What we know and what we should know about mollusc fisheries and aquacultures in the Wadden Sea

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CPR = Common Pool Resource
EVA II = Evaluation Project part 2 of the current Dutch shellfishing policy (1993-2003)
IFQ = Individual Fishing Quota
TAC = Total Allowable Catch

Abstract

At present, large-scale fishery in the Wadden Sea focuses on shrimp and shellfish, i.e. mussels and cockles. Small-scale fisheries exist for several species of fish, e.g. eel, smelt and flatfish, and worms used for bait. This review paper focuses on the shellfish fisheries, including the culture of mussels.

The first problem of any fishery is to avoid the so-called "tragedy of the commons", perhaps better referred to as the "tragedy of open access resources". A typical example of this tragedy is the European flat oyster, which disappeared from the Wadden Sea between 1940-1950 due to overfishing. Sociological studies indicate that it is not easy to devise a management regime that leads to a sustainable exploitation of a common pool resource like shellfish, but successful examples do exist. In the past, traditional rules of local communities exploiting a common resource incorporated the knowledge accumulated over many generations on how heavily the resource could be exploited. Nowadays, the speed with which new technologies are introduced and the potential risks associated with new technologies prevent such trial and error learning by local communities. Scientific investigations are the only means left to determine the Total Allowable Catch (TAC) if sustainability is the goal. According to recent insights the most efficient regime, both from an economic and an ecological point of view, is to then divide this TAC among individual fishermen, leading to a system of Individual Fishing Quota's (IFQ's).

The second problem for the fishermen, which is of more recent origin, but rapidly increasing in importance, is that they are not the single users of the resource. In fact, the primary status of the Wadden Sea at present is that of a nature area of international importance. Other uses of the Wadden Sea are allowed, as long as they do not significantly affect the natural values of the area. Thus, a fishery may be sustainable in the narrow sense, i.e. the exploited stock is maintained in the long run, yet cause significant harm to the natural values of an area, i.e. the fishery is not sustainable in the broad sense.

These concepts are applied to mollusc fisheries in the Dutch Wadden Sea. During the second half of the previous century, fishing for cockles and mussels was increasingly mechanised. Compared to the other parts, the Dutch part of the Wadden Sea is most heavily exploited with these mechanical dredges. A heated debate between fishermen and conservationists has been raging in the Netherlands since 1990 on the question whether these mechanised fisheries can be considered sustainable in the broad sense. This paper investigates the questions that need to be answered and the hypotheses that need to be tested to settle this debate.

Introduction

Fisheries aiming to persist in the Wadden Sea are nowadays faced with two problems. First, they must be sustainable in the narrow sense. That is, the fishery should be organised in such a way that harvests of the target species can be sustained in the long run. Second, they must be sustainable in the broad sense. That is, the fishery should be organised in such a way that the harvesting of fish or shellfish does not cause major and irreparable damage to the natural habitats. The first demand is a *conditio sine qua non* if the fishermen not only want to earn a decent living themselves, but are also concerned about the possibilities of future generations to earn as decent a living from the fishery. This demand is as old as the profession itself. The second demand is of more recent origin and follows from the increasing awareness and appreciation among the citizens in the countries bordering the Wadden Sea of the large natural values and uniqueness of this area. For hundreds of years the intertidal flats were primarily seen as a possible source of new land and successive embankments led to a continuing decline of surface area. In the Netherlands, the turnaround came only a few decades ago when in 1974 a broad-based committee set up by the Dutch government concluded that in the Dutch Wadden Sea no major embankments should be carried out (Mazure, 1974). In the last few decades the governments of the Wadden Sea countries have signed many international treaties to protect the natural values of the area. According to these treaties, human activities, like the fishery, are allowed, as long as these activities do not significantly harm the natural values. The problem is to define what constitutes significant harm and to determine the ecological effects of one specific human activity in a complex and dynamic ecosystem like the Wadden Sea, where many other human activities take place as well. If it is concluded that a fishery does not cause significant harm to the natural values, it is sustainable in the broad sense, which automatically entails sustainability in the narrow sense. However, the reverse does not apply. At least in theory, there may be harvesting techniques or harvesting intensities that do not deplete the stock of harvested fish or shellfish in the long run, yet cause major damage to particular habitats or non-targeted species. For convenience, I will refer to sustainability in the narrow sense as *stock sustainability* and to sustainability in the broad sense as *ecological sustainability*.

