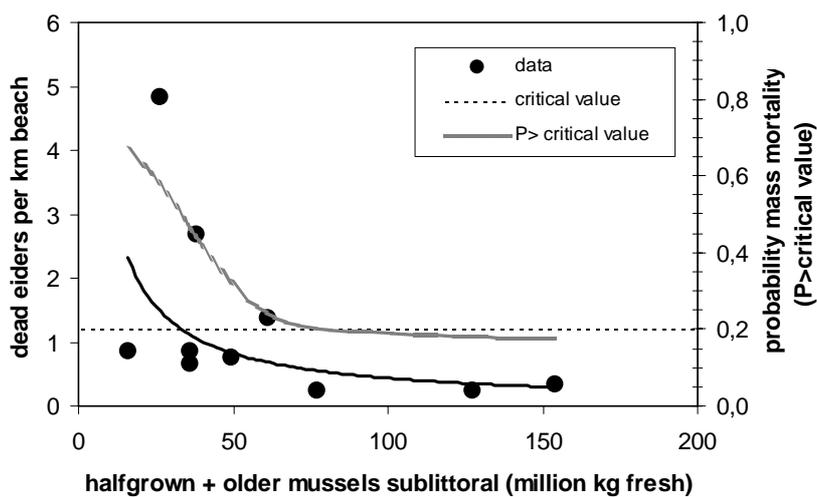
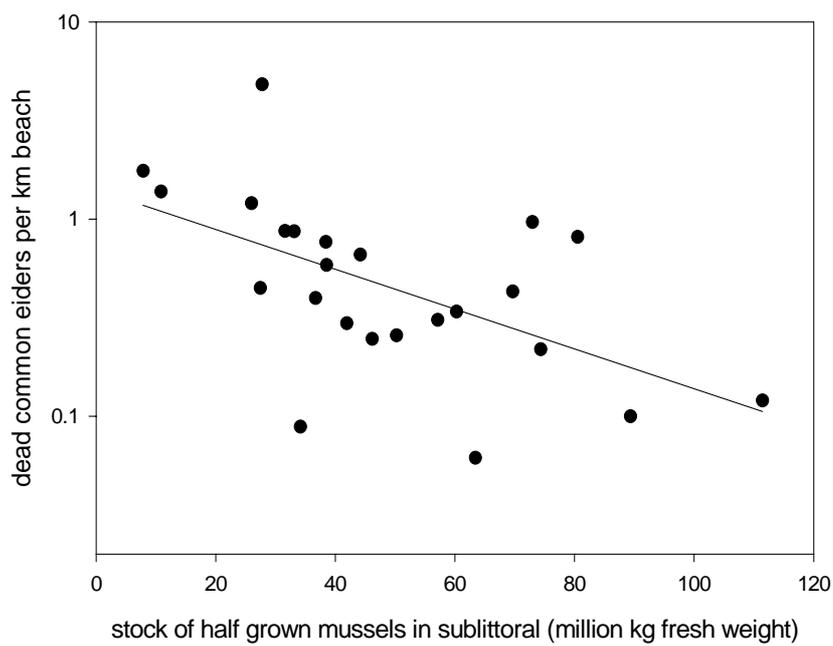


Figure 79: (a) Relationship between the mortality of common eiders (expressed in number of dead eiders per km beach) and the stock of immature sublittoral mussels in the Wadden Sea, estimated via back-calculation from the landings. The correlation is $r=-0.57$, $N=25$, $P=0.003$. (b) Relationship between the mortality of common eiders (expressed as dead eiders per km beach) and the constructed stock of half-grown + older sublittoral mussels (Bult et al., 2003b). Also indicated the regression line, the criterion of mass mortality and the probability of mass mortality. From Ens & Kats (2004).

It is important to consider what effect the cultivation of mussels may have had since the start of the 1950s on the food supply of the eider ducks. After a long period of absence, common eiders started breeding again in the Netherlands somewhere around 1900. At the time that mussel culture was introduced around 1950, the breeding population was already quite large and the rate of increase did not change. Thus, there is no evidence that the introduction of mussel culture affected the breeding population (Ens & Kats, 2004). However, during winter the local breeding birds are nowadays heavily outnumbered by birds breeding elsewhere and the strong increase in the wintering population occurred after mussel culture was introduced. The dependency of the wintering population on the stock of sublittoral mussels is clear from the increased mortality when this stock is low. Additional support comes from (1) the positive correlation between the number wintering in the western Wadden Sea and the stock of sublittoral mussels, and (2) the negative correlation between the number counted on the North Sea and the stock of sublittoral mussels, suggesting that the ducks moved to the North Sea when food was scarce in the Wadden Sea (Figure 80). The important question though is how mussel culture affects the stock of sublittoral mussels in the western Wadden Sea. On the basis of the study of Bult *et al.* (2003b) and chapter 4 of this report, the following can be said. A first attempt to calculate the overall effect of mussel culture on the subtidal mussel stocks during the 1990s points to an increase of the total subtidal stock in Dutch coastal waters by a factor 2. As a considerable part of seed mussels and half-grown mussels is transplanted to the Oosterschelde, where very few eiders spend the winter, the net increase in the Wadden Sea was tentatively estimated as ca. 15%. However, due to lack of data, it cannot be excluded that during years of scarcity, transport of mussels from culture lots in the Wadden Sea to culture lots in the Oosterschelde was increased, thereby increasing the food shortage for the common eiders. Before 1990, more mussels were landed from the Wadden Sea instead of the Oosterschelde, but the efficiency with which seed mussels were grown into consumption-sized mussels was less. Summarizing, our current knowledge does not allow us to draw firm conclusions on the relationship between mussel culture and the food stocks for common eiders.

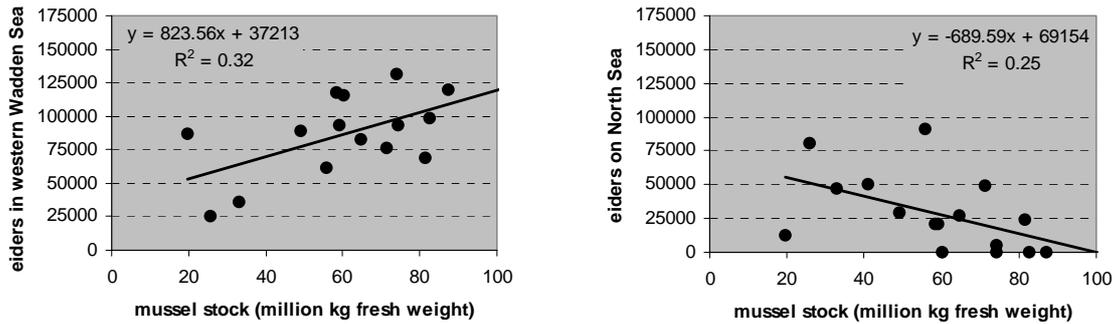


Figure 80: (a) The number of common eiders counted in the western part of the Dutch Wadden Sea as a function of the total stock of sublittoral mussels as estimated from landings. (b) The number of common eiders counted on the North Sea as a function of the total stock of sublittoral mussels in the Dutch Wadden Sea as estimated from landings. The data for these graphs were taken from Tables 2.1 and 5.2 in *Ens & Kats (2004)*, and it was assumed that missing counts of the North Sea could be taken as 0 for the years before 1990.

5.4 Conclusions

- The food reservation policy was unable to prevent food shortages for the reference numbers of shellfish-eating birds in years with fishery-induced food shortage.
- The numbers of oystercatchers wintering in Wadden Sea have declined from 260000 to 175000.
- The food shortage for oystercatchers in the Wadden Sea is probably largely the result of the absence of intertidal mussel beds in the 1990s.
- In the Wadden Sea, the ecological food requirement for oystercatchers is around 3 times higher than the physiological food requirement.
- The ecological food requirement for oystercatchers in the Wadden Sea was estimated at around 200 kilos of cockle flesh per bird in the absence of mussel beds. There is a margin for error in this ecological food requirement which is difficult to determine accurately, but which could amount to some dozens of kilos. Every hectare of stable mussel bed represents a relative reliable food source for 30 to 40 oystercatchers for which then no cockles need to be reserved.
- As a result of cockle fishing the carrying capacity for oystercatchers in the Wadden sea has declined in recent years in the order of 15000 birds.
- The numbers of eider ducks which winter in and around the Wadden Sea have decreased. In several years mass mortality occurred due to food shortage, particularly due to a shortage of sublittoral mussels.
- The risk of increased mortality among eider ducks rises as the stocks of half-grown and mature sublittoral mussels in the Wadden Sea in December fall below the level of 60 million kilos net fresh weight. The margin of error in this estimate is large, but cannot be estimated due to lack of knowledge.

6 Evaluating the policy of closed areas in Wadden Sea

In 1993 certain areas in the Wadden Sea were permanently closed to shellfish fishing as part of the new Sea and Coastal Fisheries Policy. Here, we investigate whether the closed areas fulfilled their original goals of (1) undisturbed development, (2) monitoring and research, (3) protection and restoration of important habitats.

6.1 Undisturbed development

Undisturbed development is a general goal in the management of the Wadden Sea, and the establishment of undisturbed areas was one of the goals in the trilateral Wadden Sea cooperation. Whether or not the development in the closed areas was undisturbed by fishery depends on the extent to which the fishermen refrained from fishing in the closed areas. The likelihood that illegal fishing occurred was addressed by Kamermans *et al.* (2003c), who questioned the ministry of LNV and the PO Kokkels on this issue. According to the information she received, a few minor infringements occurred, but on the whole, the system of licenses, fishing plans and black boxes seemed effective in keeping the closed areas free from fishery.

The next question is whether there were differences between open and closed areas in the development of sediment, seagrass, benthic fauna and birds, which could be ascribed to fishery:

1. There were indications for a lowered silt content on tidal flats that had been open to cockle fishery during a longer period. This difference can be explained by the low cockle stocks and consequently a reduced production of faeces and pseudofaeces in these open areas
2. The recovery of seagrass was reduced by cockle fishery outside the closed areas.
3. The recovery of mussel beds did not show a clear relationship to open and closed areas, in line with the observation that there was no clear relationship with recruitment of mussels and cockle fishery in the preceding season(s) at the scale of the Wadden Sea.
4. Closing areas to cockle fishery had a very clear effect on the cockle stock, which was higher in the closed areas. Initially, recruitment was also higher in the closed areas. Probably as a result of the increased cockle stocks in the closed areas, recruitment became higher in the open areas at the end of the study period.
5. The shift in recruitment of cockles towards higher tidal zones was especially pronounced in the open areas, possibly as a result of the loss of fine sediments due to the reduction of the cockle stocks by fishery in low-lying sandy areas already poor in fine sediments.
6. Kraan *et al.* (2004) provide evidence for a general increase of worms in fished areas in the (relatively sandy) western part of the Wadden Sea (Kraan *et al.*, 2004), whereas Leopold *et al.* (2003a) provide evidence for an increase of the worm *Nereis diversicolor* on moderately to intensively fished cockle beds throughout the Wadden Sea. This could explain, at least partly, the increase of worm-eating birds

that was observed in the open areas (Leopold *et al.*, 2003b). But the distribution of these worm-feeding birds was probably also influenced by the development of mussel beds. These beds started to develop first in the open areas.

7. We did not observe an increase of oystercatchers in the closed areas, compared to the open areas, but Verhulst *et al.* (2004) observed that oystercatchers in closed areas were in better condition, compared to animals in open areas.

Thus, safe-guarding the closed areas from fishery resulted in demonstrably more 'natural' conditions for most parameters. It should be noted though that in the case of worm-feeding birds, it is possible that 'more natural' means 'fewer birds'.

6.2 Monitoring and research

One goal of the monitoring of the benthic fauna of the Wadden Sea in protected areas is to understand the natural processes that govern the distribution and abundance of the benthic animals. Another goal is to act as reference point and allow the detection of trends and changes that are relevant for management, like the effects on the ecosystem of changing temperatures and changes in eutrophication. The areas permanently closed in 1993 have served as an important factor in the EVA II research program. This was possible because they were sufficiently representative for the Wadden Sea as a whole. The conclusions drawn on sediment and benthic fauna, tentative as they may sometimes be, had not been possible without the closed areas. Summarizing, the closure was well argued, was effective and the arguments for closure still hold for the future.

6.3 Protection and restoration of important habitats

Damage to seagrass beds was effectively avoided in the permanently closed areas, whereas damage occurred to seagrass in one of the open areas. There is a risk that newly established seagrass fields will not be detected in time. Thus, unless a watertight monitoring and reporting regime can be developed, permanently closed areas are the best way to protect newly developing seagrass beds.

It was expected that the closed areas would play a role in the return of intertidal mussel beds, especially the areas that were closed in 1999 on the basis of their high potential for the development of mussel beds. This turned out not to be the case. This can be ascribed to the consistent protection of all newly developing mussel beds against cockle fishery in areas both open and closed to fishery.

Due to the almost complete absence of mussel fishery on the tidal flats during the evaluation period, we could not compare the effectiveness of permanently closing areas to mussel fishery to the effectiveness of protective measures in open areas with regard to the recovery of intertidal mussel beds.

6.4 Conclusions

- The permanently closed areas showed changes in development in comparison with open areas that must be ascribed to the absence of fishery effects. Thus, the closed areas were effective in safe-guarding undisturbed development.
- The permanently closed areas were important for monitoring and research.
- The closed areas were more effective in the protection of newly established seagrass from cockle fishery than the protective measures in open areas.
- Effective protection of both old and new mussel beds from cockle fishery was achieved both inside and outside the closed areas.
- Due to the absence of mussel fishery on the tidal flats, the effectiveness of closing areas to mussel fishery could not be evaluated.

7 Long-term ecosystem changes and future developments in the Wadden Sea

7.1 Carrying capacity for shellfish and eutrophication

7.1.1 Introduction

In the years before 1980, an increasing eutrophication of the Dutch coastal waters and the Wadden Sea was reported many times (Postma & Rommets, 1970; van Bennekom *et al.*, 1975; de Jonge & Postma, 1974). Van Beusekom *et al.* (2001) mentioned that concentrations of phosphorus and nitrogen compounds increased roughly fivefold since the beginning of the 20th century. In other publications (de Vries *et al.*, 1998; Zevenboom *et al.*, 2003; Cadée, 1986; Cadée & Hegeman, 1993; Cadée & Hegeman, 2002; Laane *et al.*, 1999) it was mentioned that increased concentrations of N and P led to an increasing algae biomass and an increased primary production. De Jonge (1990) was among the first to show a strong positive correlation between phosphate loads from Lake IJssel and the primary production in the Marsdiep. This stirred a discussion in the policy making arena on source, cause and effect of the eutrophication of the Wadden Sea (see e.g. de Vries *et al.*, 1998; Zevenboom *et al.*, 2003). Laane (1992) reported on the background concentrations of nutrients in the main rivers and gave an estimate of these background concentrations for the North Sea coastal zone. This was followed by an extensive hindcasting operation by van Raaphorst *et al.* (2000) leading to estimates of natural background concentrations. From all these publications, mainly based on the monitoring data collected by Rijkswaterstaat, it is clear that the concentrations of N and P have increased manifold compared to the natural background concentrations. Total inorganic phosphorus concentrations reached their maximum winter values around 1982 (de Jonge, 1997) to 1986 (Laane *et al.*, 1999) of 4 to 5 times (Laane *et al.*, 1999), perhaps even 8 times (de Jonge, 1997) their natural background values. For total inorganic nitrogen content, this ratio was about 3 (Laane *et al.*, 1999) to 4-6 (van Raaphorst *et al.*, 2000) during the whole period 1980-1990. (Beukema *et al.*, 2002) mentioned an increased macrobenthic biomass on the Balgzand area (south-western Wadden Sea) from the beginning of his investigations in the early 1970s to the beginning of the 1980s.

From the mid 1980s, phosphorus loads and to a lesser extent also nitrogen loads began to decrease. The OSPAR Commission (2003) reported a reduction of N-discharges from the Netherlands alone with 30% for the period 1985 to 2000, almost completely due to industrial reduction and better treatment of household discharges. According to OSPAR Commission (2003), a 70% reduction of P-discharges was achieved in that same period: industry and households reached a 82% reduction and agricultural discharges were reduced with 13%. Measurements in the Dutch coastal zone show about 50-60% reduction in total-P, and about 15% reduction of total-N concentrations.

However, in the literature an effect on the ecosystem in terms of decreasing primary or secondary production or biomass (algae or benthic macrofauna) was not reported. Moreover, for example Cadée & Hegeman (1993) wrote that despite lower P-loads, primary production remained high. Later, they concluded (Cadée & Hegeman, 2002) that *Phaeocystis* content, as well as primary production, decreased since around 1995. Although de Jonge (1990) stressed the importance of nutrients for primary production, others often conclude that light is of overriding importance, e.g. Colijn & Cadée (2003), and that nutrient concentrations are not low enough to become limiting. However, these studies are based on measured data of chlorophyll, nutrients and light (mostly Secchi depths), plus certain values for light and nutrient half saturation constants. Mass budgets of nutrients are never considered in such analyses. Based on a model study for the North Sea coastal zone, de Vries *et al.* (1998) concluded that there was no reduction in primary production in the period 1985-1995, despite the reduction in phosphorus loads. The model, however, did not contain descriptions of secondary producers nor adsorption processes. Also, the presented figures did show a drastic decrease of primary production for the region near Terschelling with about 60% (for the period 1985-1995).

With the insight that there are hardly any system wide data of the Wadden Sea that may help us to analyse the possible effects of the reduction of P- and N-loads, we decided to apply the integral ecosystem model EcoWasp (Brinkman, 1993; Brinkman & Smit, 1993; Brinkman, 1993). The model is based on mass budgets for all components, and we feel that the model best covers the crucial processes of the system, and therefore, is suitable to estimate the expected effects of changing nutrient inputs on primary and secondary producers, and on the nutrient dynamics in sediment and water. This was done for the 24 year period 1976-1999. A previous version of the model was applied to the western Wadden Sea (Brinkman & Smit, 2001), and to the Sylt-Rømø bight (Fast *et al.*, 1999).

A short description of some data and forcings will be given first and then the model results are summarised. A brief description of the model is given in paragraph 1.5.8 of this report.

7.1.2 Data overview– forcings and Wadden Sea characteristics

Loads of nutrients showed a remarkable trend regarding phosphate. The fresh water from Lake IJssel (merely reflecting water from the river Rhine, and thus also partly representing the trend in the North Sea coastal zone) and the content of the Dutch western Wadden Sea water both showed a total-P decrease from the end of the eighties onward (Figure 81).

Whereas the reduction in P-load is roughly 50%, the nitrate+ammonium reduction is not more than about 15% (OSPAR Commission, 2003). Since the increase of nutrient loads in the period before 1980 was generally considered as a cause of the increasing algae content and primary production, one might expect that decreasing nutrient loads are followed by a decreasing primary production and algae biomass. The extent depends among others on how crucial phosphate and/or nitrate are for

algae growth. In Figure 82 chlorophyll-a measurements are shown. Chlorophyll-a shows a slight decrease for the Marsdiep site, but hardly for the centre of the western Wadden Sea, as was also noted by Luttkhuizen (pers. comm.). Here, a major drawback is that the frequency of measurements must be considered insufficient after 1995.

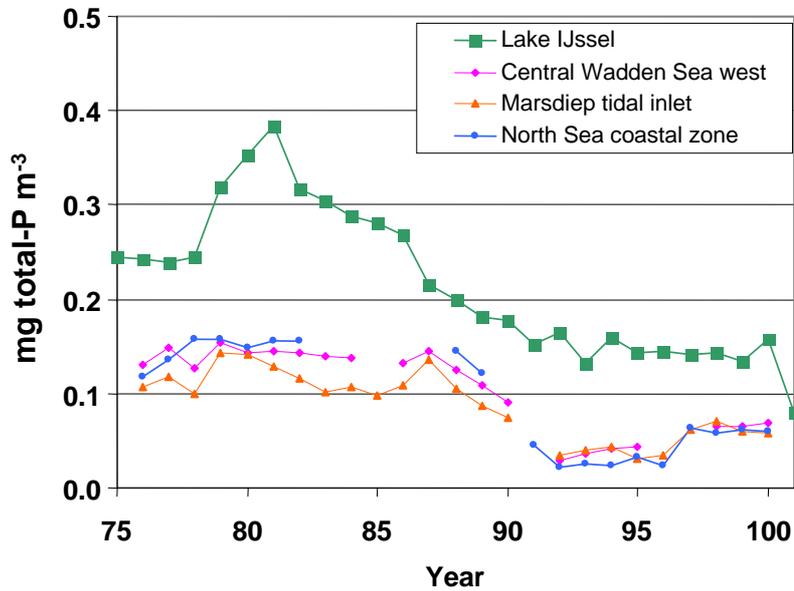


Figure 81: Yearly average total Phosphate (mg P/l) for two stations in the western Wadden Sea for the years 1975-2000. From Brinkman & Smaal (2003).

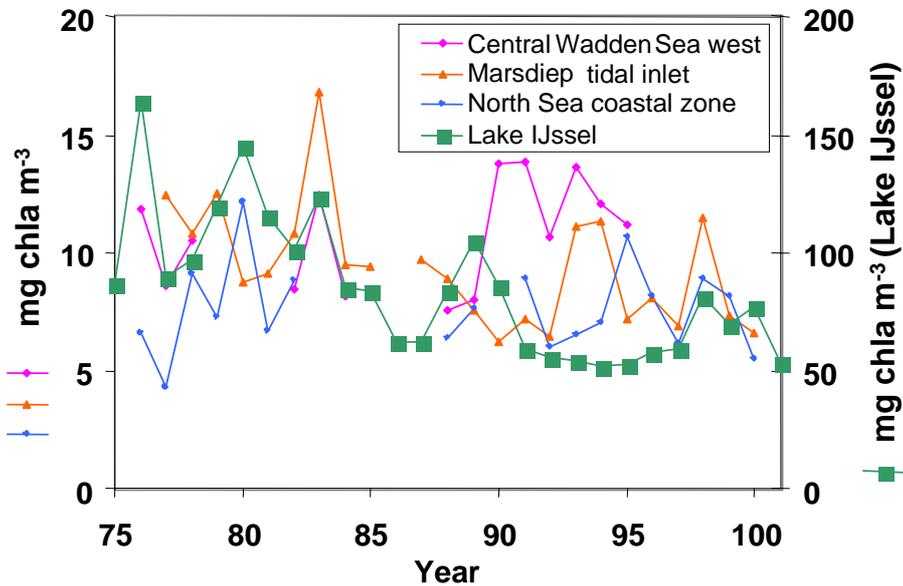


Figure 82: Chlorophyll-measurements in the Marsdiep tidal inlet, the North Sea coastal zone (Noordwijk-2), the fresh water Lake IJssel (Vrouwenzand), and the centre of the western Wadden Sea (DooveBalg-West). From Brinkman & Smaal (2003).

7.1.3 Fine-tuning the model

Most model parameters were found using literature data. Primary production rate constants of algae show a large range. Nutrient half-saturation constants were kept low in order to reach nutrient limitation just at low concentrations for N, P and Si. Low values were also chosen for the light half saturation. Filtration and respiration rates by mussels are size dependent. We had to choose filtration rates that were slightly below most of the laboratory data. Respiration rates were in agreement with the lowest values reported in literature; see Brinkman & Smaal (2003) for more details. Assimilation efficiencies were set to relatively high values, e.g. of 0.8 for non-diatoms.

Resuspension parameters were tuned by fitting the long term suspended solid data against the computed contents of suspended matter. All suspended particles (algae and silt, etc) contribute to the extinction coefficient, and thus determine the under water light climate. Exchange with the North Sea and the flows through the tidal inlets of Vlie and Marsdiep were taken from (Ridderinkhof, 1988).

Adsorption characteristics were mainly based on data for Lake Veluwe (Brinkman & van Raaphorst, 1986), but adapted somewhat in order to represent a marine system rather than a fresh water system. Sediment characteristics were derived from the silt map of Zwarts *et al.* (2004) that was slightly adapted.

7.1.4 Model results

The subsequent simulation with the input data for the period 1976-1999 revealed an increase of primary and secondary production, and of the maximum possible mussel biomass from 1976 to about 1982. From that moment, a decrease of these three followed, with a lowest value around 1992. A slight increase followed, but on average, maximum mussel biomass in the period 1990-1999 was about 52% of that in the period 1980-1989. The real shellfish biomass is expected to be somewhere between zero and this maximum, and depends among others, on spatfall success, storms, ice and fisheries (Figure 83).

The results show a similar pattern as for example mussel landings do (Figure 69), which might be regarded as the most complete data set on shellfish richness for the whole period. An important implication of the results is that the maximum possible amount of shellfish that can be extracted from the system nowadays is lower than about 20 years ago.

Primary production, as simulated by the model, also decreased, but to a lesser extent. This is a consequence of the existing feed-back mechanisms (see also the discussion below). Because Colijn & Cadée (2003) stressed the importance of the light climate, it is interesting to check whether this has changed as well. Unfortunately, the available data are not consistent. The Rijkswaterstaat monitoring data show a drastic decrease of the suspended solid content since about 1987-1990 (see also de Jonge & de Jong,

2002), but at the same time the Secchi-depths hardly changed. For the moment, this part of the system behaviour remains unsolved.

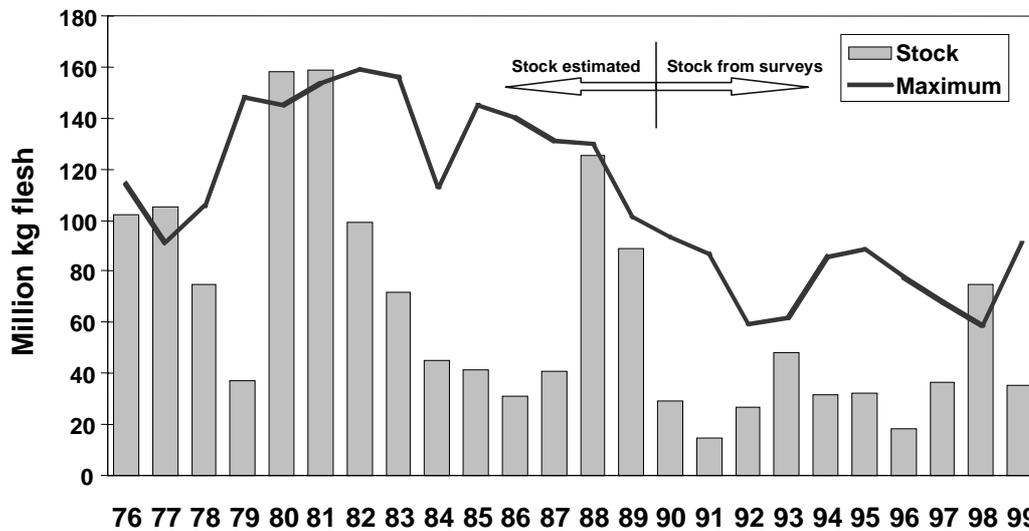


Figure 83: Total stock of shellfish (cockles and mussels) in the western Wadden Sea for the years 1975-2000. Also indicated the maximal stock according to calculations with the ecosystem model ECOWASP. From Brinkman & Smaal (2003).

According to the simulation results, limiting nutrients are subsequently silicon, phosphorus and nitrate. Silicon is depleted early in the year, quickly followed by phosphorus. Since we choose relatively low half-saturation values for phosphate limitation ($0.2 \mu\text{M}$ for non-diatoms and $0.17 \mu\text{M}$ for diatoms), and low Smith-values for light limitation ($I_k=20 \text{ W m}^{-2}$ for non-diatoms, and 8 W m^{-2} for pelagic diatoms), we found a relatively long period with low dissolved P values (ortho-P). Increasing the half-saturation values would increase the summer values for [ortho-P], but would also lengthen the period of P-limitation. The statement by van Beusekom *et al.* (2001) that nitrate is the limiting nutrient cannot be confirmed by our study for the western part of the Dutch Wadden Sea. The model computes that phosphorous is –together with silicon- the major primary production limiting nutrient.

A second important conclusion from this EVA-II sub-study was that mussel beds induce feedbacks in the system. The active mechanism is the storage of nutrient rich compounds in the sediment of the system (especially by mussels present on mussel beds), leading to an enhanced release of N and P during warmer periods in the (following) years. Since in warmer (i.e. summer) periods nutrient concentrations tend to be low, primary and thus secondary production benefit from such an extra release. A first estimate was that 10-30% extra production might be possible (Figure 84). This process may work over seasons and years, depending on the accumulation of biodeposits. For mussels in wild beds the process continues over time as a function of mussel activity, while on culture plots biodeposit accumulation will stop and be resuspended during fishing, and will start again when new mussels are brought to the culture plots. Therefore, mussel beds not only benefit the systems since they provide food for birds or valuable habitat for other benthic organisms, but they also stimulate production.

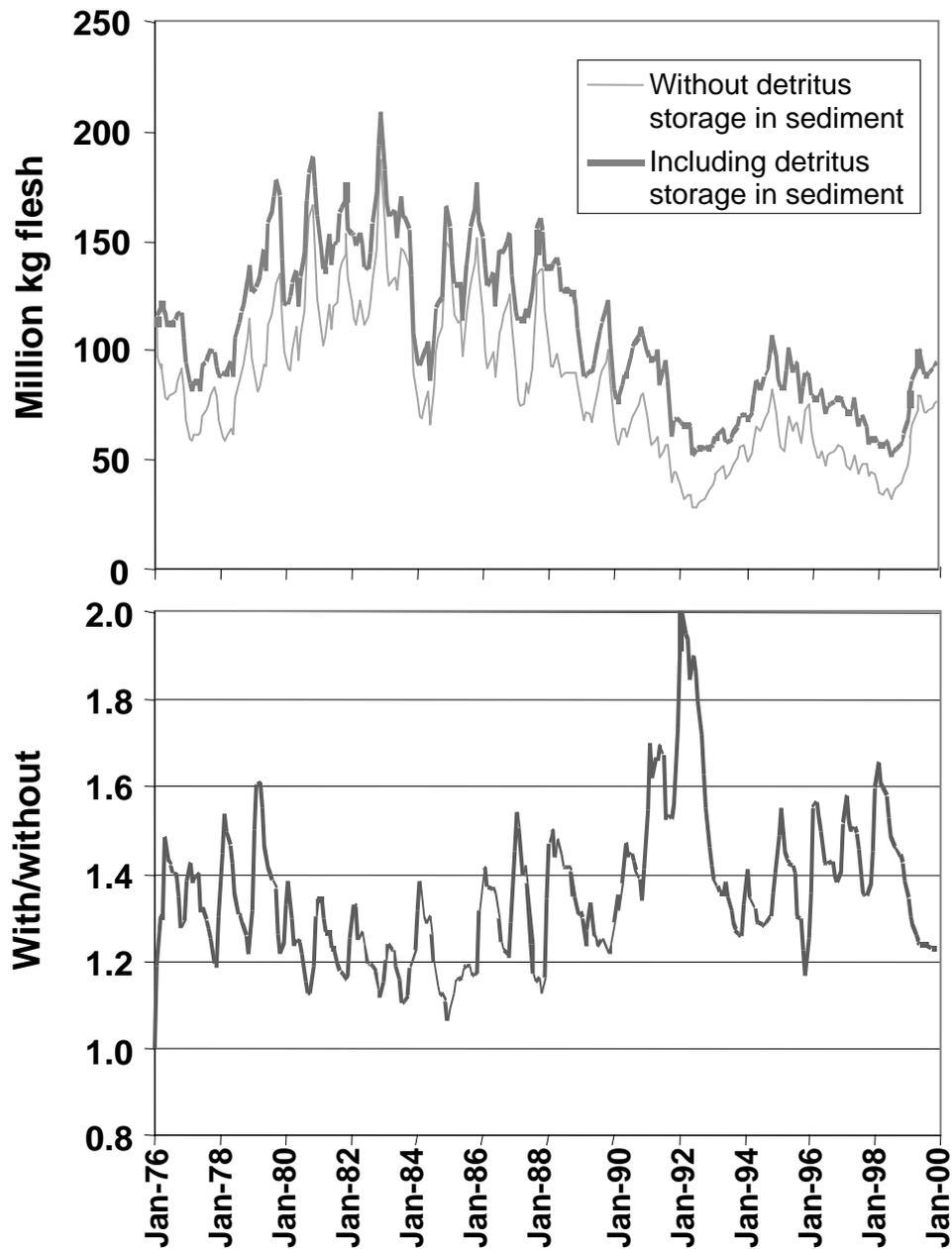


Figure 84: (a) Computed maximum shellfish biomass (in mussel-equivalents) in case no sediment storage of organic matter occurs (thin line) and in case storage is allowed in the model (thick line). Such a storage in and subsequent release of nutrients from the sediment is especially important under the relatively poor nutrient conditions present in the years 1990-1999. (b) The ratio of the maximum biomass with storage and without storage. From Brinkman & Smaal (2003).

7.1.5 Discussion

We assume, based on our own expertise, that the model covers most of the Wadden Sea key processes. However, as with any model, it remains a simplification of 'reality'. The model results are strictly determined by the mathematical descriptions of key processes and the chosen parameter values. The spatial schematisation and the numerical algorithms will add some uncertainty, but we expect this to be minor relative to the model sensitivity related to the process descriptions. The major model limitation concerns the formulation of primary production, where we used a fixed cell quota description (constant ratio C:N:P) and only three types of algae. This makes it impossible for algae to adapt their internal nutrient storage to the external conditions, nor for other algal species having different quota's of and affinities for N, P or Si to develop blooms.

A second limitation concerns the highest trophic level. We modelled benthic filter feeders as the upper most level, and used blue mussels as our model organism. That implies that all benthic biomass results have to be interpreted in terms of mussel activities. In case other species become important (such as cockles or sand gapers *Mya arenaria*), then a transformation to other maximum biomass values has to be performed. Cockles and *Mya arenaria* are generally assumed to have lower filtering rates, and therefore may reach higher stocks than mussels.

Coupled to this second limitation is that the model does not compute 'real' biomass values, but theoretical maximum possible biomass values: the available food (i.e. phytoplankton) is optimally consumed. Processes like predation on small mussels by shrimps, etc., are not implemented and reproduction is only simply described. As a result, the benthic fauna biomass values that are computed are expected to be higher to much higher than those present in the field.

Yet, we feel that the model produces relevant results. The computations are all based on mass budgets, and thus, the available nutrients for primary production are known as good as possible, with all major processes (input, output, sediment storage, adsorption, storage in living biomass and suspended detritus) accounted for. Secondly, the benthic filter feeder activities are size-dependent activities and size and numbers are modelled, which is a major improvement compared to almost any other existing model. Third: the water column light climate is coupled to the alga biomass. Thus, this relevant feed-back mechanism is fully accounted for. Finally, computed primary production, growth rates of individual mussels, filtration and respiration rates of mussels (very small to adult sized), field uptake of mussel beds of particulate matter, oxygen, and release of e.g. ammonium all are in range with available measurements.

The conclusions on the maximum possible shellfish biomass and algae contents have been criticised, mainly because field observations were said not to support the model results. But, we have to deal with the problem that sufficient field data are hardly available: most benthos data originate from a part of the western Wadden Sea (Balgzand), or are only available for the period from 1992. Chlorophyll-data for the

western Wadden Sea are almost absent from 1995, and the NIOZ primary production data for the period 1976-1990 are only available in 1985 and 1986. Regarding the observations, one must also realise that a direct effect of nutrient reductions on phytoplankton and primary production could hardly be expected, since the shellfish biomass greatly affects phytoplankton biomass and primary production. This was explained in a working document (Brinkman, 2004). Such a feed-back also implies that all model analyses where grazers are absent or not dynamically modelled, by definition fail to produce results that can be used to study the effects of nutrient reduction. In a filter feeder rich system, a reduction of nutrient loads (as dissolved plus organic nutrients) leads to much less reduction of algae than in a system where filter feeders are absent. Also, since the real filter feeder densities vary considerably from year to year, the system response in terms of chlorophyll-a content is also varying strongly and will reflect the changes in shellfish even more than the changes in nutrient loads. In addition, there may be time lags in the response of the stock of filter feeders to changes in food availability. Long-lived species like *Mya arenaria* will respond on another time scale than species with a shorter generation time. For the Balgzand area, Beukema *et al.* (2002) found no decrease in benthic biomass despite lower primary production. According to Dekker (pers. comm.), the current high benthic biomass on the Balgzand area is due to the dominance of adult *Mya*. In more general terms, biomass may show no obvious response while production may change, hence turnover changes. This was demonstrated in the Oosterschelde system after completion of the coastal engineering project (Smaal *et al.*, 2001) and this may also be the case for the Wadden Sea as shown for the Balgzand area.

The observed nutrient concentrations from the RIKZ monitoring data are high enough to contradict a nutrient limitation of primary production. On the basis of these data, Colijn & Cadée (2003) concluded that primary production was limited by light, not by nutrients. On the other hand, Philippart *et al.* (2000) concluded that a changed N/P-ratio was very well correlated with a changing algae species composition in the NIOZ-data series for the Marsdiep tidal inlet, thus suggesting an important role for nutrients. Secondly, they stated that primary production and phytoplankton abundance on that same site was highest in spring and not in summer when light availability was maximal. Kromkamp (pers. comm.) mentioned that in the Oosterschelde, primary production was not far from P-limitation. Since the DIN/DIP-ratio in the Wadden Sea is much higher in the Wadden Sea (over 40, and sometimes >150, (de Vries *et al.*, 1998)), Kromkamp's observation supports our conclusion on the importance of phosphorus for the system response in the Wadden Sea. Herman (pers. comm.) suggested that a) the real shellfish stock was probably steered by the available phytoplankton in the preceding year, and b) phosphorus likely has a major effect on the production of the system, being the limiting nutrient in the 1990s, whereas N probably was the limiting nutrient in the 1980s. He also showed that the ratio primary production/shellfish biomass was very well correlated with the flesh content (or condition) of landed mussels. Van der Meer (pers. comm.) showed an overview of the NIOZ- primary production data, illustrating a decline in primary production in the 1990s, relative to the (few) data in the 1980s. Based on an analysis where he filtered out effects of other factors like e.g. temperature, Van der

Meer also showed that part of that decline is a result of lower Secchi-depth as measured by the NIOZ on one location in the Marsdiep.

Here we encounter a contradiction already touched upon. The NIOZ-data set show a slight decrease of Secchi-depth, while the RIKZ-monitoring data show a slight increase. In case light is indeed the most determining factor, and not nutrients, one might expect a further increase of the chl-a content and /or of the benthic biomass. Such an increase of phytoplankton would increase the NIOZ primary production data as well. This, however, is not the case, and this observation is therefore consistent with our conclusion on the impact of nutrients.

Finally, it should be mentioned that any analysis (statistical or by a model simulation) has to rely on the available data. It is almost always the case that there are too many gaps in the time series. In our situation, the chlorophyll-monitoring in the Wadden Sea was reduced to 4 measurements per year from 1995 onwards, or even completely stopped at other sites. Such scarcity of data seriously affects the quality of the analysis. In line with this observation is the remark that continuation of shellfish biomass surveys is crucial for future system analysis.

7.1.6 Expected future nutrient loads

The present nutrient load reduction is a result of merely industrial and household sanitation measures. In future, a further reduction of P and even more N needs to be achieved, according to the European Water Framework Directive (2000/60/EC). Agricultural discharges, that remained almost unchanged since 1980, have to be reduced as well. In 1991, the European Nitrates Directive (91/676/EEC) came into effect which sets limits to these diffuse sources. According to the Water Framework Directive, coastal waters should reach a 'good ecological condition', which definitely will imply that primary and secondary production will be reduced more in the future. This will in due course bring the carrying capacity in the Wadden Sea close to its natural level. Mussel beds may partly compensate for this declining carrying capacity. In this respect, undisturbed mussel beds will have a longer lasting effect than mussels on culture lots.

7.2 Other factors: climate, tides and oysters

In addition to nutrient loads and eutrophication various other factors that have impact on the Wadden Sea ecosystem are relevant in the framework of this report. The occurrence of severe versus mild winters has great impact on recruitment success of bivalves (Beukema, 1992), and it is apparent that average winter temperatures have increased over the past decade (Verbeek, 2003). This change may have hampered successful recruitment of mussels and cockles. On the other hand, severe winters are detrimental for adult cockle stocks, and the survival of the strong cohort of 1997 may be due to the absence of severe winters since. If climate change continues, with the associated increase in temperature, the reproduction of cockles,

mussels and Baltic clams could decline even further (Beukema, 1992; Beukema & Dekker, 2004).

Winter storms are detrimental for the survival of unstable mussel beds in particular (Seed, 1976; Nehls & Thiel, 1993). From meteorological data Brinkman & Smaal (2003) show that the frequency of strong wind forces is lower in the nineties and was high in the sixties. Yet, severe storms in 1990 (Jan and Feb), 1995 (Feb) and 2001 (Dec) are coupled to damage to mussel beds (Brinkman & Smaal, 2003).

Suspended matter concentrations have been relatively low in the last decade. According to our analyses, there is a good correlation with flesh content of landed mussels: condition is high in years with low concentrations of suspended matter (Brinkman & Smaal, 2003). The concentration of suspended matter depends among others on wind force and wind direction, dumping and dredging in the coastal zone, coastal nourishment and long-term variations in the tidal range.

Observations show a rapid proliferation of Pacific oysters (*Crassostrea gigas*) in the Wadden Sea (Dankers *et al.*, 2004) and the Ems-Dollard (Tydeman, 1999). Since first recorded in the 1980s, the species has proliferated all over the Wadden Sea, not only in the Dutch part but also in Lower Saxony (Wehrmann *et al.*, 2000) and Schleswig-Holstein (Reise 1998b; Nehls & Ruth, 2004). Particularly on mussel beds locally high densities are observed, but also on other parts of the tidal flats and along the shores, oysters have settled. The distribution through larval phase and through wave driven transport of small individuals occurs quite rapidly. An excessive spatfall after the warm summer in 2003 has resulted in many new spots with oysters. Growth rates can be quite high, filtration capacity is high as well. During the shellfish survey in the spring of 2004, approximately 11.5 million kg oysters and a bed area of at least 400 ha was recorded (Smaal *et al.*, 2004). It is quite likely that the rapid development of the Pacific oyster in the Dutch Wadden Sea will continue. The development in the Oosterschelde estuary (Kater & Baars 2003) illustrates the colonizing potential of the species. The apparent absence of natural enemies and the resistance to extreme climate conditions support the idea that the species will continue to colonize the Wadden Sea. As a consequence, the formation of a new habitat type in the form of oyster reefs is likely, but competition for food and space with other bivalves will increase and as a result the stocks of these other bivalves may decline.

Thus, on the basis of our current knowledge, there are no reasons to expect stocks of mussels and cockles to increase in the future. Instead, all evidence suggests stocks will decline. This will negatively affect the birds and fishermen exploiting these stocks.

7.3 Conclusions

- According to model calculations for the western Wadden Sea, maximal shellfish populations were lower in the 1990s compared to the 1980s, as a result of lowered nutrient loads.

- In many years, actual shellfish stocks were below the maximal stocks as a result of recruitment dynamics and losses due to storms, ice winters, predation and fishery.
- Mussel stocks, and to a lesser extent cockle stocks, can compensate in part for the declining carrying capacity, because they accumulate organic matter. This gives rise to extra local mineralization, which stimulates the productivity of the area.
- According to nutrient policies, the nutrient loads are expected to decline further, which will lead to a further decline in maximal shellfish stocks.
- The expected changes in climate might reduce the likelihood of large spatfalls of cockles and mussels.
- The expected increase of the Pacific oyster might go at the expense of other shellfish stocks.
- The expected decline in stocks of mussels and cockles will negatively affect the birds and fishermen exploiting these stocks.

8 Ecosystem changes and ecological impacts of cockle fishery in the Oosterschelde

8.1 Introduction

The Oosterschelde is one of the two remaining tidal areas in the Dutch Delta area. Three other tidal inlets, the Haringvliet, Veerse Gat and the Grevelingen, were closed as part of the Delta plan. The Delta plan was conceived after a storm flood disaster in 1953, which killed several thousand people. According to the original Delta plan, the Oosterschelde should also be closed off, but the joint opposition of fishermen and nature conservationists gained sufficient clout to prevent this. The Oosterschelde was important for mussel culture (mainly carried out with seed mussels from the Wadden Sea), the culture of flat oysters (*Ostrea edulis*) and the mechanical cockle fishery that developed in the course of the 1970ties. In addition, the Oosterschelde was, and still is the Dutch centre for processing of shellfish and for shellfish trade. Due to large scale hydraulic construction works this water system has undergone considerable changes, and adaptation processes continue to play an important role (Nienhuis & Smaal, 1994). As the characteristics of the Oosterschelde water system differ considerably from the Wadden Sea and specific processes are of influence on the future carrying capacity for cockles and oystercatchers, the Oosterschelde has been treated as a separate case within the EVA II research programme.

8.2 Catches and areas fished

The cockle stock in the Oosterschelde fluctuates widely (Figure 85). During the period 1992-2002 the area was entirely closed to cockle fishing on a number of occasions. In the years when fishing was permitted the yield averaged 1.3 million kilos of flesh, or 22% of the stock (Kamermans *et al.*, 2003c; Kamermans *et al.*, 2003a).

Figure 86 gives for the winters between 1990 and 2002 a quantitative estimate of the various causes of death of the cockles during winter (i.e. between September and May). On average 39% of the cockle fresh weight present in September was on average predated by oystercatchers, on average 13% was fished (including the years without fishery), on average 5% died in winter by causes other than predation and on average 1% died as a result of freezing in ice winters. On average 42% of the total fresh weight present in September was still present in May the next year. Calculations commenced when the cockles were one year old, so predation of cockle spat by knots and gulls is not included.

In the Oosterschelde, cockle fishery mainly takes place on the tidal mud flats. 15.3% of the flats were fished, with the cockle dredge actually touching 6.5% of the sea bed area (Table 10). Of the area permanently under water only 1.1% was fished; the

touched area amounted to 0.2% of the total. Combination of fisheries data with cockle habitat maps shows that the most suitable cockle habitat, located high on the large tidal flats, was fished with the highest intensity (Geurts van Kessel *et al.*, 2003).

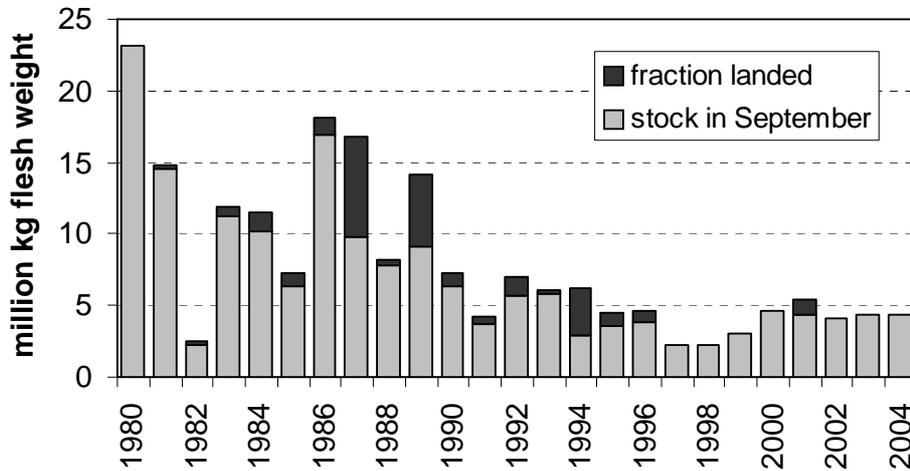


Figure 85: Cockle stocks in the Oosterschelde (million kg flesh weight) in autumn. In black the amount taken by suction dredges. Before 1990 stocks were not assessed in a standardized fashion. From Geurts van Kessel *et al.* (2003).

Table 10: Surface touched by cockle dredge and area disturbed by cockle fishery (a quadrant is called disturbed when the fished area, i.e. the surface touched by the cockle dredge, exceeds 2%) for years when fishery was allowed in the Oosterschelde. A distinction is made between littoral and sublittoral areas and the disturbance is expressed as an absolute value (in ha) and as percentage of the total surface. From Kamermans *et al.* (2003c). In brackets the average values when the years without fishing (1997-2000) are included in the calculation.

Year	Surface touched by cockle dredge				Area disturbed by cockle fishery			
	lit (%)	lit (ha)	sublit (%)	sublit (ha)	lit (%)	lit (ha)	sublit (%)	sublit (ha)
1992	4.6	523	0.1	15	13.6	1540	0.8	194
1993	2.1	236	0.1	27	6.2	701	0.6	143
1994	11.8	1346	0.5	127	23.2	2642	2.7	635
1995	4.3	483	0.1	15	12.8	1460	0.8	181
1996	9.1	1040	0.1	16	21.0	2386	0.6	154
2001	7.0	795	0.1	24	15.5	1711	0.8	192
average	6.5		0.2		15.3		1.1	
	(3.9)		(0.1)		(9.2)		(0.6)	

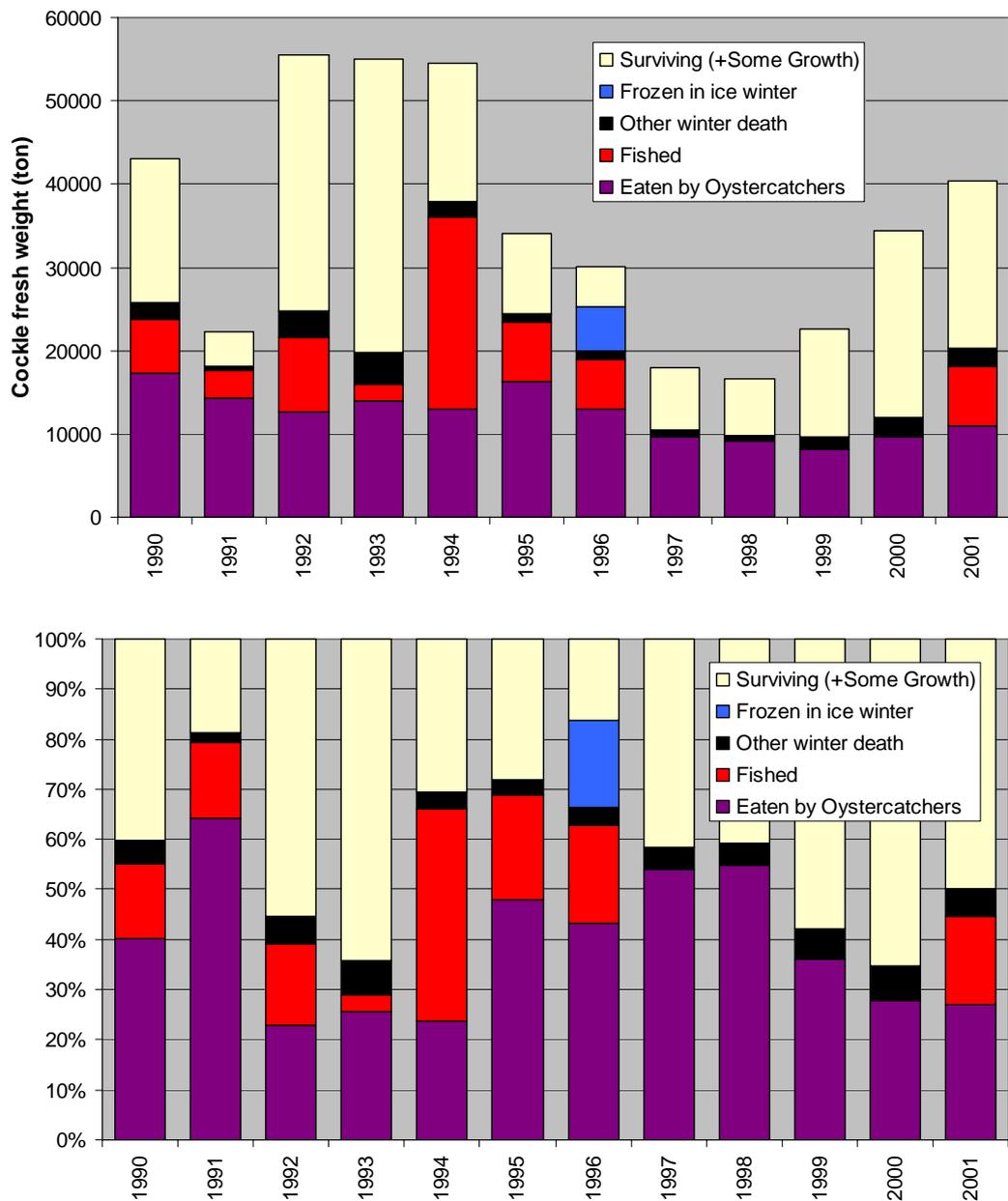


Figure 86 Causes of cockle mortality in the Oosterschelde estimated for different winters (1990 indicates the winter season 1990/1991). From the data on cockle growth and summer survival in Kamermans et al. (2003b) and the cockle predation and winter mortality estimated in Rappoldt et al. (2003b), the total loss of fresh weight from September to May can be attributed to the various causes of mortality. (a) Mortality of cockles expressed as tons fresh weight adding up to total loss of fresh weight from September to May. (b) Causes of mortality as a fraction of the total fresh weight present in September.

8.3 Effects on the Cockle population

In 1993 two permanently closed areas were designated in the Oosterschelde: part of the Roggenplaat and the Noordtak (see also Figure 1; LNV, 1993b). In the nineteen nineties the cockle biomass per square metre in the closed areas of the Roggenplaat was lower than the average over the entire flat (Geurts van Kessel *et al.*, 2003). In the Noordtak the total stocks were lower than in the other designated areas, but densities were higher. Individual cockle weights were also lower. As a consequence, these permanently closed areas have long been the poorest cockle grounds in terms of biomass. As in the Wadden Sea, cockle fishing is reducing cockle stocks in the Oosterschelde (Figure 87). Whereas stocks have declined in the open areas, they have remained constant in the permanently closed areas (Figure 88).

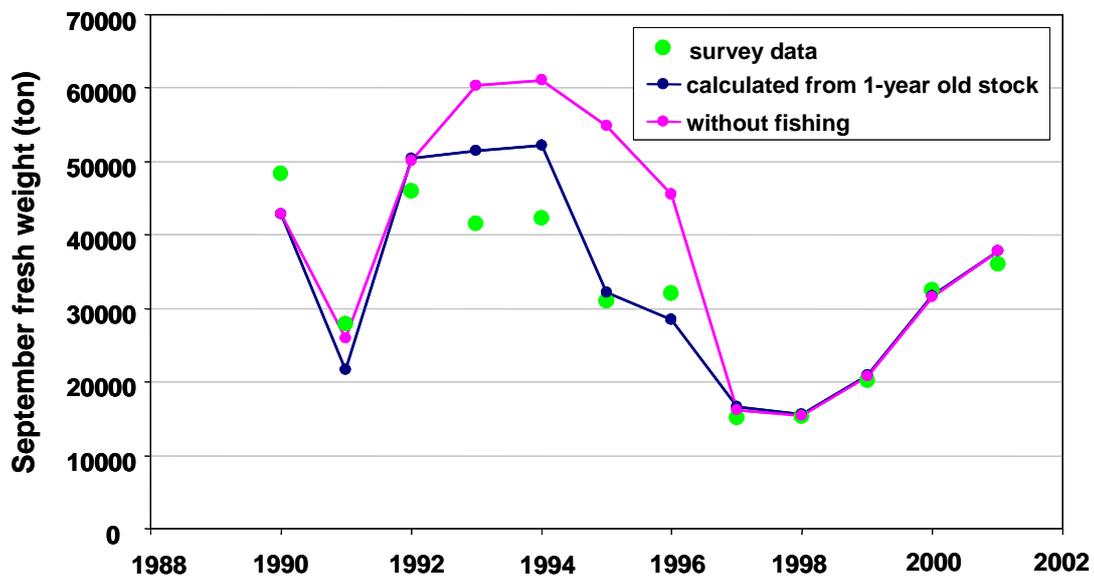


Figure 87: The cockle stock in the Oosterschelde in September, including and excluding fishery, calculated from the amounts of one year old cockles in May (without using the information on older cockles) in combination with the data on cockle growth and summer survival in Kamermans *et al.* (2003b), and the cockle predation and winter mortality estimated in Rappoldt *et al.* (2003b) for the older year classes. Also given the September estimate of the total cockle stock derived from the spring survey.

The effect of cockle fishery on the spat fall in the Oosterschelde could only be studied in areas that were open for fishery, because there were no representative permanently closed areas. This means that effects on recruitment had to be studied within an area where the distribution of cockle beds had adjusted already to a more or less permanent fishery pressure. Comparison of the number of recruits one year after fishery did not show a significant correlation, but in some years fishery had a positive correlation with the number of surviving recruits two years later. In other years there was no discernible effect (Kamermans *et al.*, 2003a). These findings differed from the results of similar calculations for the open areas in the Wadden Sea. The number of recruits one year after fishery in the Wadden Sea was negatively correlated with fishery, whereas no significant correlations were found with of the number of recruits two years after fishery (Kamermans *et al.*, 2003a).

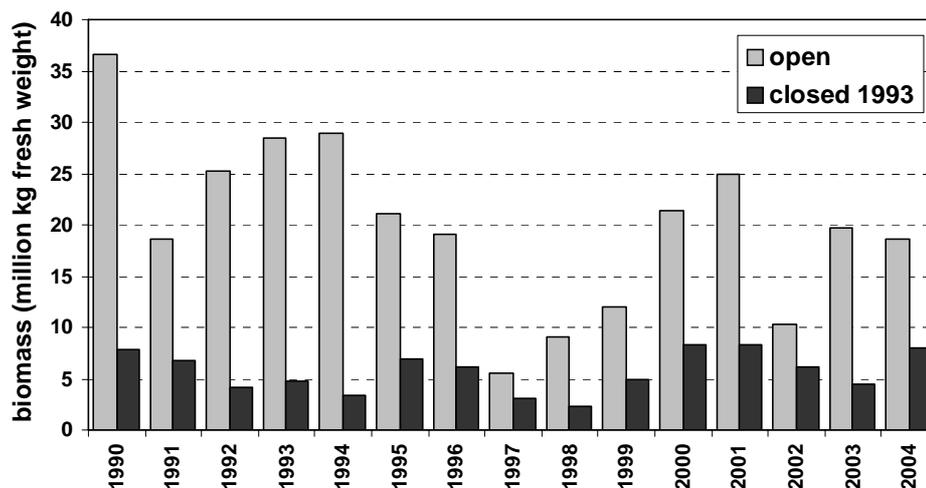


Figure 88: Stock of cockles (million kg fresh weight) in areas that were open and areas that were permanently closed since 1993 for cockle fishing. From Kamermans *et al.* (2003a).

8.4 Development of the carrying capacity for cockles and oystercatchers

8.4.1 Carrying capacity for cockles

During the research period it was established that the carrying capacity of the Oosterschelde for cockles declined in comparison with the reference period of 1987-1991 (Geurts van Kessel *et al.*, 2003). These changes are, at least partly, related to the influence of a storm surge barrier in the mouth of the former estuary and the reduction of the tidal range and the speed of the currents since then. The exchange of sand with the Voordelta has also been reduced. The change in the tidal prism made the volume of the gullies in the Oosterschelde too big in comparison to the transportation capacity for sediment. As a consequence, sediment that eroded on the tidal flats was 'trapped' in the borders of the now oversized gullies (Figure 89). This trend, which was predicted before the construction works were carried out, will go on during the next decades and even centuries (Kohsiek *et al.*, 1987; Hesselink & Maldegem, 2003). On the long term (centuries) this erosion process will lead to an increase in shallow subtidal waters and an almost complete loss of tidal flats and their wading birds. This does not take into account sea level rise effects due to global warming, which will reinforce this development.

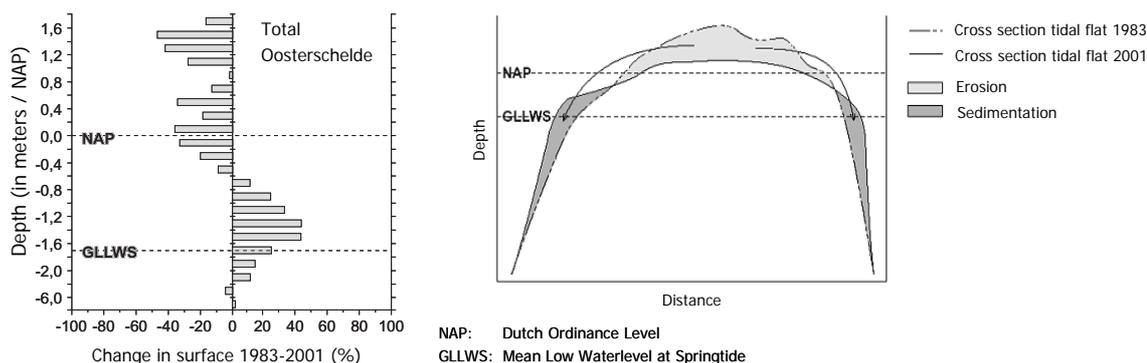


Figure 89: (a) Percentage increase or decrease of the different height classes in the Oosterschelde between 1983 and 2001 (negative = erosion, positive = sedimentation). (b) Schematic representation of the effect of erosion on the development of a tidal flat in the Oosterschelde. From Geurts van Kessel *et al.* (2003)

For cockles, a habitat model was made on basis of exposure time during low tide and velocities of the tidal currents (Kater *et al.*, 2003b). This model could not be validated on other tidal areas, due to the differences in other aspects than exposure time and current velocities, so these results are considered as indicative. The decrease was estimated at about 20% reduction of the cockle stock between 1983 and 2001 (Figure 90). This short term effect was ascribed to a relative shift of suitable cockle habitat from the most landwards parts of the Oosterschelde (subareas 'Noordtak' and 'Kom') to the area in the middle of the Oosterschelde. On the long term, a further decrease in suitability for cockles is predicted, mainly as a consequence of the above mentioned erosion of higher parts of the tidal flats. This is in agreement with the observation that the best cockle beds in the past were observed on the higher parts of the intertidal area. The decrease of the potential cockle stock is estimated at about 14% between 2001 and 2020 (Kater *et al.*, 2003b).

Additional loss of cockle habitat could be caused by the exposure of medieval peat banks that are present in easterly part of the Oosterschelde. Most of these banks are covered with a layer of sand, but at least part of them will get exposed after erosion of the sandy top layer (Geurts van Kessel *et al.*, 2003). A third phenomenon that may lead to a negative effect on cockles as well as on oystercatchers is the population increase of the Pacific oyster *Crassostrea gigas* (Figure 91). This species can compete with cockles for space and food (Kater, 2003; Kater & Baars, 2003).

The Pacific oyster was introduced in 1964 by the shellfish industry as an alternative for the depleted stocks of the native European flat oyster *Ostrea edulis* (Drinkwaard, 1999). By 1980, about 15 ha of the tidal flats in the Oosterschelde were covered by Pacific oysters (Kater & Baars, 2003). In 1990 and 2002 this surface had increased to about 210 and 640 ha, respectively (Figure 92). Most reefs of Pacific oysters are situated rather low in the tidal range, lower than the best cockle habitats (Kater & Baars, 2003). But some competition for space with cockles is likely (Figure 93), and the expected erosion of the tidal flats will change the habitat in favour of the Pacific oyster (Geurts van Kessel *et al.*, 2003). The Pacific oyster colonised subtidal areas as well; the subtidal stocks have been estimated to cover about 700 ha by means of sonar observations (Kater *et al.*, 2002).

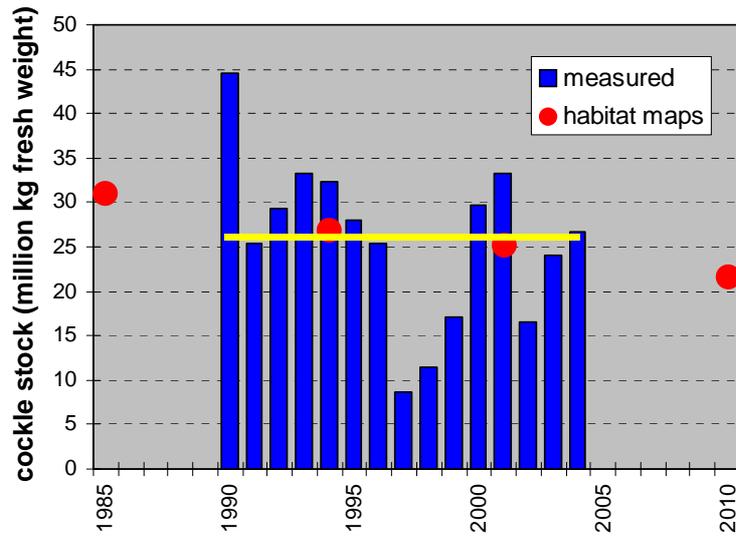


Figure 90: Total cockle stock in May in the Oosterschelde, estimated on the basis of four habitat maps (red dots) and on the basis of the annual surveys by RIVO. The yellow line indicates the mean value from the surveys. From Geurts van Kessel et al. (2003).



Figure 91: A reef of Pacific oysters (*Crassostrea gigas*) in the Oosterschelde. Photo Nathalie Steins.

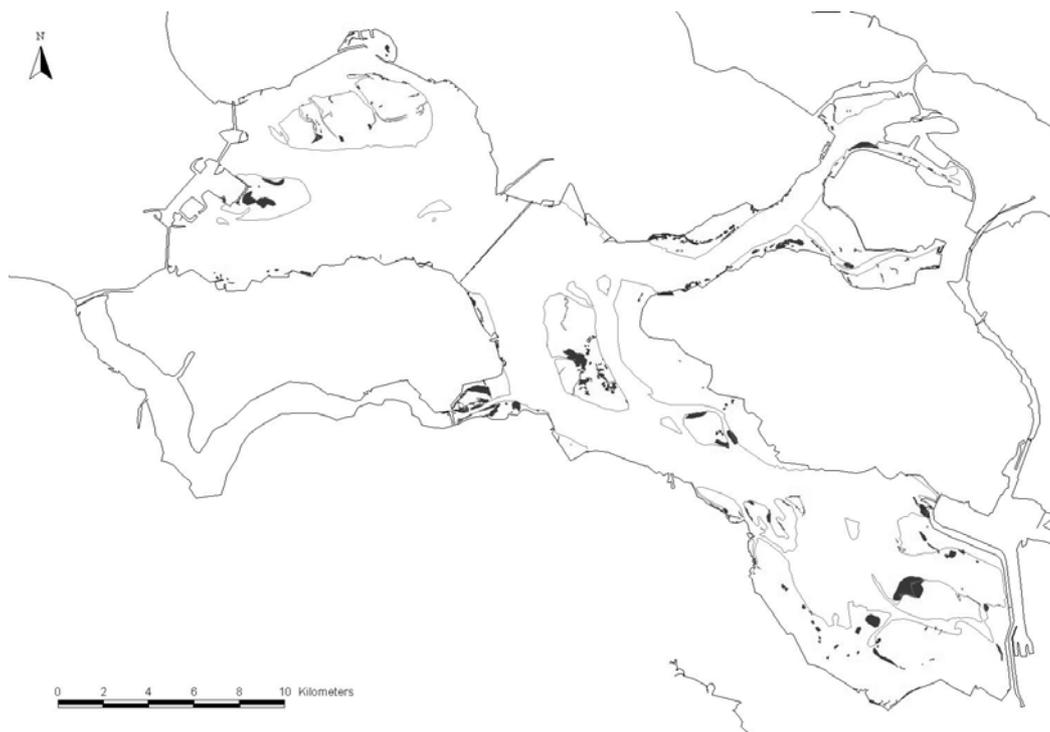


Figure 92: Location of beds of Pacific oysters on the intertidal flats in the Oosterschelde in 2002. From Kater *et al.* (2003a).

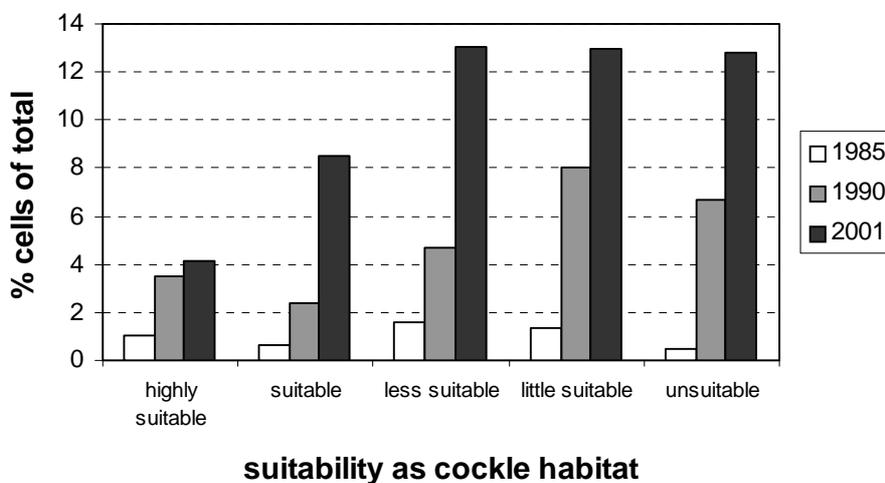


Figure 93: Percentage grid cells of various cockle habitat classes that were occupied by Pacific oysters in 1985, 1990 and 2001. From Geurts van Kessel *et al.* (2003)

There are indications that the Pacific oyster has an influence on the availability and the composition of the phytoplankton, which is the main food source for filter feeders like cockles (Geurts van Kessel *et al.*, 2003). Food limitation for filter feeders is likely in the far ends of the Oosterschelde ('Noordtak' and 'Kom'), where the filtration pressure is high and the residence time of the water is relatively long. The

filtration capacity of all shellfish in these areas (mainly cockles, mussels and Pacific oysters) leads to a filtration time that more or less equals the turnover time of the phytoplankton in these areas (Figure 94, Figure 95). A shift in the composition of the phytoplankton species in the Oosterschelde as a whole following the expansion of the Pacific oyster gives an additional indication of a heavy predation pressure. Smaller species, with a shorter turn-over time, increased whereas bigger species decreased (Wetsteyn *et al.*, 2003).

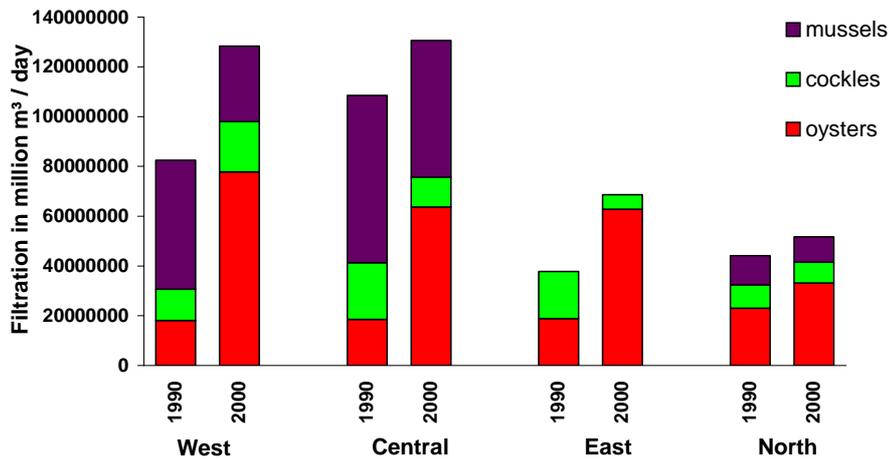


Figure 94: Filtration by mussels, cockles and oysters per subarea (in million m³ per day) around 1990 and around 2000. From Geurts van Kessel *et al.* (2003)

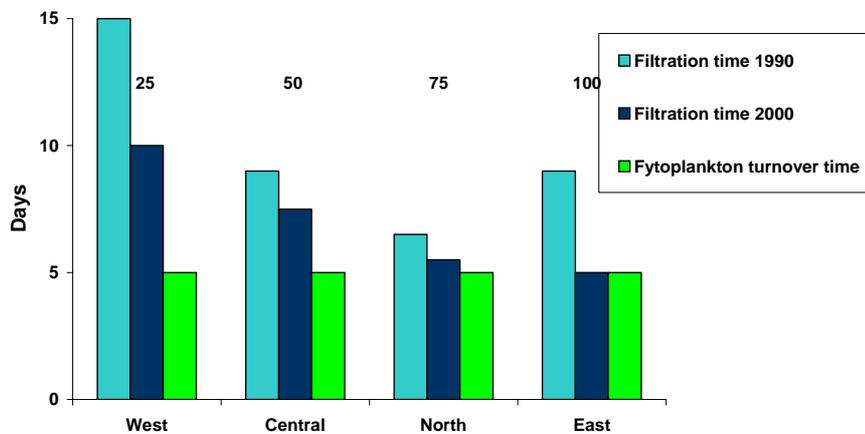


Figure 95: Filtration times for shellfish around 1990 and 2000 (based on surveys in spring) and turn-over time of the phytoplankton per subarea. The residence time of sea water in the subareas is indicated above the bars. From Geurts van Kessel *et al.* (2003)

Another change in the Oosterschelde that is relevant for the carrying capacity for cockles and other shellfish is the reduction of the primary production in some parts of the estuary (Figure 96), due to a decrease of the transparency of the water since halfway the 1990s (Wetsteyn *et al.*, 2003; Figure 97). This change is possibly due to an increase in concentration levels of humic acids, originating either from the fresh water discharges into the Oosterschelde, or from the increased exposure of peat

banks within the Oosterschelde itself, in combination with increased residence time of the water.

The total reduction in the carrying capacity for cockles, by the combined effect of eroding mud flats, exposure of peat layers, competition with Pacific oysters and reduced primary production will certainly be more than the erosion effect alone, which was estimated at 14% between 2001 and 2010 (Figure 90; Geurts van Kessel *et al.*, 2003). It is expected that the tidal flats in the western (Roggenplaat) and in the central region of the Oosterschelde (Vondelingsplaat and Slikken van de Dortsman) will maintain their carrying capacity for cockles relatively long.

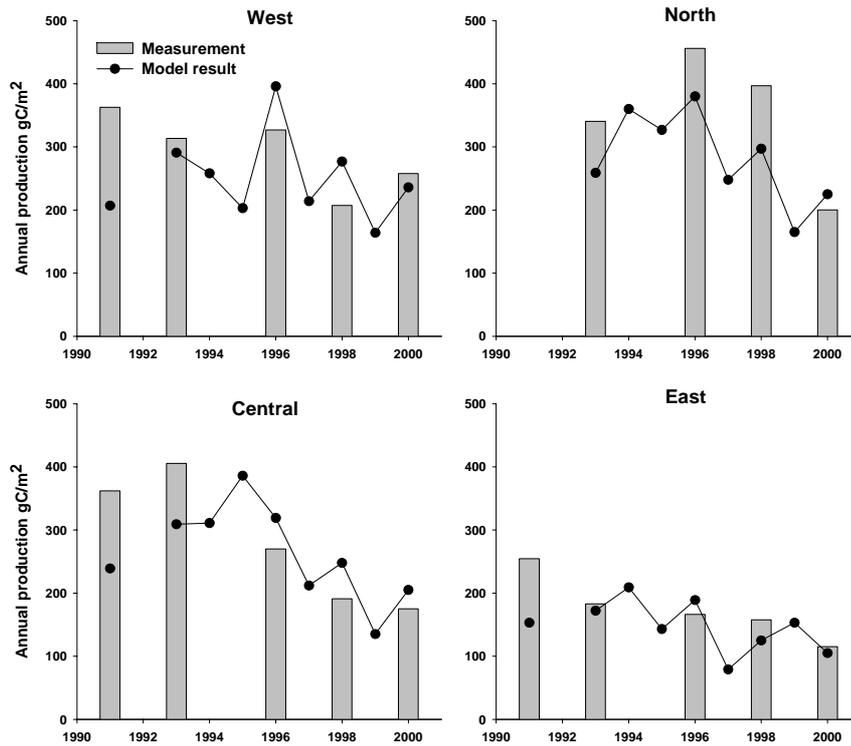


Figure 96: Annual primary production as measured (bars) and according to model calculations (lines) for different subareas. From Geurts van Kessel *et al.* (2003)

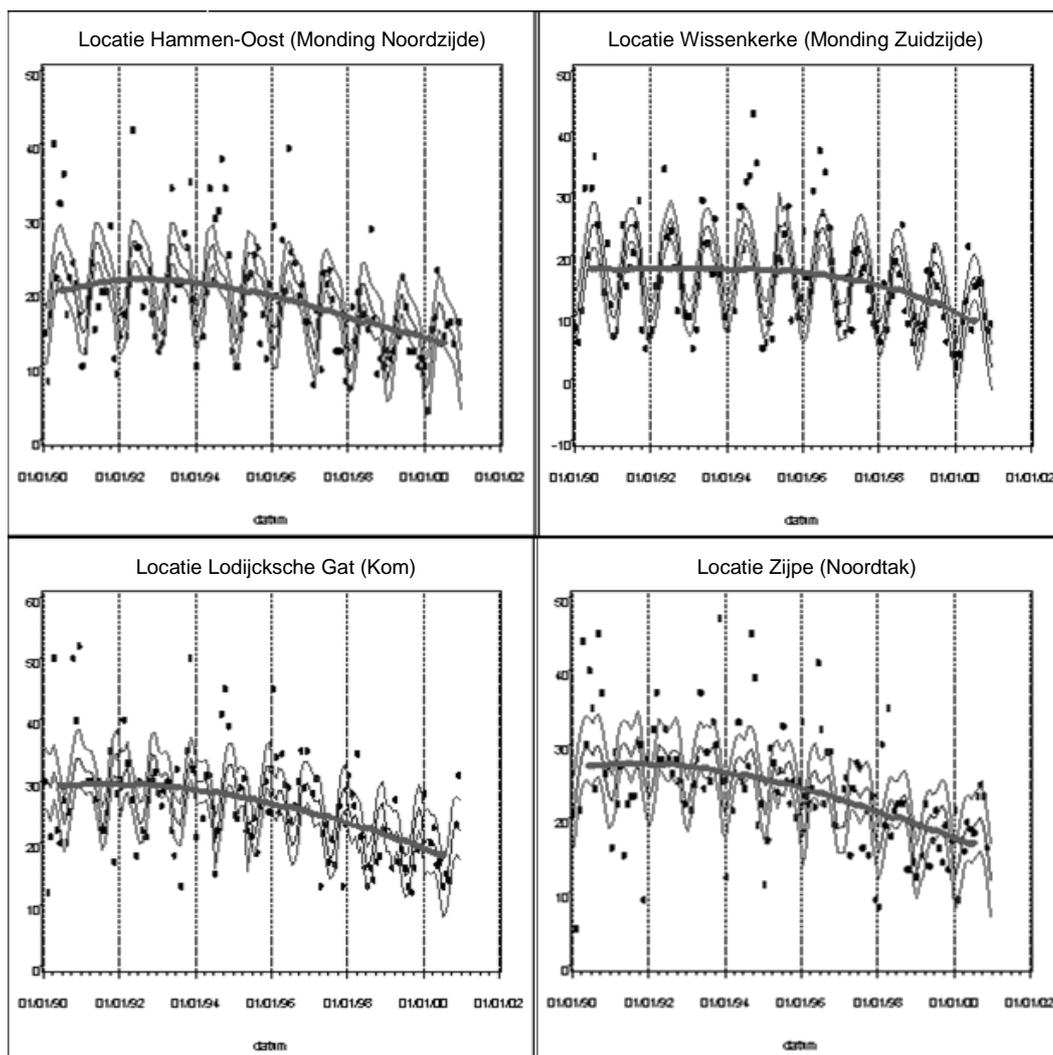


Figure 97 Change in transparency of the water (in dm) on 4 locations in the Oosterschelde: upper left Hammen-Oost (north side of the mouth of the Oosterschelde), upper right Wissenkerke (south part of the mouth), lower left Zijpe (Noordtak) en lower right Lodijksche Gat (Kom). All graphs show a downward trend in the period 1990-2001. The strongest decline is in the subareas with the longest retention time: Kom and Noordtak. From Geurts van Kessel *et al.* (2003).

8.4.2 Carrying capacity for oystercatchers

Oystercatchers in the Oosterschelde mainly prey upon cockles. Other potential prey items are relatively scarce or mainly restricted to subtidal waters (mussels on culture lots). Bult *et al.* (2000) estimate that 15% of the oystercatchers depended on intertidal mussel culture lots, before these were moved to deeper water in the beginning of the 1990s. Pacific oysters can not be exploited by oystercatchers because their shells are too thick and strong. So the stock size of cockles is one of the important parameters that determine how many oystercatchers can feed in the Oosterschelde during the winter period. This stock size is expected to decline by 14% between 2001 and 2010 due to morphological changes. For oystercatchers, this reduction is expected to take

place on the best feeding grounds, high in the tidal zone where the highest cockle biomass can be found and where the cockles are accessible when the lower tidal area is submerged. So the reduction of 14% during the period 2001 – 2010 is certainly a minimum estimate for the reduction in the number of oystercatchers during the same period. Peat layers, Pacific oysters and reduced phytoplankton production in parts of the Oosterschelde will probably cause additional reductions of the cockle stocks and thereby further the carrying capacity for oystercatchers.

8.5 Food reservation for oystercatchers

Between 1982 and 1987 the completion of large-scale coastal engineering works in the Oosterschelde led to the disappearance of 17% of the intertidal flats (excluding the Krammer-Volkerak). This led to a decline in the number of birds depending on these flats, including the oystercatcher (Schekkerman *et al.*, 1994). For this reason, bird numbers in the period from 1987 to 1990 serve as a reference for food reservation in the Oosterschelde, instead of the period 1980-1990 that is used for the Wadden Sea. Between 1987 and 1990 there were on average 64000 oystercatchers spending the winter in the Oosterschelde. It was estimated that about 54400 did not live on mussels (Bult *et al.*, 2000). Since that time the littoral mussel culture lots have been moved to deeper water and are no longer available to the oystercatchers. This is one of the reasons that, since the end of the 1980s, the number of oystercatchers spending the winter in the Oosterschelde has fallen to 35000 (Figure 98).

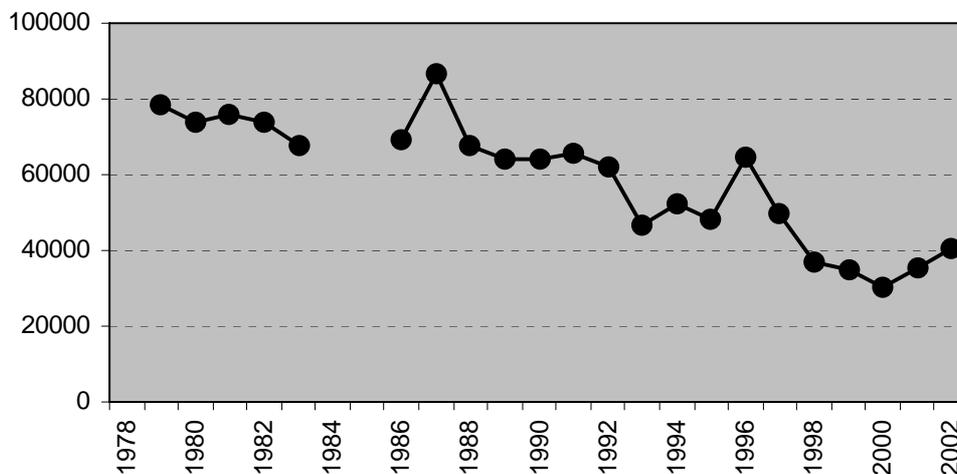


Figure 98: Number of oystercatchers wintering in the Oosterschelde. Numbers are averaged per year for the months September until March. Data RIKZ. From Rappoldt *et al.* (2003c).

The physiological food requirement of an oystercatcher from September to March inclusive of around 60 kilos of flesh in the Oosterschelde is slightly lower than in the Wadden Sea. This is due in part to the milder climate. The ecological food requirement is also lower. This is estimated at 150 kilos of cockle flesh per oystercatcher here, with a margin for error of some dozens of kilos (Rappoldt *et al.*,

2003b). The difference between the Wadden Sea and the Oosterschelde is due to better access to the feeding grounds as well as the lower physiological food requirement. A previous estimate of the ecological food requirement of oystercatchers in the Oosterschelde using a different methodology arrived at a very similar figure (de Vlas, 2002).

The food reservation policy in the Oosterschelde was adapted in 1999 and 2000 by increasing the amount reserved. The reference number of oystercatchers was also lowered. The change in policy addresses the decline in the carrying capacity for oystercatchers as a result of the transfer of mussel cultivation lots to deeper water (Bult *et al.*, 2000). The current food reservation is based on the 54400 non-mussel-eating oystercatchers during the six winter months. Apart from cockles there are few sources of food available for these oystercatchers (Figure 99). The poor food supply from the reference period to the end of the 1990s could be attributed to declining cockle stocks. The decline of the oystercatcher population is linked to the poor food stocks. A direct analysis of the relationship between return rate and food stocks shows that return rates are low when food stocks are low (Figure 100a). The return rate also shows a clear relationship to the food stress calculated with the model WEBTICS: when food stress is high, return rate the next year is low (Figure 100b).

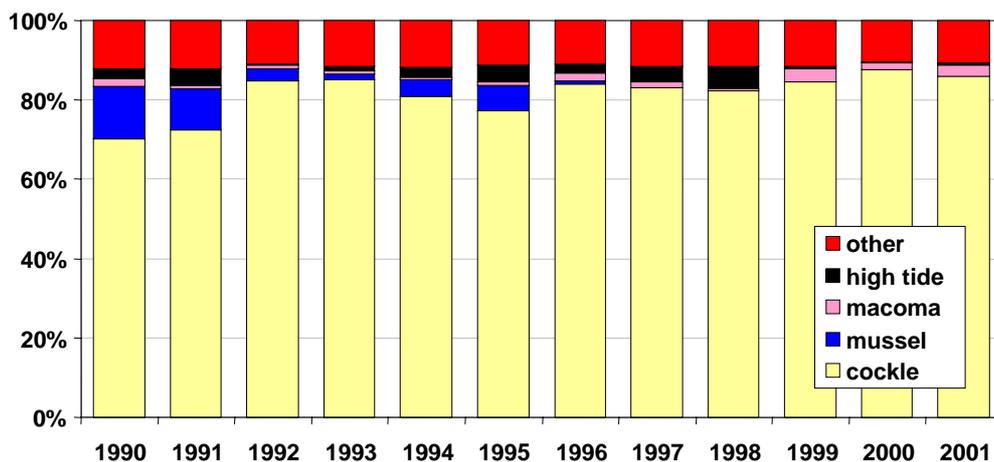


Figure 99: Calculated prey choice of oystercatchers during winter in the Oosterschelde for the years 1990-2001. From Rappoldt *et al.* (2003b).

It is estimated that 8.1 million kilos of cockle flesh will be required to achieve the potential carrying capacity in the Oosterschelde for 54400 oystercatchers. Such cockle stocks have only been reached three times in the past twelve years. That explains the decline in the numbers of oystercatchers compared with the reference period. Model calculations indicate that, to date, the lowering of the tidal mud flats and the associated shortening of foraging time have not played a significant role in the decline.

If the cockle stocks of the 1990s are representative for the future, the number of oystercatchers in the Oosterschelde could fluctuate around 39000. This is slightly more than the current population. Without cockle fishing, as was the case during this

period, including the early 1990s, when the reservation was lower - the carrying capacity is estimated to increase by a number in the order of 3300 oystercatchers. The above calculation did not take account of cumulative impacts of cockle fishery on the cockle stock. As shown in Figure 76 and in Figure 87, leaving out fishing as a cause of cockle mortality leads to larger cockle stocks towards the end of a cockle peak. Hence, the effect of fishing in successive years is a significant reduction of the cockle stock and may lead to food shortages that would otherwise not have occurred. The importance of this effect depends on the frequency of severe winters and large spatfalls. When cumulative impacts of cockle fishery on the cockle stock are taken into account, it is tentatively estimated that the carrying capacity without cockle fishery would increase by a number in the order of 5700 oystercatchers (Rappoldt *et al.*, 2003b).

So far, the erosion of the tidal flats and the concomitant reduction in available feeding time for the oystercatchers has not had a significant impact according to our model calculations. However, when the heights projected for 2010 were used, we calculated that the carrying capacity of the Oosterschelde would decline by about 9400 oystercatchers (Rappoldt *et al.*, 2003b). This decline is solely due to the decline in available feeding time and does not include projected declines in cockle stock as a result of habitat changes.

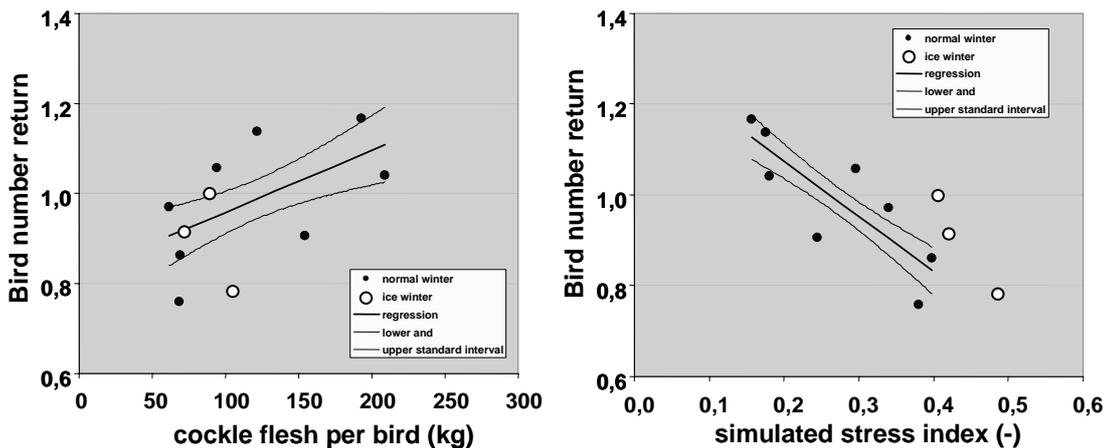


Figure 100: (a) The return of the number of oystercatchers in the next year as function of the non-fished cockle stock in September (after Rappoldt *et al.*, 2003b, Figure 4.5B). Values below and above 1 mean a decreasing and increasing number of birds respectively. The regression line describes the average return after a normal winter ($P=0.14$, type-II error of 0.75 for a significance level of 0.05). The curves give the standard confidence interval (Draper & Smith, 1981) for values read from the regression line. (b) The return of the number of oystercatchers in the next year as function of the simulated stress index during a winter (after Rappoldt *et al.*, 2003b, Figure 5.29). Values below and above 1 mean a decreasing and increasing number of birds respectively. The regression line describes the average return after a normal winter ($P=0.011$, type-II error of 0.14 for a significance level of 0.05). The curves give the standard confidence interval (Draper & Smith, 1981) for values read from the regression line.

8.6 Evaluation of the policy of closed areas in the Oosterschelde

In 1993 designated areas in the Oosterschelde were also closed to fishing. The selection criteria for these areas were not clearly defined at the time. In contrast with

the Wadden Sea, the closed areas in the Oosterschelde were not representative of the shellfish stocks in the region: cockles grow poorly in these areas (Geurts van Kessel *et al.*, 2003).

8.7 Concluding remarks

The calculations with the oystercatcher model indicate that the following sequence of events during the 1990s determined the development of oystercatcher numbers in the Oosterschelde (Rappoldt *et al.*, 2003b):

The transfer of intertidal mussel cultivation lots to deeper water in the beginning of the 1990s, in combination with the decline in cockle stocks and simultaneous intensive cockle fishery have most probably led to the decline of the oystercatcher population to its' current size.

The lowering of the mud flats, caused by the storm surge barrier and its effect on the potential cockle stock, competition between cockles and Pacific oysters for food and space, and the decreasing primary production, played a modest role during the 1990s, but will certainly be determining factors for the future development of the carrying capacity of the Oosterschelde for both cockles (Geurts van Kessel *et al.*, 2003) and oystercatchers (Rappoldt *et al.*, 2003b).

8.8 Conclusions

- The carrying capacity of the Oosterschelde for cockles has declined by about 20% between 1983 and 2001, and an additional reduction of 14% is expected in the period 2001–2010, due to changes in morphology.
- The introduction of the Pacific oyster in 1964 was the start of a fast proliferation of these oysters. After colonization of rocky substrate on dike edges, tidal flat areas became covered with oysters in low densities that eventually formed reefs, now in the order of 700 ha. It is likely that the oysters have an impact on the ecosystem through competition for food and space, and may limit cockle populations, hence influence food availability for oystercatchers.
- Further reductions in cockle stocks can be expected by exposure of peat layers, competition with Pacific oysters and reduced primary production.
- Fishing for cockles leads to a lower cockle stock.
- The food reservation policy was unable to prevent a food shortage for the reference numbers of oystercatchers in the Oosterschelde in years with fishery-induced food shortage.
- The numbers of oystercatchers in the Oosterschelde have declined. In recent years there has been a slight recovery in the numbers of oystercatchers.
- The ecological food requirement for oystercatchers in the Oosterschelde was estimated at around 150 kilos of cockle flesh per bird in the absence of mussel beds. There is a margin for error in this ecological food requirement which is

difficult to determine accurately, but which could amount to some dozens of kilos.

- As a result of cockle fishing the carrying capacity for oystercatchers in the Oosterschelde has declined in recent years by an estimated number in the order of 3,300 birds.
- Reduction of the cockle stock and shorter foraging times on cockle beds due to the continuing erosion of the tidal flats will have a negative impact on the carrying capacity for oystercatchers.

9 Synopsis

9.1 Research questions and answers

In chapter 1 the policy questions were translated into research questions. In this chapter we first repeat the research question (underlined) and then give our answer.

1a. How and to what extent do the different forms of shellfish fishing impact on the important benthic biotopes?

Cockle fishery on intertidal flats – direct impacts. Cockle fishery by suction dredging removes cockles of one or more years old. In the Wadden Sea, a good spatfall of cockles occurs on average once every six years. During the past ten years, on average 25% of the surface of the cockle beds in the open areas was touched by a cockle dredge each year. More than half of the surface of the beds in the open areas was fished each year, where fished means that at least 2% of the area was actually touched by the cockle dredge. As a result, a larger proportion of the biomass of mature cockles was to be found in the areas closed for shellfish fishing. Suction dredging has a direct negative impact on mussel beds and seagrass beds, when fishing occurs in these habitats. However, fishing plans effectively exclude mussel beds and seagrass beds from cockle fishing, except for one newly established seagrass bed along the Groningen coast, which disappeared after having been fished for several years. Cockle fishery leads to considerable mortality of non-target benthic fauna in the top layer of the sediment on the fished bed, running into dozens of percent and also removes dispersed mussels. Suction dredging also leads to a decrease in the silt content of the top layer of the sediment in the short term.

Cockle fishery on intertidal flats – indirect effects. There are also indications for a long-term effect of cockle fishery on the sediment. Since cockles capture silt through their pseudofaeces, the long-term effect is probably a consequence of the systematic decrease in cockle stock as a result of cockle fishing. There are no indications that suction dredging reduces the prospects of re-establishment of seagrass beds, but systematic research is lacking. At the scale of the Wadden Sea there is no evidence for a decrease in the recruitment of mussels as a result of cockle fishing, despite the fact that such evidence does exist at small spatial scales. Less cockle spat developed in the open areas than in the closed areas. However, the difference has disappeared since 2000 and recruitment was even slightly higher in the open areas during the last three years. A possible explanation is a negative effect of high cockle densities on recruitment and the fact that high densities of cockles occurred in the areas closed for fishing. In our study on cockle beds throughout the Wadden Sea, several worm species declined in response to cockle fishery, with the exception of *Nereis diversicolor*, which increased in areas that were intensively fished. In a study in the western Wadden Sea, a more general shift towards worms was observed.

Mussel fishery on intertidal flats. Mussel beds enrich the surrounding sediment, so the biological loss that results from removal of a mussel bed is greater than the loss of the mussel bed itself. Mussel fishery on stable mussel beds may lead to a long-term decrease in the coverage of such mussel beds, as was demonstrated in the Wash. In order to restore mussel bed areas the Sea and Coastal Fisheries Policy does not allow mussel fishery on stable mussel beds in intertidal areas. Large scale recruitment of mussels in the intertidal areas occurred on average once every 4 years over the past 50 years. Successful recruitment is the primary condition for the formation of new mussel beds area. Once established other factors become relevant. In the Dutch Wadden Sea relatively unstable seed beds often disappear during winter storms, and observations in lower Saxony suggest that high bird predation may also lead to loss of seed beds. The combination of only some good spatfalls since 1990 and considerable losses of young mussel beds led to a relatively slow recovery of the mussel stocks. In the nineties, after the disappearance of the intertidal mussel beds, a good spatfall occurred in part of the area in 1994, but most of these beds disappeared during the subsequent winter and spring. In 1999 and particularly in 2001 large seed bed areas have established, and about 50% of these new beds survived. At present, after 12 years almost without fishery, about 2100 ha of relatively young, but more or less stable beds are present. A controlled fishing experiment on newly established mussel seed beds showed a decrease in the coverage of such mussel beds directly after fishing, but no evidence was found for either a positive or a negative long-term effect on these beds in terms of coverage. The role of mussels that disappeared naturally during winter was not studied, so it is not possible to make a comparison with the yield of the mussels that were fished and transported to the culture lots.

Mussel fishery and mussel culture in subtidal areas. The Sea and Coastal Fisheries Policy does allow fishery on all mussel beds in the subtidal and this could potentially explain why there are hardly any old mussel beds in the subtidal areas of the Wadden Sea and Oosterschelde at present. By transporting mussels from areas with high recruitment but poor growth, to areas with poor recruitment but high growth, mussel culture increases the average standing stock of mussels, despite subsequent harvest. A first attempt to calculate the overall effect of mussel culture on the subtidal mussel stocks during the 1990s points to an increase of the total subtidal stock in Dutch coastal waters by a factor 2. As a considerable part of seed mussels and half-grown mussels is transplanted to the Oosterschelde, the net increase in the Wadden Sea was tentatively estimated as ca. 15%. We did not observe effects of sublittoral mussel fishing on mussel seed production and fishing for mussel seed does occur in roughly the same areas year after year. However, fishery effects on spatfall in subtidal areas cannot be excluded because available data for analyses of fishery effects on spatfall are limited, and comparison with reference areas is not possible. We did not study effects of sublittoral mussel fishing on epibenthic species. A more detailed and quantitative assessment of the total effect of mussel farming and fishing on biodiversity in the Dutch Wadden Sea is difficult to make because comparative information from untouched mussel beds, fished beds and culture locations are missing.

1b. How and to what extent does shellfish fishing affect the food supply of oystercatchers and eider ducks, which feed on large shellfish, and other wild birds which are dependent on these biotopes?

Cockle fishery. Cockle fishery reduces the food stock of oystercatchers. On the basis of model calculations, it is estimated that this direct effect of cockle fishery amounts to a decrease of the carrying capacity of Wadden Sea and Oosterschelde for oystercatchers with a number in the order 15000 and 3300 birds respectively, during the evaluation period. These model calculations do not take cumulative effects of cockle fishery on stock sizes, recruitment and age distribution of cockles into account. At present, there is no evidence that cockle fishery has had a negative impact on common eiders, which may be due to the fact that cockles are not a preferred prey for common eiders as a result of their thick shells. Cockle fishery may influence the food supply of knots through its influence on stocks of small shellfish. There are indications that the quality of cockles in fished areas is reduced. It is possible that cockle fishery favours some worm species that are an important food source for birds feeding on worms.

Mussel fishery. The primary reason for the decline in the number of oystercatchers wintering in the Wadden Sea from 260000 to 175000 is the disappearance of the intertidal mussel beds. This disappearance was caused by mussel fishery in combination with recruitment failure and possibly winter storms. The number of common eiders which winter in and around the Wadden Sea have also decreased. Under the assumption that mussel fishery does not impact recruitment of mussels in the subtidal, mussel culture has, on average, improved the food supply of common eiders during the evaluation period. However, scarcity of sublittoral mussel seed and the lack of mussel seed fishery from intertidal seed stocks resulted in low stocks of mussels on culture plots in a number of years. As a consequence, common eiders have experienced several years with mass mortality related to low stocks of sublittoral mussels. Fluctuations in shellfish stocks are a natural phenomenon. However, due to lack of data, it cannot be excluded that during years of scarcity, transport of mussels from culture lots in the Wadden Sea to culture lots in the Oosterschelde was increased, thereby increasing the food shortage for the common eiders.

2a. Has the area of intertidal mussel beds been restored to the desired level? If not, is that due to shellfish fishing, other human impact or natural factors?

The policy aim is 2000-4000 ha of stable intertidal mussel beds. If 'stable' is equated to 'having survived at least one winter' it can be concluded that the area has been restored to the desired level at the end of the evaluation period. From 1990 to 1994 there were practically no mussel beds in the Wadden Sea. Since 1995, there has been a recovery to 2500 ha in 2002. This recovery was mainly due to natural circumstances, because almost no fishery was carried out since 1992.

2b. Have the seagrass fields recovered to the maximum possible extent? If not, is that due to shellfish fishing, other human impact or natural factors?

Recovery of seagrass fields has occurred, but it was not maximal, since one new establishment disappeared again due to cockle fishery in the period 1999-2002. About 30% of this fished area showed recovery in 2003.

2c. Are the methods previously used to calculate the food requirements of shellfish-eating birds correct?

The method previously used was not correct. The amount of food that must be present per bird at the start of winter (the ecological food requirement) is around 2.5 to 3 times higher than the physiological food requirement, depending on factors like emersion time, distribution of the prey and the efficiency with which the birds can harvest the food. The ecological food requirement for oystercatchers in the Wadden Sea was estimated at around 200 kilos of cockle flesh per bird in the absence of mussel beds. For the Oosterschelde the figure is 150 kilos. There is a margin for error in this ecological food requirement which is difficult to determine accurately, but which could amount to some dozens of kilos. The margin of error in the estimate of the ecological food requirements of the common eider is greater than for oystercatchers, since our knowledge of the feeding ecology of common eiders is crude compared to the details of our knowledge on the feeding ecology of oystercatchers. The risk of increased mortality among eider ducks rises as the stocks of half-grown and mature sublittoral mussels in the Wadden Sea in December fall below the level of 60 million kilos net fresh weight. Food shortage can also have natural causes, like long periods with poor shellfish recruitment, so food reservation policy does not account for periods of natural food shortage.

2d. How do the observed numbers of birds compare with the target or reference numbers?

The numbers of oystercatchers in Wadden Sea and Oosterschelde have declined as a result of food shortages. In the Wadden Sea from 260000 to 175000. In the Oosterschelde from 64000 (of which an estimated 54400 did not feed on mussels) to 35000. In recent years there are indications of a slight recovery in the Oosterschelde and a stabilization of numbers in the Wadden Sea. The number of eider ducks which winter in and around the Wadden Sea have decreased from 130000 to 100000, partly due to several years of mass mortality.

2e. How can any discrepancies in these numbers be explained?

The decrease in the number of common eiders wintering in Dutch coastal waters is most likely due to several years with high mortality as a result of food shortages. The main food stock in short supply were sublittoral mussels, but other food stocks probably also played a role. The decrease in the number of oystercatchers wintering in the Dutch Wadden Sea is primarily due to the disappearance and subsequent slow recovery of the intertidal mussel beds, and to a lesser extent due to the continuing cockle fishery. The decrease in the number of oystercatchers wintering in the Oosterschelde is primarily due to the lowered stocks of cockles to which cockle fishery has contributed.

3a. Is the current food reservation policy sufficient to prevent shellfish fishing in the long term having a detrimental effect on populations of shellfish-eating birds?

The policy of food reservation was unable to prevent a food shortage due to fisheries for the reference number of shellfish-eating birds. The current food reservation policy is insufficient, because it is not based on the ecological food requirements of the birds. It should be noticed that the food reservation policy does not account for periods of natural food shortage. In addition, the implicit assumption that the ecosystems of the Wadden Sea and Oosterschelde can return to the state they had during the reference period, may be questioned.

3b. Are there indications that numbers of wading birds which do not feed on large shellfish have improved or declined? And are any such developments the result of shellfish fishing, of other human factors or of natural factors?

In the Wadden Sea, the number of knots has increased during the early 1990s. More recently, numbers have decreased. Both increase and decrease seemed primarily to occur in the open areas, but it is difficult to assign knots counted during high tide to low tide feeding areas. The number of several species of waders feeding primarily on worms has increased during the evaluation period. For most of these species, the increase occurred primarily in the areas open to cockle fishery. It cannot be excluded that the increase of worm-feeding waders is related to an increased density of some worm species as a result of cockle fishery.

9.2 Additional conclusions

Apart from conclusions that were drawn to answer the research questions phrased at the start of the study, a number of important insights emerged during the study:

Permanently closed areas were an important tool in our investigations of the effects of shellfish fishery. Safe-guarding the closed areas from fishery also resulted in demonstrably more 'natural' conditions for most parameters. It should be noted that in the case of worm-feeding birds, it is possible that 'more natural' means 'fewer birds'.

The disappearance of the mussel beds from the tidal flats of the Wadden Sea at the end of the 1980s had a significant impact on the entire ecosystem. Generally, birds feeding on shellfish showed a decline following the disappearance of the mussel beds, whereas birds feeding on worms tended to increase. For the oystercatcher the role of mussel beds seems prominent. The decrease since 1990 is mainly caused by the absence of mussel beds. The fact that oystercatchers primarily decreased in closed areas with relatively high cockle stocks can be partly explained by mussels being slightly more common in the closed areas during the 1980s and the fact that mussel beds initially returned in the open areas.

It seems likely that autonomous developments in the Wadden Sea and Oosterschelde will lead to a decline in the carrying capacity for shellfish in these coastal ecosystems. The question therefore arises as to whether the situation prevailing some years prior

to the publication of the Sea and Coastal Fisheries Policy Document can continue to serve as a reference point for bird populations and fisheries. This point is further elaborated in section 9.3.

Mussel stocks, and to a lesser extent cockle stocks, can compensate in part for the declining carrying capacity, because they accumulate organic matter. This gives rise to extra localised mineralization, which stimulates the productivity of the area.

Spat fall of cockles is less frequent than in the past in the low-lying and sandy parts of the Wadden Sea. This has important consequences for the functioning of the ecosystem. Several hypotheses to explain this phenomenon exist: (1) an increased predation of spat in the low lying areas as a result of an increased density of shrimp, (2) a shift of silt from low-lying areas to areas higher in the intertidal zone, possibly due to cockle fishery, (3) selective fishery on cockles in low lying areas creating a selection pressure on cockles to settle high in the intertidal zone.

9.3 Fixed targets in a changed and changing ecosystem

The choice of targets and reference values in the Sea and Coastal Fisheries Policy of 1993 appears rather practical. For the birds in the Wadden Sea, the numbers in the 1980s serve as the reference. For the intertidal mussel beds, the areas in the 1970s serve as the reference. This differs from the AMOEBE approach for the Wadden Sea, where the reference period is 1930 and the reference values for benthic organisms are taken from measurements in the 1980s Baptist *et al.* (1997). To arrive at the value for 1930, it is attempted to correct for anthropogenic influences that have occurred in the meantime. Neither choice addresses the shifting baseline problem, namely that marine ecosystems may have changed considerably in historical times due to fishery (Jackson *et al.* 2001; Jackson, 2001). Wolff (2000a) concludes that at least 42 species have gone extinct from the Dutch Wadden Sea during the past 2000 years. Habitat destruction (like the closure of the Zuiderzee) played a part in at least 26 cases, overexploitation in at least 17, and pollution in at least 3. Species that went extinct many centuries ago include the gray whale (*Eschrichtius robustus*), the grey seal (*Halichoerus gryphus*), the white-tailed eagle (*Haliaeetus albicilla*), the dalmatian pelican (*Pelecanus crispus*) and the common eider (*Somateria mollissima*). Species that went extinct less than a century ago are the harbour porpoise (*Phocoena phocoena*), the sturgeon (*Acipenser sturio*), the sting ray (*Dasyatis pastinaca*), the European flat oyster (*Ostrea edulis*), the whelk (*Buccinum undatum*) and the worm *Sabellaria spinulosa*. Losing the oyster and *Sabellaria* led to the demise of fauna that depended on the reefs these species built. Following decreased exploitation in the remnants of their former distribution area, some species have successfully recolonized the Wadden Sea. The common eider breeds again in the Wadden Sea since about 1900 and an increasing number of grey seals inhabits the Wadden Sea since about 1960. The white-tailed eagle may well follow suit this century. Some species will never return, unless helped by man, leading Wolff (2000b) to advocate reintroduction programs for the gray whale and the Dalmatian pelican. From this perspective, the targets in the Sea and Coastal Fisheries Policy are extremely modest. If 'being nature' is the primary goal of

the Wadden Sea, then there is no logical reason to take the 'present' state of the Wadden Sea ecosystem, from which a number of characteristic species are lacking, as the baseline.

At the same time it must be realized that to all intents and purposes, it is impossible to return the Wadden Sea to a historical 'pristine' wilderness state. Due to both intended and unintended human intervention, a large number of new species has invaded the area and become a permanent part of the ecosystem. So far, none of these introduced species appears to have caused the extinction of indigenous species (Wolff, 2000a). However, some newcomers have a dramatic impact on the ecosystem. A notable example is the Pacific oyster, which builds extensive and massive reefs, which are quite different from mussel beds or the reefs of the now extinct European flat oyster, i.e. a new habitat has become part of the Wadden Sea ecosystem. For the spring of 2004, the total surface covered by beds of Pacific oysters was estimated at 4 km² (Smaal *et al.*, 2004), but the species is now present throughout the Wadden Sea and spreading rapidly (Dankers *et al.*, 2004). Pacific oysters directly compete with mussels for space and several mussel beds have already turned into oyster beds. Apart from such irreversible internal changes to the ecosystem, the Wadden Sea is also subject to many external forces, which have an important impact on the ecosystem. These include decreasing nutrient loads as a result of policies to decrease the level of eutrophication of Dutch waters, dredging activities in the coastal zone and man-induced global climate change (see chapter 7).

Thus, the Wadden Sea is a changed ecosystem that will continue to change. Yet, stakeholders tend to maintain fixed targets. Conservation organizations typically fight for fixed areas of intertidal mussel beds and fixed numbers of birds. The mussel farmers aim for an annual production of 100 million kg fresh weight of mussels (PO Mosselcultuur, 2004). The cockle fishermen aim for an average annual yield from Dutch coastal waters of 4-6 million kg cockle flesh (ODUS, 2004). These mussel bed areas, bird numbers and shellfish catches apply to the 1970s and the 1980s, but the above makes clear there is no guarantee that the internal changes and external influences will allow these values in the future. In fact, it seems rather unlikely as argued in chapter 7.

While it may seem so, this is not a plea to simply abandon clear targets, since the evaluation of policies requires targets. What we want to say is that the current targets and reference values should be reconsidered in the light of the knowledge that has become available as part of the EVA II investigations.

10 Recommendations

10.1 Practical recommendations

- There is a high risk that seed mussel beds will be lost during their first winter. A pragmatic solution to determine the area of the beds is therefore to take the surface areas of mussel beds in April each year as the policy reference value.
- In years in which seed mussel fishing is permitted on the flats, it must be decided on which mussel seed beds fishery will be allowed and on which beds it will not be allowed. We suggest to use the stability criteria as formulated within the framework of EVA II (Brinkman *et al.*, 2003a).
- EVA II has shown that newly established seagrass beds are not sufficiently protected in areas open for shellfish fishery, despite fishing plans. We recommend to either permanently close all potential growing areas of seagrass for shellfish fishery, or to create a better information system on seagrass beds ensuring adequate protection of all old and newly established seagrass beds in areas open for shellfish fishery.

10.2 Adequate biological monitoring

- The EVA II research programme has made clear that monitoring of important biological parameters is fragmented and sometimes inadequate, especially in the Wadden Sea. For instance, the monitoring of chlorophyll in the Wadden Sea has been reduced to such a low temporal and spatial resolution that it can no longer be used to derive estimates of primary production in the Wadden Sea. Yet, adequate conservation of both Wadden Sea and Oosterschelde requires an adequate monitoring programme. It should address the issues of controlling parameters, specific species, biodiversity and habitats, in order to determine, *inter alia*, whether the target numbers are being reached. Such a programme should also look at the location and intensity of utilitarian use.
- The EVA II research programme has made us aware that we lack adequate information on sublittoral mussel stocks, an important component of the ecosystem. A major share of the sublittoral mussels are found on sublittoral culture lots. The suggested monitoring programme should therefore include the recording of cultivation activity on mussel culture lots, and specifically the times of introduction and removal of mussel stocks.
- The EVA II research programme has made us aware that we are not informed on the potential biodiversity of undisturbed sublittoral mussel beds, compared to cultivated mussels on mussel culture lots. Therefore, research is required into undisturbed sublittoral mussel beds. To this end, unfished research areas should be set up in the sublittoral areas and these should be monitored on a regular basis.

10.3 Research into fishing techniques

- The EVA II research programme has identified several problems with current cockle fishing practices. In research into new cockle fishing techniques, attention should be paid to techniques which release less silt from the sediment, which facilitate more selective fishing for commercially valuable (i.e. large) cockles and which promote growth by means of thinning or reseeded.
- The EVA II investigations suggest that fishing mussel seed beds according to the Jan Louw principle does not stabilize these beds, but also does not lead to extra loss of surface. However, important information is lacking to fully evaluate the latter finding. Further research into the Jan Louw hypothesis could clarify whether mussels disappear due to storms or predation. Attention should be given to the fate of mussels which are washed away during winter storms. Are these mussels predated by birds, or mineralized by bacteria?
- It would be beneficial to both the fishermen and nature, if ways could be found to decrease the reliance of the fishermen on natural mussel seed beds. We therefore recommend to carry out research into the collection of mussel larvae as an alternative or supplement to seed fishing.

10.4 Major ecosystem developments

- Declining eutrophication reduces the potential carrying capacity of the Wadden Sea to more natural values. It is recommended to investigate the consequences of this phenomenon in more detail. What is the contribution, if any, to the decline in the production of mussels?
- To gain a better understanding of the effects of changing nutrients on the functioning of the ecosystem and in order to improve predictions on the carrying capacity for higher trophic levels and for sustainable exploitation, we advise to further develop, calibrate and validate ecosystem models including multispecies phytoplankton populations and the different groups of benthic and pelagic suspension feeders.
- Further research is required into the shift of the spatfall of cockles to higher-lying, muddier locations in the Wadden Sea. What are the causes and what are the consequences?
- It seems very likely that Pacific oysters will continue to increase in both Oosterschelde and Wadden Sea. Research could identify opportunities for effective control of Pacific oyster stocks.
- Phenomena like the declining eutrophication, the shifting distribution of cockles and the rise of the Pacific oyster, make it clear that the Wadden Sea is a dynamic ecosystem under the influence of many external factors. As a consequence, it may be advisable to review the fixed target numbers for birds and fisheries. *Mutatis mutandis* the same applies to the Oosterschelde.

10.5 Other research questions relevant to policy-making

- Recruitment of cockles, mussels and other shellfish is highly variable in space and in time, and of great significance to both birds and fishermen. More insights into the factors determining recruitment success would be helpful in studies seeking to predict the effects of climate change, eutrophication and human activities on the ecosystems of Wadden Sea and Oosterschelde.
- The present estimate of the ecological food requirement of the common eider leaves much to be desired. We therefore consider continuation of the research into the feeding ecology of the eider ducks as desirable. This should address the suitability of various sources of food and the fluctuations in their availability in space and time.
- For common eiders, we lack a population model that allows us to estimate at which average rate of mortality, the population will start to decline. We advise to develop such a model.
- For oystercatchers, we can calculate how changes in shellfish stock will lead to changes in carrying capacity, but we cannot predict how quickly the population will become adjusted to the new shellfish stocks, nor do we know the quantitative impact of other factors on the population changes. This requires a dynamic population model.
- Further research could identify opportunities for the formation of mussel beds in the Oosterschelde.
- In case it is decided to permanently close areas with a high potential for the development of seagrass fields, we recommend to develop separate habitat maps for the two species of seagrass to identify the areas with the highest potential.

11 Terms and definitions

Biomass = Weight of living organisms. In this context: the weight of flesh (usually per square meter) of animals or a species in an area.

Black box = Automatic recording system based on satellite positioning.

Carrying capacity = The maximum biomass which a particular species on a particular surface area can achieve in the given circumstances.

Closed areas = policy designation for areas permanently closed to fisheries which affect the seabed under the Sea and Coastal Fisheries Policy Document.

Cockle bed = The definition of a cockle bed is based on a number usually in excess of around 50 cockles per square meter, at a particular location.

Ecological food requirement = The quantity of food which must be available within the ecosystem per bird at the start of the winter, so that the bird can provide for its physiological need for food.

Eutrophication = enrichment of water with nutrients, particularly by the addition of phosphates and nitrates to the ecosystem.

Fishing plans = Plans drawn up by the fisheries sector establishing the rules for fisheries in a given year. The plans are binding on all participating fishermen.

Flesh weight = Weight of the flesh present in a shellfish, as opposed to fresh weight which includes the shell and trapped sea water.

Food reservation = The reservation of a quantity of shellfish which must be left in place for wintering shellfish eaters without the birds suffering clear food stress.

Fresh weight = Total live weight of animals. In shellfish this usually means including the shell and the sea water trapped in the shell. Synonymous with net fresh weight, when associated silt, shell fragments, dead shells and other debris are excluded.

Increased mortality risk among eider ducks = If in any winter more than 12 dead birds per 10 kilometres are washed up on the shore due to lack of food, then there is an increased mortality risk.

Gross fresh weight = Total live weight of animals, including the shell and the sea water trapped inside the shell, and also including silt and dead shell material

Half-grown mussels = Mussels between one and two years old.

Littoral = Generally: 'belonging to the coast'. In this context: flats in the Wadden Sea and Oosterschelde which are under water at high tide and uncovered at low tide.

Mineralization = The release of nutrients as a result of biological decomposition.

Mussel bed = A mussel bed is a benthic community dominated by blue mussels and consists of a spatially well defined, irregular collection of more or less protruding smaller clumps of mussels, separated by open spaces.

Net fresh weight = Total live weight of animals, including the shell and the sea water trapped inside the shell, but excluding silt and dead shell material (see also gross fresh weight).

Nutrients = nutritious substances. In this context the term is applied more precisely to inorganic nutrients.

Open areas = Policy designation for areas not permanently closed to fisheries under the Sea and Coastal Fisheries Policy Document.

Physiological food requirement = The quantity of food which a bird must consume during a given period in order to remain in good condition. In this report the period in question is the winter.

Predation / predators = there is predation if an animal or organism catches and eats a number of individuals of another species. (Natural preying of one animal on others).

Reference numbers = The average numbers of birds present according to counts in the Wadden Sea in the years 1980-1990 and in the Oosterschelde in the years 1987-1990. Policy aims to bring the population (back) up to these numbers. Hence the term target numbers is also used.

Regime shift. Sudden change in the marine ecosystem, characterised by a break in the trend of species composition and numbers per species.

Seed mussels = Mussels up to a year old.

Shellfish eaters = Birds, the majority of whose diet is made up of bivalve molluscs.

Spat fall = Settlement of shellfish larvae from the water on the sea bed.

Sublittoral = Area of the tidal waters which is permanently under water.

12 Reports produced as part of the EVA II research program

In all, 22 scientific reports and 10 technical background reports were produced as part of the EVA II research program. All these reports are in Dutch and can be downloaded from www.eva2.nl.

12.1 List of EVA II reports

The scientific reports below were evaluated by the scientific audit committee set up for the purpose, consisting of Prof. W.J. Wolff, Prof. C.H.R. Heip & Prof. P.L. de Boer. The comments of the audit committee were added at the end of each report and it was indicated how the comments were incorporated in the final text.

Brinkman, A.G. & Bult, T. Geschiede eulitorale gebieden in de Nederlandse Waddenzee voor het voorkomen van meerjarige natuurlijke mosselbanken. (Suitable eulittoral areas in the Dutch Wadden Sea for the occurrence of mature natural mussel beds) Main report on project F2 of EVA II, the second phase of the evaluation research into the impact of shellfish fisheries on nature values in the Wadden Sea and Oosterschelde 1999-2003. Alterra report 456, 1-306. 2003. Wageningen, Alterra.

Brinkman, A.G., Bult, T., Dankers, N., Meijboom, A., den Os, D., van Stralen, M.R. & de Vlas, J. Mosselbanken: kenmerken, oppervlaktebepaling en beoordeling van stabiliteit. (Mussel beds: characteristics, determining surface area and evaluating stability) Report on project F1 of EVA II, the second phase of the evaluation research into the impact of shellfish fisheries on nature values in the Wadden Sea and Oosterschelde. Alterra report 707, 1-70. 2003a. Wageningen, Alterra.

Brinkman, A.G., Kater, B.J., Aarts, G. & Baars, J.M.D.D. Mogelijke effecten van kokkelvisserij op mosselzaadval in de Waddenzee. (Possible effects of cockle fishing on mussel spat fall in the Wadden Sea) Alterra report 901. 2003b. Wageningen, Alterra.

Brinkman, A.G. & Smaal, A.C. EVA II project F7: Onttrekking en natuurlijke productie van schelpdieren in de Nederlandse Waddenzee in de period 1976-1999. (Withdrawal and natural production of shellfish in the Dutch Wadden Sea 1976-1999) Alterra report 888, 1-243. 2003. Wageningen, Alterra.

Bult, T.P., Baars, D., Ens, B.J., Kats, R.K.H. & Leopold, M.F. B3: Evaluatie van de meting van het beschikbare voedselaanbod voor vogels die grote schelpdieren eten. (Evaluation of the measurement of available food supply for birds which eat large shellfish) Dutch Institute for Fisheries Research (RIVO) report C018/04. 2003a.

Bult, T.P., Ens, B.J., Lanter, R.L.P., Smaal, A.C. & Zwarts, L. Korte Termijn Advies Voedselreservering Oosterschelde: Samenvattende Rapportage in het kader van EVA

II.. (Short term advice on food reservation in the Oosterschelde: summary report within the framework of EVA II) Report by the National Institute for Coastal and Marine Management (RIKZ)/2000.042, 1-60. 2000. Middelburg, (RIKZ).

Bult, T.P., van Stralen, M.R., Brummelhuis, E. & Baars, D. Mosselvisserij en - kweek in het sublitoraal van de Waddenzee. (Mussel fishing and cultivation in the sublittoral areas of the Wadden Sea). Dutch Institute for Fisheries Research (RIVO) report C049/04, 1-74. 2003b. Yerseke, (RIVO).

Dankers, N., Meijboom, A., Cremer, J.S.M., Dijkman, E., Hermes, Y. & te Marvelde, L. EVA II project F6: Historische ontwikkeling van droogvallende mosselbanken in de Nederlandse Waddenzee, (Historical development of intertidal mussel beds in the Dutch Wadden Sea) report no. 876. Alterra report. 2003. Wageningen, Alterra.

Ens, B.J., de Jong, M.L. & Ter Braak, C.J.F. EVA II project C4: resultaten kokkelvisserij experiment Ameland (Results of Ameland cockle fishing experiment). Alterra report 945, 1-144. 2003. Wageningen.

Ens, B.J. & Kats, R.K.H. Evaluatie van voedselreservering Eidereenden in de Waddenzee (Evaluation of food reservation for eider ducks in the Wadden Sea) – report within the framework of EVA II, project B2. Alterra report 931, 1-155. 2003. Wageningen.

Essink, K., de Vlas, J., Nijssen, R. & Poot, G.J.M. Heeft mechanische kokkelvisserij invloed gehad op de ontwikkeling van zeegras in de Nederlandse Waddenzee (Has mechanised cockle fishing affected the development of seagrass in the Dutch Wadden Sea?). Report by the National Institute for Coastal and Marine Management (RIKZ)/2003.026, 1-54. 2003. Haren/Den Haag, Rijksinstituut voor Kust en Zee (RIKZ).

Geurts van Kessel, A.J.M., Kater, B.J. & Prins, T.C. Veranderende draagkracht van de Oosterschelde voor kokkels (Oosterschelde: changing carrying capacity for cockles). Reporting on Themes 2 and 3 from the 'Long term research programme on food reservation in the Oosterschelde', within the framework of EVA II. National Institute for Coastal and Marine Management (RIKZ) Rapport National Institute for Coastal and Marine Management (RIKZ) Dutch Institute for Fisheries Research (RIVO) report C62-03. 2003. Middelburg.

Kamermans, P., Bult, T., Kater, B.J., Baars, D., Kesteloo-Hendrikse, J.J., Perdon, J. & Schuiling, E. EVA II project H4: Invloed van natuurlijke factoren en kokkelvisserij op de dynamiek van bestanden aan kokkels (Impact of natural factors and cockle fishing on the dynamics of cockle stocks (*Cerastoderma edule*) and Baltic clams (*Macoma balthica*) in the Wadden Sea and the Eastern and Western Scheldt. Dutch Institute for Fisheries Research (RIVO) report C058/03. 2003a. Yerseke.

Kamermans, P., Kesteloo-Hendrikse, J.J. & Baars, D. EVA II project H2: Evaluatie van de geschatte omvang en ligging van kokkelbestanden in de Waddenzee, Ooster-

en Westerschelde. (Evaluation of estimated size and location of cockle stocks in the Wadden Sea and the Eastern and Western Scheldt) Dutch Institute for Fisheries Research (RIVO) report C054/03. 2003b. Yerseke.

Kamermans, P., Schuiling, E., Baars, D. & van Riet, M. EVA II project A1: Visserij-inspanning. (Fishing effort) Dutch Institute for Fisheries Research (RIVO) report C057/03. 2003c. Yerseke.

Kater, B.J., Brinkman, A.G., Baars, J.M.D.D. & Aarts, G. Kokkelhabitatkaarten voor de Waddenzee en de Oosterschelde. (Cockle habitat maps for the Wadden Sea and the Eastern and Western Scheldt) Dutch Institute for Fisheries Research (RIVO) report C060/03. 2003. Yerseke, (RIVO).

Leopold, M.F., Dijkman, E.M., Cremer, J.S.M., Meijboom, A. & Goedhart, P.W. EVA II project C1/3: de effecten van mechanische kokkelvisserij op de benthische macrofauna en hun habitat. (Effects of mechanised cockle fishing on the benthic macrofauna and their habitat) Alterra report 955. 2003a. Wageningen.

Leopold, M.F., Smit, C.J., Goedhart, P.W., van Roomen, M., van Winden, E. & van Turnhout, C. EVA II project C2: langjarige trends in aantallen wadvogels, in relatie tot de kokkelvisserij en het gevoerde beleid in deze (Long-term trends in numbers of wading birds in relation to cockle fishing and cockle fishing policy). Alterra report 954. 2003b. Wageningen.

Rappoldt, C., Ens, B.J., Dijkman, E. & Bult, T. Scholeksters en hun voedsel in de Waddenzee. (Oystercatchers and their food in the Wadden Sea) Report for project B1 of EVA II, the second phase of the evaluation research into the impact of shellfish fisheries on nature values in the Wadden Sea and Oosterschelde 1999-2003. Alterra report 882, 1-152. 2003a. Wageningen.

Rappoldt, C., Ens, B.J., Dijkman, E., Bult, T., Berrevoets, C.M. & Geurts van Kessel, J. Scholeksters en hun voedsel in de Oosterschelde (Oystercatchers and their food in the Oosterschelde). Report for project D2 theme 1 of EVA II, the second phase of the evaluation research into the impact of shellfish fisheries on nature values in the Wadden Sea and Oosterschelde 1999-2003. Alterra report 883, 1-137. 2003b. Wageningen.

Smaal, A.C., van Stralen, M.R., Kersting, K. & Dankers, N. De gevolgen van experimentele bevissing voor bedekking en omvang van litorale mosselzaadbanken - een test van de Jan Louw hypothese en van mogelijkheden voor natuurbouw. (The consequences of experimental fishing for coverage and size of littoral seed mussel beds - a test of the Jan Louw hypothesis and opportunities for nature development measures) Dutch Institute for Fisheries Research (RIVO) report C022/04. 2003. Yerseke, (RIVO).

Zwarts, L., m.m.v. Dubbeldam, W., Essink, K., van de Heuvel, H., van de Laar, E., Menke, U., Hazelhoff, L. & Smit, C.J. Bodemgesteldheid en mechanische kokkel-

visserij in de Waddenzee (Condition of the seabed and mechanical cockle fishing in the Wadden Sea). National Institute for Fresh Water Management and Waste Water Treatment (RIZA) report. 2003. Lelystad, (RIZA).

12.2 Technical background reports

A number of technical background reports have also been written within the framework of EVA II, or with partial funding from the EVA II budget. These reports have not all been assessed for scientific merit by the audit committee.

Brinkman, A.G., Ens, B.J. & Kats, R.K.H Modelling the energy budget and prey choice of eider ducks *Somateria mollissima*. Alterra report 839. 2003. Wageningen, Alterra.

de Jong, M.L., Ens, B.J. & Kats, R.K.H. Aantallen Eidereenden in en rond het Waddengebied in januari en maart 2002. (Numbers of eider ducks in and around the Wadden Region in January and March 2002) Alterra report 630, 1-26. 2002. Wageningen, Alterra.

de Jong, M.L., Ens, B.J. & Kats, R.K.H. Aantallen Eidereenden in en rond het Waddengebied in de winter van 2002/2003. (Numbers of eider ducks in and around the Wadden Region in the winter of 2002/2003) Alterra report 794, 1-35. 2003. Wageningen, Alterra.

Kater, B.J. Ecologisch profiel van de Japanse oester. (Ecological profile of the Pacific oyster) Dutch Institute for Fisheries Research (RIVO) report C032/03, 1-32. 2003. Yerseke, (RIVO).

Kater, B. J. & Baars, J. M. D. D. De invloed van de Oosterscheldewerken op de relatie tussen abiotische factoren en biomassa van kokkels. (The impact of the Oosterschelde Project on the relationship between abiotic factors and the biomass of cockles) Dutch Institute for Fisheries Research (RIVO) report C055/02. 2002. Yerseke, (RIVO).

Kater, B.J. & Baars, J.M.D.D. Reconstructie van oppervlakten van litorale Japanse oesterbanken in de Oosterschelde in het verleden en een schatting van het huidig oppervlak. (Reconstruction of areas of littoral Pacific oyster beds in the Oosterschelde and an estimate of their current area) Dutch Institute for Fisheries Research (RIVO) report C017/03, 1-43. 2003. Yerseke, (RIVO).

Rappoldt, C., Ens, B.J., Kersten, M. & Dijkman, E. Wader Energy Balance & Tidal Cycle Simulator WEBTICS, technical documentation version 1.0. Report on projects B1 and D2 of EVA II, the second phase of the evaluation research into the impact of shellfish fisheries on nature values in the Wadden Sea and Oosterschelde 1999-2003. Alterra report 869, 1-95. 2003. Wageningen.

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Appendix 1 Beoordeling van het wetenschappelijke eindrapport

'THE EFFECTS OF SHELLFISH FISHERY ON THE ECOSYSTEMS OF THE DUTCH WADDEN SEA AND OOSTERSCHELDE'

VAN DE TWEEDE FASE VAN DE WETENSCHAPPELIJKE EVALUATIE VAN HET NEDERLANDSE SCHELPIEVISSERIJBELEID (EVA II)

Inleiding

Het wetenschappelijke eindrapport 'The effects of shellfish fishery on the ecosystems of the Dutch Wadden Sea and Oosterschelde' doet verslag van de tweede fase van de wetenschappelijke evaluatie van het Nederlandse schelpdiervisserijbeleid (EVA II). Hoewel het rapport ten behoeve van een bredere kring van geïnteresseerden in het Engels is geschreven, doet de auditcommissie verslag van haar bevindingen in het Nederlands omdat de commissie verwacht dat vooral de Nederlandse samenleving in haar bevindingen is geïnteresseerd.

Het EVA II onderzoek is uitgevoerd om een aantal beleidsvragen te beantwoorden die, na eerdere consultatie van de auditcommissie, zijn vertaald in de volgende onderzoeksvragen:

- 1.1 Hoe en in welke mate beïnvloeden de verschillende vormen van schelpdiervisserij de belangrijke bodembiotopen?
- 1.2 Hoe en in welke mate beïnvloedt de schelpdiervisserij het voedselaanbod van scholekster en eidereend, die van grote schelpdieren leven, en andere vogels die van deze biotopen afhankelijk zijn?
- 2.1 Heeft het areaal droogvallende mosselbanken zich hersteld tot het gewenste niveau? Zo niet, is dat dan te wijten aan de schelpdiervisserij, aan andere menselijke invloeden of aan natuurlijke factoren?
- 2.2 Hebben de zeegrasvelden zich maximaal kunnen herstellen? Zo niet, is dit dan te wijten aan de schelpdiervisserij, aan andere menselijke invloeden of aan natuurlijke factoren?
- 2.3 Kloppen de methoden die eerder zijn gebruikt voor de berekeningen van de voedselbehoefte van schelpdieretende vogels?
- 2.4 Hoe verhouden de waargenomen aantallen vogels zich tot de streefaantallen ofwel referentieaantallen? Hoe kunnen eventuele afwijkingen daarin worden verklaard?
- 3.1 Is het huidige voedselreserveringsbeleid voldoende om te voorkomen dat de schelpdiervisserij op de lange termijn negatieve effecten kan uitoefenen op de populaties van schelpdieretende vogels?
- 3.2 Zijn er aanwijzingen dat wadvogels die niet van grote schelpdieren leven zich in negatieve of positieve zin hebben ontwikkeld? En zijn die eventuele

ontwikkelingen het gevolg van de schelpdiervisserij, van andere menselijke factoren of van natuurlijke factoren?

Voor veel van bovenvermelde vragen is uit wetenschappelijk oogpunt de beste aanpak de uitvoering van experimenten waarin delen van de Waddenzee en de Oosterschelde met een verschillende voorgeschiedenis wel en niet worden bevestigd. De betrokken onderzoekers blijken zich dit zeer wel bewust te zijn geweest. Uit wetenschappelijk oogpunt is het daarom zeer teleurstellend dat maatschappelijke oppositie een experimentele aanpak grotendeels onmogelijk heeft gemaakt. Dit maakt de zeggingskracht van de uitkomsten van EVA II minder groot dan hij had kunnen zijn. Afgezien van een enkele experimentele studie, is het onderzoek nu grotendeels gebaseerd op correlatieve studies, studies met wiskundige modellen en op de resultaten van een quasi-experiment, te weten de vergelijking van voor de visserij open en gesloten gebieden. De onderzoekers hebben deze bronnen van informatie over het algemeen tot het uiterste benut.

De auditcommissie is van mening dat deze eindrapportage een zorgvuldige en afgewogen indruk maakt. Dat wil niet zeggen dat de commissie geen kanttekeningen heeft maar die tasten de hoofdlijnen van het betoog niet aan.

Aan het begin van de EVA II studie heeft de auditcommissie er op gewezen dat het noodzakelijk zou zijn niet alleen de effecten van de schelpdiervisserij te bestuderen, maar ook het waddensysteem met al zijn biotische en abiotische factoren in hun onderlinge samenhang in zijn geheel te bezien. Om het risico te vermijden dat bepaalde ontwikkelingen ten onrechte aan de schelpdiervisserij zouden worden toegeschreven, dienden ook de effecten van andere menselijke ingrepen en van eventuele natuurlijke ontwikkelingen te worden verkend. Om die reden zouden tenminste moeten worden bezien:

- de effecten van de bouw van stormvloedkering in de Oosterschelde;
- de effecten van andere bodemberoerende menselijke activiteiten;
- de effecten van teruglopende eutrofiëring;
- de effecten van het storten van baggerspecie op verschillende plaatsen langs de Nederlandse kust;
- de effecten van het optreden van exotische soorten;
- de effecten van klimaatvariëaties door de Noord-Atlantische Oscillatie;
- de effecten van klimaatverandering door het broeikaseffect.

In de volgende paragrafen wordt nagegaan in hoeverre naar het oordeel van de auditcommissie EVA II de hierboven gestelde vragen heeft kunnen beantwoorden. De auditcommissie geeft daarom per vraag aan welke conclusies haars inziens kunnen worden getrokken. Hierbij heeft de auditcommissie zich beperkt tot het gebied van de natuurwetenschappen; economische, juridische, bestuurlijke en andere niet-natuurwetenschappelijke aspecten zijn door de commissie niet bezien. De auditcommissie heeft afgezien van het vermelden van kleine onvolkomenheden die de uitkomsten van het onderzoek niet of nauwelijks beïnvloeden.

Hoe en in welke mate beïnvloeden de verschillende vormen van schelpdiervisserij de belangrijke bodembiotopen?

Kokkelvisserij

De door EVA II verzamelde gegevens en enkele andere onderzoekers suggereren dat mechanische kokkelbevissing, zowel op korte, midden-lange als lange termijn, leidt tot een slibarmere wadbodem. Het beschikbare waarnemingsmateriaal en de daarop toegepaste statistische analyse zijn volgens de auditcommissie echter onvoldoende om genoemde uitspraken met zekerheid te doen. Bovendien vinden er in de Waddenzee ook veranderingen in het slibgehalte plaats die niet kunnen worden toegeschreven aan de kokkelvisserij.

Het EVA II onderzoek en ander in de wetenschappelijke literatuur gerapporteerd onderzoek leiden tot de volgens de auditcommissie onomstotelijke conclusie dat in de beviste gebieden kokkelvisserij niet alleen leidt tot een sterke afname van de aantallen en dichtheden van volwassen kokkels maar ook tot een afname met vaak tientallen procenten van jonge kokkels en andere in de bodem levende schelpdieren, borstelwormen en kreeftachtigen.

Door Piersma et al. (2001) is aangetoond dat kokkelvisserij een nadelig effect heeft op de vestiging van nieuw kokkelbroed in het volgende jaar. Sommige waarnemingen in EVA II bevestigen deze conclusie, maar andere observaties ondersteunen deze niet. In tegenstelling tot de Waddenzee, lijkt kokkelvisserij in de Oosterschelde geen duidelijke of soms zelfs een positieve invloed te hebben op de kokkelbroedval. Een definitieve conclusie kan naar het oordeel van de auditcommissie nog niet worden getrokken.

Blijkens het onderzoek van EVA II en andere onderzoekers treedt herstel van de effecten van kokkelvisserij op bodemdieren op; de duur van de herstelperiode is afhankelijk van het type bodem en levensgemeenschap en kan oplopen tot tenminste 6 jaar. Suggesties in de wetenschappelijke literatuur dat zeer langdurige of zelfs permanente schade zou optreden, konden in het EVA II onderzoek niet worden bevestigd (het onderzoek heeft maar 4 jaar geduurd), maar ook niet verworpen. De auditcommissie meent echter dat ook bij een herstelduur van omstreeks 5 jaar en voortgaande visserij een permanente invloed op de Waddenzee (en Oosterschelde) theoretisch mogelijk is. Het totale oppervlakte aan goede kokkelgebieden voor de visserij beslaat namelijk ongeveer 7% van de Waddenzee en dat blijkt overeen te komen met de gebieden met een rijke fauna aan andere bodemdieren. Als de visserij jaarlijks 1-2% van de Waddenzee bevist en daarbij geleidelijk opschuift tot genoemde 7% geheel bevist is, zou het eindresultaat zijn dat alle rijke gebieden van de Waddenzee continu in een toestand van herstel, dus een suboptimale toestand, verkeren.

Broedval van jonge kokkels was volgens EVA II in de eerste jaren na instelling van voor de visserij gesloten gebieden hoger in de gesloten dan in de open gebieden, maar dat verschil is geleidelijk verdwenen. De meest aannemelijke verklaring is dat de

toenemende dichtheden volwassen kokkels in de gesloten gebieden een negatief effect hebben op de broedval; dit is volgens de auditcommissie echter niet bewezen.

Volgens EVA II en andere onderzoekers is de omvang van de broedval van kokkels op laaggelegen, zandige platen in de Waddenzee in de loop der jaren afgenomen ten gunste van broedval op de hogere en slikgigere platen. Deze conclusie acht de auditcommissie hard. Naast selectieve bevissing en predatie, bijvoorbeeld door garnalen, is als mogelijke verklaring ook een door de visserij veroorzaakte erfelijke verandering in de kokkels aangevoerd; dit is volgens de auditcommissie niet onmogelijk, maar tot dusver niet aangetoond. Andere mogelijke verklaringen, te weten een grotere predatie van garnalen op kokkelbroed in de afgelopen jaren of een verminderde broedval door een verminderd slibgehalte van de laaggelegen platen, zijn evenmin hard gemaakt. Een mogelijke verklaring die volgens de auditcommissie ook nog zou kunnen worden gezien, is hoogteverandering van de platen.

Kokkelvisserij bevissen mosselbanken niet en veroorzaken daar dan ook geen schade, incidentele gevallen daargelaten. Het EVA II onderzoek in combinatie met het werk van andere onderzoekers leidt volgens de auditcommissie tot tegenstrijdige conclusies m.b.t. het effect van kokkelvisserij op de vestiging van nieuwe mosselbanken.

Het effect van kokkelvisserij op sublitorale bodembiotopen is naar het oordeel van de auditcommissie door EVA II en andere onderzoekers onvoldoende onderzocht om tot een oordeel te kunnen komen.

EVA II en ander onderzoek heeft volgens de auditcommissie aangetoond dat kokkelvisserij zonder restricties een desastreus effect heeft op zeegrasbegroeiingen in beviste gebieden.

Mosselzaadvisserij

Waarnemingen van verschillende onderzoekers in de periode voor EVA II hebben laten zien dat mosselzaadvisserij kan leiden tot het volledig verdwijnen van oude mosselbanken op het droogvallende wad. De auditcommissie ondersteunt deze conclusie.

De experimentele toetsing van de zg. Jan-Louw-hypothese in het EVA II onderzoek heeft volgens de auditcommissie niet laten zien dat bevissing de stabiliteit van jonge mosselbanken verhoogt. Het experiment heeft wel laten zien dat in het onderzochte geval banken van jonge mossels in de getijzone konden worden bevist zonder dat deze banken sneller in omvang afnamen dan niet beviste banken. Of deze conclusie algemene geldigheid heeft, zal echter nog nader moeten worden onderzocht.

Opmerkingen in het rapport aangaande de invloed van mosselvisserij op de diversiteit van de epibenthische fauna zijn naar het oordeel van de auditcommissie goed overwogen en logisch, maar worden niet door harde onderzoekgegevens onderbouwd.

Hoe en in welke mate beïnvloedt de schelpdiervisserij het voedselaanbod van scholekster en eidereend, die van grote schelpdieren leven, en andere vogels die van deze biotopen afhankelijk zijn?

Kokkelvisserij

Het is onweerlegbaar, ook voor de auditcommissie, dat kokkelvisserij het aanbod van kokkels voor scholeksters negatief beïnvloedt.

Gebaseerd op modelsimulaties heeft EVA II aannemelijk gemaakt dat door de kokkelvisserij in de Waddenzee ongeveer 15.000 scholeksters minder en in de Oosterschelde ongeveer 3.300 minder vogels voorkomen dan zonder deze visserij het geval zou zijn geweest. Deze aantallen moeten volgens de auditcommissie niet worden gezien als een exacte schatting; ze geven een orde van grootte weer.

Verhulst et al. (2004) maken volgens de auditcommissie aannemelijk dat scholeksters in de voor de visserij gesloten gebieden in de Waddenzee in een betere conditie verkeren dan vogels uit de open gebieden.

EVA II laat een significante afname van de aantallen van de kanoetstrandloper in de Waddenzee zien sinds het begin van de jaren 90. Werk van onderzoekers uit de groep van Piersma maakt volgens de auditcommissie aannemelijk dat dit samenhangt met veranderingen van de bodemfauna veroorzaakt door de mechanische kokkelvisserij. Mogelijk zijn de sterftepercentages van kanoetstrandlopers in de Waddenzee sterk toegenomen.

Volgens EVA II zijn kokkels een weinig profitabele prooi van eidereenden. De auditcommissie leidt hier uit af dat de kokkelvisserij slechts een beperkte invloed zal hebben gehad op de sterfte van en de aantallen eidereenden in de Waddenzee.

Volgens EVA II zijn de aantallen wormen etende vogels in de Waddenzee toegenomen, met name in de voor de visserij opengestelde gebieden. Dit gaat samen met de toename van een specifieke wormensoort, de zeeduizendpoot, die veel als voedsel wordt opgenomen. De relatie met de kokkelvisserij is echter onduidelijk. Andere onderzoekers vinden een toename van meerdere soorten wormen na kokkelvisserij. De auditcommissie concludeert dat toename van wormen na kokkelvisserij niet onmogelijk lijkt, maar dat daarvoor nog geen hard bewijs is geleverd.

Mosselzaadvisserij

De auditcommissie concludeert dat mosselzaadvisserij het aanbod van mosselen voor scholeksters en eidereenden negatief kan beïnvloeden door het wegvissen van mosselbanken op het bij eb droogvallende wad en, voor eidereenden, door het wegvissen van sublitorale mosselbanken en het vervolgens afvoeren van de vangst naar de Oosterschelde.

Het vrijwel volledig verdwijnen door mosselzaadvisserij en mogelijk andere oorzaken van oude mosselbanken op het wad omstreeks 1990 heeft het aantal scholeksters in de Waddenzee met omstreeks 85.000 vogels doen afnemen. Deze conclusie van EVA II berust mede op een modelsimulatie en moet volgens de auditcommissie worden gezien als een orde-van-grootte schatting.

Mosselkweek

Volgens EVA II zijn niet te grote, dunschalige mosselen zoals die op mosselkweekpercelen in de Waddenzee voorkomen, de preferente prooi van eidereenden. Veranderingen in het kweekproces, met name toegenomen afvoer naar de Oosterschelde, hebben vermoedelijk geleid tot een vermindering van het aanbod van deze preferente prooien en daardoor tot afname van de eidereendenstand door voedseltekort. Extra parasietenbelasting van de eenden kan daarbij een bijkomende rol hebben gespeeld. De auditcommissie acht deze verklaringen wel aannemelijk maar niet bewezen.

Een verandering van het kweekproces, bestaande uit het verplaatsen van mossels van bij laagwater droogvallende kweekpercelen in de Oosterschelde naar kweekpercelen die altijd onder water blijven, heeft het aantal scholeksters in de Oosterschelde met omstreeks 9.600 vogels doen afnemen. De auditcommissie acht deze verklaring aannemelijk maar niet bewezen.

Uit EVA II komt een schatting voort dat de mosselkweek in de Waddenzee leidt tot een 15% hogere mosselbiomassa en dus aanbod van voedsel voor eidereenden dan in een natuurlijke situatie het geval zou zijn. De auditcommissie sluit niet uit dat dit juist is, maar acht deze conclusie niet goed onderbouwd. Ook over de jaarlijkse variatie van dit percentage is geen informatie beschikbaar, zoals de EVA II rapportage ook aangeeft.

Heeft het areaal droogvallende mosselbanken zich hersteld tot het gewenste niveau? Zo niet, is dat dan te wijten aan de schelpdiervisserij, aan andere menselijke invloeden of aan natuurlijke factoren?

Het areaal droogvallende mosselbanken in de Waddenzee heeft zich langzaam hersteld van vrijwel geen mosselbanken in 1990 tot omstreeks 2.500 ha in 2002. Daarmee is de ondergrens van de streefwaarde van 2.000-4.000 ha (de natuurlijke bandbreedte is 1.000 – 6.000 ha) gepasseerd. Dit herstel is gebaseerd op een variërende natuurlijke broedval die werd ontzien door het instellen van gesloten gebieden voor alle vormen van schelpdiervisserij, door het uitsluiten van bevissing van mosselbanken in de visplannen van de kokkelvisserij en door het slechts bij uitzondering bevissen van droogvallende mosselbanken door de mosselzaadvisserij.

In de Oosterschelde komen geen mosselbanken in het bij laagwater drooggevalen gebied meer voor. De auditcommissie wil hierbij opmerken dat ze er in het verleden wel zijn geweest. Of ze zijn verdwenen door de aanleg van de stormvloedkering, de

mosselcultuur, de uitbreiding van de Japanse oester of nog een andere oorzaak is de commissie niet bekend.

Hebben de zeegrasvelden zich maximaal kunnen herstellen? Zo niet, is dit dan te wijten aan de schelpdiervisserij, aan andere menselijke invloeden of aan natuurlijke factoren?

Het eindrapport van EVA II laat zien dat in de Waddenzee zeegrasbegroeiingen zich voornamelijk hebben uitgebreid in de voor de schelpdiervisserij gesloten gebieden. In de open gebieden trad naast uitbreiding ook wegvissen van zeegras op. De auditcommissie heeft aan deze waarnemingen niets toe te voegen. Of er in de gesloten gebieden sprake is geweest van maximaal herstel is echter de vraag. De invloed van door de mens veroorzaakte eutrofiëring en verandering van het lichtklimaat door baggeren en storting van baggerspecie is volgens de auditcommissie niet duidelijk.

Er zijn door EVA II geen aanwijzingen gevonden dat mechanische kokkelvisserij de vestigingskansen van zeegras naderhand beïnvloedt. De auditcommissie acht deze conclusie weinig onderbouwd.

Kloppen de methoden die eerder zijn gebruikt voor de berekeningen van de voedselbehoefte van schelpdieretende vogels?

De methoden die eerder gebruikt zijn voor de berekening van de voedselbehoefte van scholeksters en eidereenden zijn volgens de auditcommissie grotendeels juist als men zou willen berekenen wat een vogel per jaar moet opnemen om in leven te blijven. Dit is de fysiologische voedselbehoefte. De aanleiding tot deze berekeningen was echter de wens om verhoogde sterfte van deze wadvogels te voorkomen; in dat geval dient men uit te rekenen wat beschikbaar moet zijn voor de vogels. Dat is in EVA II de ecologische voedselbehoefte genoemd. De auditcommissie meent dat EVA II daarvan een redelijke schatting maakt, te meer omdat de EVA II schatting valt in de range van schattingen door andere onderzoekers gemaakt voor andere Europese wadgebieden.

Hoe verhouden de waargenomen aantallen vogels zich tot de streefaantallen ofwel referentieaantallen? Hoe kunnen eventuele afwijkingen daarin worden verklaard?

De referentieaantallen voor scholeksters zijn gebaseerd op de periode 1980-1990 voor de Waddenzee en 1987-1990 voor de Oosterschelde; ze bedragen 260.000 voor de Waddenzee en 64.000 voor de Oosterschelde. Voor de eidereend is het referentieaantal voor de Waddenzee 130.000; de aantallen in de Oosterschelde zijn van oudsher te verwaarlozen.

Er is volgens de auditcommissie geen twijfel dat de aantallen scholeksters in de Waddenzee zijn afgenomen tot ongeveer 175.000 sinds 1996-97 en in de Oosterschelde tot 35.000 in 1998-2002. De aantallen eidereenden in de Waddenzee zijn afgenomen tot 40-80.000 in de periode 2000-2003; de variatie hangt samen met het deel van de populatie dat in de Noordzee voor de kust van de Waddeneilanden verblijft. De auditcommissie mist in het eindrapport een beschouwing over mogelijke uitwisseling van de populaties met die in wadgebieden elders en over beïnvloeding van die populaties door factoren die aldaar werkzaam zijn.

EVA II voert volgens de auditcommissie voldoende argumenten aan om deze afnames te verklaren uit voedselgebrek in de Waddenzee en Oosterschelde. De redenering dat voor de eidereend een parasitaire besmetting als oorzaak kan worden uitgesloten, is volgens de auditcommissie overtuigend, maar niet strikt bewezen. Als oorzaak van het voedselgebrek voor scholeksters noemt EVA II in de eerste plaats het verdwijnen van de oude mosselbanken rond 1990 en in mindere mate het effect van de kokkelvisserij. De auditcommissie acht dit acceptabele verklaringen die in redelijke mate door waarnemingen zijn onderbouwd. De auditcommissie zou hierbij wel toegelicht willen zien waarom het vrijwel volledig verdwijnen van de mosselbanken in 1990 niet onmiddellijk is gevolgd door grootschalige sterfte van scholeksters zoals zich bij de eidereend voordeed. Met name figuur 48 van het rapport is hierbij intrigerend: waarom bleven de aantallen in de gesloten gebieden hoog tot het seizoen 1996-97? Als oorzaak voor het voedselgebrek van eidereenden noemt EVA II in de eerste plaats veranderingen in het kweekproces van de mosselcultuur. De auditcommissie acht dit een aannemelijke verklaring maar wijst er op dat deze onvoldoende door metingen op de kweekpercelen wordt geschraagd.

Is het huidige voedselreserveringsbeleid voldoende om te voorkomen dat de schelpdiervisserij op de lange termijn negatieve effecten kan uitoefenen op de populaties van schelpdieretende vogels?

Het wetenschappelijk eindrapport van EVA II constateert dat het huidige voedselreserveringsbeleid onvoldoende is gebleken om negatieve lange-termijn effecten op scholeksters en eidereenden te voorkomen. De auditcommissie onderschrijft dit.

Zijn er aanwijzingen dat wadvogels die niet van grote schelpdieren leven zich in negatieve of positieve zin hebben ontwikkeld? En zijn die eventuele ontwikkelingen het gevolg van de schelpdiervisserij, van andere menselijke factoren of van natuurlijke factoren?

Het eindrapport van EVA II laat zien dat in de Waddenzee de kanoetstrandloper en de kluut met zekerheid na een trendbreuk omstreeks 1990 zijn afgenomen, terwijl bontbekplevier, bonte strandloper, drieteenstrandloper en rosse grutto na een trendbreuk in die periode significant zijn toegenomen. Voor de kanoetstrandloper wordt een relatie met de schelpdiervisserij gesuggereerd hetgeen wordt ondersteund

door het werk van de groep van Piersma. Het is onaannemelijk dat de achteruitgang van de kluut iets met schelpdiervisserij te maken heeft; een andere verklaring is evenwel niet beschikbaar. De toename van de overige vier soorten sinds omstreeks 1990 wordt in verband gebracht met een toename van wormen op het wad, met name zeeduizendpoten. De auditcommissie meent dat de toename van de wormen etende soorten niet met zekerheid aan de effecten van de kokkelvisserij kan worden toegeschreven.

De effecten van de bouw van stormvloedkering in de Oosterschelde

De bouw van de stormvloedkering in de mond van de Oosterschelde en de bijbehorende werken hebben gevolgen gehad voor het hele ecosysteem van deze zeearm. Rond de tijd van de bouw veranderden de levensomstandigheden van vrijwel alle planten en dieren in de Oosterschelde in meer of mindere mate door de verandering van het getijverschil en de stroomsnelheden. De auditcommissie steunt de conclusie van EVA II dat dit omstreeks 1987 tot een vermindering van de aantallen scholeksters in de Oosterschelde heeft geleid.

Inmiddels blijkt dat de bouw van de stormvloedkering ook leidt tot erosie van de bij laagwater droogvallende gebieden. De auditcommissie onderschrijft de conclusie van EVA II dat dit nog geen effect heeft gehad op de aantallen voedselzoekende scholeksters maar dat dit in de toekomst wel te verwachten is.

De effecten van andere bodemberoerende menselijke activiteiten

Het eindrapport van EVA II bespreekt een reeks van andere bodemberoerende menselijke activiteiten (handkokkelaars, pierenspitters, zagerspitters, zandwinning) en concludeert dat de effecten in vergelijking met de kokkel- en mosselzaadvisserij verwaarloosbaar zullen zijn. De auditcommissie kan dit onderschrijven. Over de mogelijke effecten van de garnalenvisserij is volgens EVA II te weinig bekend. De auditcommissie onderschrijft dat maar concludeert tegelijkertijd dat het slecht voorstelbaar is dat de garnalenvisserij de achteruitgang van scholeksters en eidereenden heeft veroorzaakt en verantwoordelijk is voor het verdwijnen van mosselbanken en zeegrasbegroeiingen.

De effecten van teruglopende eutrofiëring

De EVA II studie haalt verschillende gegevens aan waaruit blijkt dat de gehalten aan voedingsstoffen in het kustwater en de westelijke Waddenzee teruglopen. Dit blijkt niet alleen voor fosfaat te gelden maar ook voor de stikstofverbindingen. Bij de toename van de gehalten aan voedingsstoffen (eutrofiëring) in de periode 1960-1980 werd deze toename aangewezen als oorzaak van toename van de primaire en secundaire productie en toenemende biomassa's van phytoplankton en bodemdieren.

Het ligt dan voor de hand om bij afnemende gehalten te bezien of producties en biomassa's ook afnemen.

Helaas zijn hiervoor onvoldoende veldwaarnemingen beschikbaar. Om die reden is door EVA II gewerkt met het ECOWASP-model, een mathematisch model van het ecosysteem van de westelijke Waddenzee waarmee de ontwikkelingen in dat gebied kunnen worden gesimuleerd. Hoewel het ECOWASP-model een zeer groot aantal relaties en processen mathematisch beschrijft en daardoor een zeer complex model is geworden, blijft het natuurlijk zo dat het een vereenvoudiging is van de werkelijkheid. Maar naar het oordeel van de auditcommissie heeft EVA II een redelijke balans weten te vinden tussen vereenvoudiging van de werkelijkheid en complexiteit van het model.

Na publicatie van de publieksversie van het EVA II rapport is er met name op deze modelstudie veel kritiek gekomen. De auditcommissie wil niet ingaan op kritiek van hen die de basisrapportage van deze studie niet goed hebben gelezen, maar wel een aantal andere naar voren gebrachte zaken in beschouwing nemen.

Als eerste is er de vraag of voedingsstoffen of het licht de primaire productie in de westelijke Waddenzee beperken. Als uitsluitend het licht beperkend zou zijn, zou afname van de voedingsstoffen geen enkel effect hebben. In het wetenschappelijke eindrapport van EVA II wordt een aantal argumenten aangedragen waarom toch voedingsstoffen beperkend zijn. De auditcommissie is geneigd deze argumentatie te onderschrijven voor tenminste een deel van het jaar.

In de tweede plaats werd opgemerkt dat noch biomassa's (chlorofyll), noch productie van het phytoplankton in de Waddenzee zouden afnemen. De schrijvers van de EVA II eindrapportage betogen naar het oordeel van de auditcommissie terecht dat afname van de chlorofyll-gehalten in een systeem met variërende hoeveelheden filtrerende bodemdieren niet goed meetbaar zal zijn. De primaire productie neemt blijkens gegevens van het Koninklijk Nederlands Instituut voor Onderzoek der Zee echter wel degelijk af sinds omstreeks 1995. Mogelijke na-ijleffecten door langzaam vrijkomende voedingsstoffen die zijn gebonden aan kleien in mosselbanken en elders in het Waddengebied kunnen overigens maken dat de afname van de phytoplanktonbiomassa (chlorofyll) langzamer gaat dan zou worden verwacht op basis van metingen van de input van voedingsstoffen van elders in het waddensysteem.

In de derde plaats werd gesteld dat de biomassa van de bodemdieren op het Balgzand tot nu toe helemaal geen afname laat zien. Het eindrapport van EVA II gaat hier niet op in. De auditcommissie zou echter het volgende in overweging willen geven. Het ECOWASP-model berekent in de eerste plaats de mogelijke secundaire productie ('aangroei') van bodemdieren in de hele westelijke Waddenzee. Deze potentiële productie (een proces) voor de hele westelijke Waddenzee kan niet goed worden vergeleken met de biomassa (een toestand) van een deelgebied van die westelijke Waddenzee, zeker niet als die biomassa voor een belangrijk deel uit langlevende organismen zou bestaan.

Verder vroeg men zich in verschillende commentaren af of de modeluitkomst die een afnemende maximale schelpdierbiomassa laat zien, wel de afname kan verklaren in de vogelaantallen. Dit is volgens de auditcommissie in principe te onderzoeken; als eerste benadering kan men in figuur 79 de ecologische voedselbehoefte van de referentieaantallen van scholeksters en eidereenden in de westelijke Waddenzee aanduiden.

Tenslotte wil de auditcommissie benadrukken dat teruglopende eutrofiëring grote consequenties voor het huidige waddensysteem zou kunnen hebben, inclusief de vogels en de vissers. Via het ECOWASP-model heeft een eerste verkenning van deze problematiek plaatsgevonden; naast verrassende uitkomsten heeft die ook geleid tot nog vele vragen. De auditcommissie meent daarom dat ook na EVA II middelen gevonden zouden moeten worden om deze problematiek verder te onderzoeken.

In de Oosterschelde zien we een teruglopende primaire productie. Hier wordt deze door EVA II vooral toegeschreven aan verminderde lichtdoordringing door toenemende gehalten aan humuszuren die vermoedelijk afkomstig zijn uit blootspoelende veenbanken. De auditcommissie acht dit niet onmogelijk.

De effecten van het storten van baggerspecie op verschillende plaatsen langs de Nederlandse kust

Het eindrapport van EVA II noemt het storten van baggerspecie in de kustzone van de Noordzee (= voornamelijk nabij Hoek van Holland) als oorzaak van verhoogde troebelheid in de Waddenzee hetgeen de productiviteit van het gebied nadelig zou kunnen beïnvloeden, maar gaat hier verder niet op in.

De auditcommissie wil hierover opmerken dat de trends in gestorte hoeveelheden en in troebelheid van het wad niet zodanig in de tijd verlopen dat ze gecorrigeerd zijn met een afname van bijv. zeegras of aantallen wadvogels.

De bijdrage van baggerspecie aan de troebelheid van en ook de slibsedimentatie in de Waddenzee dient volgens de auditcommissie ook te worden bezien tegen de achtergrond van een, over veel langere termijn, afnemende erosie van vroeg-Holoceen slibsediment uit de bodem van de Noordzee.

De effecten van het optreden van exotische soorten

In de Waddenzee zijn de afgelopen jaren drie exotische soorten van elders in de wereld gevestigd; in de Oosterschelde nog veel meer. Kunnen deze een oorzaak van de waargenomen veranderingen zijn geweest?

Het eindrapport van EVA II gaat alleen in op Japanse oester. Deze heeft sinds de jaren zeventig de Oosterschelde gekoloniseerd en is sinds de jaren negentig bezig met een opmars in de Waddenzee. Voor de Waddenzee geldt dat de aantallen oesters pas

aan het einde van de door EVA II beschouwde periode in aantallen van enig belang begonnen op te treden. Het optreden van de Japanse oester kan volgens de auditcommissie dus worden uitgesloten als oorzaak van de veranderingen in de Waddenzee die door EVA II zijn onderzocht. Dit laat onverlet dat voor de komende jaren en decennia de Japanse oester een grote invloed op het ecosysteem van de Waddenzee zal kunnen hebben. In de Oosterschelde omvat de Japanse oester nu (reeds) ongeveer 1/3 van alle schelpdierbiomassa.

Twee andere nieuwe soorten in de Waddenzee, de borstelworm *Marenzelleria* cf. *wireni* en de Amerikaanse zwaardschede *Ensis directus*, zijn plaatselijk van belang doch lijken naar het oordeel van de auditcommissie niet in aanmerking te komen voor de verklaring van de door EVA II onderzochte verschijnselen.

De effecten van klimaatvariaties door de Noord-Atlantische Oscillatie

De Noord-Atlantische oscillatie (NAO) is een schommeling in het klimaatsysteem van NW-Europa. Afhankelijk van de gemiddelde luchtdrukverdeling over de noordelijke Atlantische Oceaan wisselen perioden met oostelijke winden en relatief koude winters af met warmere perioden met westelijke winden. Aangetoond is dat dit samen gaat met grote veranderingen in de ecosystemen van Noordzee en aangrenzende wateren. Een dergelijke 'regime shift' zou in theorie ook een verklaring kunnen vormen voor de in EVA II onderzochte verschijnselen.

De auditcommissie meent dat het eindrapport hierop in zou moeten gaan.

De effecten van klimaatverandering door het broeikaseffect

Een recente publicatie van Beukema & Dekker (2004) maakt aannemelijk dat veranderingen in het klimaat belangrijke effecten op de ecosystemen van de Waddenzee kunnen hebben. De broedval van schelpdieren zou bijvoorbeeld kunnen afnemen door meer zachtere winters.

Opnieuw meent de auditcommissie dat het eindrapport meer zou moeten doen dan het verschijnsel noemen en dus zou moeten ingaan op de vraag of de waargenomen effecten in de Waddenzee sinds 1990 kunnen worden toegeschreven aan klimaatverandering.

Tenslotte

De EVA II eindrapportage sluit af met een beschouwing over de voortdurende verandering van de Waddenzee en het probleem dat hierdoor ontstaat bij het gebruik van vaste referentiewaarden. De auditcommissie ondersteunt deze beschouwingen maar realiseert zich dat dit voor beleidsmakers een probleem zal vormen.

N.B. Alle aangehaalde literatuur kan worden teruggevonden in het hier besproken eindrapport van EVA II.

Utrecht/Yerseke/Haren
23 juni 2004

Prof.dr. P.L. de Boer
Prof.dr. C.H.R. Heip
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Naschrift van de auteurs

Wij zijn de wetenschappelijke audit commissie zeer erkentelijk voor de grote inspanning die zij heeft geleverd bij het beoordelen en becommentariëren van het wetenschappelijk eindrapport EVA II (en eerder de vele onderliggende rapporten). Wij hebben dankbaar gebruik gemaakt van het commentaar om de eindrapportage te verbeteren en te verduidelijken. Ten opzichte van de concept versie die door de audit commissie is beoordeeld gaat het met name om de volgende zaken:

- Meer uitleg in sectie 1.5.4 over “*imputing*”, oftewel het corrigeren van vogeltellingen door het bijschatten van de aantallen vogels in gebieden die door omstandigheden niet geteld konden worden, inclusief de problemen die zich hierbij voordoen. Ook wordt meer aandacht besteed aan de problemen die ontstaan bij het toekennen van vogels die tijdens hoogwater worden geteld aan laagwater foerageergebieden.
- Meer uitleg in sectie 1.5.9.2 over de vergelijking van open en gesloten gebieden.
- Een extra figuur over de beviste oppervlakte (daadwerkelijk door de kokkelkor geraakt) afgezet tegen het uit de RIVO-surveys geschatte oppervlakte kokkelbanken (Figuur 26).
- Aangepaste tekst in sectie 3.4.1 over de effecten van kokkelvisserij op het kokkelbestand, inclusief een extra figuur over de relatie tussen recrutering en het totale kokkelbestand (Figuur 35).
- Aangepaste tekst in sectie 3.4.2 over de verandering in de verspreiding van kokkels in de Waddenzee en de mogelijke rol van kokkelvisserij.
- Meer uitgebreide tekst in sectie 3.8 over de aantalsveranderingen van de scholekster, zowel wat betreft de totale aantallen, als de aantallen in open en gesloten gebieden.
- Aangepaste tekst over de mogelijke verklaringen voor de waargenomen verandering in verspreiding van de kokkels in de Waddenzee in sectie 3.9.3.
- Aangepaste formulering van de conclusies in sectie 3.10.
- Uitbreiding van de discussie in sectie 4.4.1 over de effecten van mosselvisserij op littorale mosselbanken.
- Uitbreiding en verduidelijking van de tekst in sectie 5.2 over de voedselreservering van de scholekster, inclusief een discussie over populatie-dynamica en “*return rate*”.
- Meer informatie in sectie 5.3 over de populatie-dynamica van de eidereend en de relatie tussen eidereenden en mosselkweek, inclusief een extra figuur over de aantallen eidereenden in de Waddenzee en op de Noordzee als functie van het geschatte bestand sublittorale mosselen (Figuur 80).
- Een specificatie in sectie 6.1 welke verschillen tussen open en gesloten gebieden mogelijk of waarschijnlijk het gevolg zijn van schelpdiervisserij.
- Een uitbreiding van de discussie in sectie 7.1.5 over de afnemende draagkracht volgens het ECOWASP model en de veranderingen in de biomassadichtheden bodemdieren op het Balgzand.
- Een uitbreiding van de conclusies over draagkracht in sectie 7.4.
- Een uitbreiding van sectie 8.5 over de voedselreservering voor scholeksters in de Oosterschelde.

Het was om verschillende redenen niet mogelijk om alle commentaar te verwerken. De volgende suggesties van de audit commissie zijn niet verwerkt:

- De suggestie om middels de ecologische voedselbehoefte na te gaan of de afname in de berekende maximale schelpdierbestanden de waargenomen afname in de vogelaantallen kan verklaren. De vogelaantallen hangen niet af van de berekende maximale schelpdierbestanden, maar van de daadwerkelijk aangetroffen schelpdierbestanden. Vooral jaren met weinig schelpdieren spelen een grote rol. Wij hebben nog geen relatie kunnen leggen tussen de omvang van het maximaal mogelijke bestand en het minimaal waargenomen bestand.
- De suggestie om uitgebreid aandacht te besteden aan de effecten van klimaatvariëaties door de Noord-Atlantisch Oscillatie en de effecten van klimaatverandering door het broeikaseffect. Dit zijn belangrijke onderwerpen die een meer gedegen studie vereisen dan in het kader van dit rapport mogelijk was. Deze fenomenen kunnen mogelijk trends verklaren die zich in de hele Waddenzee hebben afgespeeld, maar het is minder waarschijnlijk dat verschillen in ontwikkeling tussen open en gesloten gebieden door klimaatvariëaties of klimaatverandering verklaard kunnen worden.