In the following I will examine past and present shellfish fisheries in the Wadden Sea from the perspective described above. Thus, I will not consider fishing for shrimp and flatfish, even though these two fisheries are currently the most widespread in the Wadden Sea as a whole (Table 1). It is certainly important to examine the sustainability of these fisheries, but I do not have the expertise to do so. Furthermore, this paper does not aim to provide an exhaustive review of all the known and missing facts on past and present shellfish fisheries in the Wadden Sea. The past will be used to exemplify the interaction between social, economical and ecological forces that make it so difficult for fisheries in general to achieve sustainability in the narrow sense. The present will mainly focus on mechanised fishing for cockles and mussels in the Dutch Wadden Sea as a means to highlight the most pressing scientific questions. The intensities of these two fisheries are much higher in the Dutch part of the Wadden Sea compared to elsewhere (Table 1). For more than a decade now, a heated controversy between conservationists and fishermen has surrounded the question whether these mechanised fisheries can be considered sustainable in the broad sense.

The tragedy of the commons

Fisheries consist of a complex interaction between ecological processes governing the population dynamics of the target species and the exploitation behaviour of the fishermen. This exploitation behaviour is governed by economical, political, social and technological developments. Despite the complexity it is becoming increasingly clear why it is so difficult for fishermen not to overexploit the stock. At the heart of the problem lies the so-called "tragedy of the commons" (Hardin, 1968). For the sake of clarity we will explain this problem assuming a hypothetical fishery without any regulations. In this case, the fishermen exploit what is called an open access resource. When the resource is fully open access, fishermen will join the fishery and/or individual fishermen will increase their harvests as long as an individual profit can be made. More and more fish will be taken and sooner or later the fish stock declines. In the extreme case, the fish population will go extinct. But even if this does not happen, the previously described process leads to what economists call rent dissipation. If there were only a single fisherman exploiting the fish stock, he would be wise to stop fishing when the difference between the market value of the landed fish and costs of fishing is maximised. However, because the resource is open access others will join and there is no benefit to individual restraint. The fishermen will increase their efforts until the costs of fishing are close to the market value of the landed fish, i.e. until rents are dissipated (FAO, 1993; Iudicello *et al.*, 1999).

In the past, local fishing communities either disappeared along with the fish, or found a way to regulate the fishery. Social scientists have studied the local rules of self-governance that have led to the sustainable exploitation of a common pool resource like a fish stock. Comparing a series of studies, Ostrom (1990) tentatively lists the following design principles for rules of self-governance that lead to successful sustainable exploitation of a common pool resource (CPR):

1. Clear boundaries to the resource and clear memberships of the users.
2. Congruence between appropriation and provision rules and local conditions. This encapsulates the accumulated knowledge obtained through trial and error by the local community on the natural variability in the resource and how best to deal with it.
3. Collective choice arenas, i.e. most users can participate in modifying the rules.
4. Good monitoring of the resource and the amount taken by each user.
5. Graduated sanctions against offenders, e.g. when fishermen taking more than their share are caught for the first time, they are punished only lightly, whereas repeated offenders receive severe punishment.
6. Conflict resolution mechanisms, as conflicts are bound to occur among users as well as between users and officials monitoring the resource and enforcing the rules.
7. Recognised rights to organise, i.e. local fishermen are allowed to design their own institutions, which are not challenged by external agents.

Not listed is design principle 8, as it deals with the nesting of large and complex CPR's. The bottom line is that the tragedy of the commons can be avoided and has been avoided in the past by local communities, which succeeded in appropriately regulating access to the fish or shellfish stocks.

The above design principles of long-enduring self-governing CPR institutions are derived from studies where a single resource was exploited. Thus, they deal with stock sustainability and not with ecological sustainability. By concentrating on a single resource other uses of the ecosystem, like other types of fisheries, tourism and nature conservation, are ignored. These are some of the reasons that lead Steins *et al.* (1999) to warn that the above principles should not be used as a priori design principles for successful collective action. An alternative, that will be used here, is to view the design principles as minimum requirements. Meeting the requirements does not guarantee sustainable exploitation of the stock (in the narrow sense), but not meeting the requirements is a strong indication of insufficient guarantees for sustainable exploitation of the stock.

A clear example of a dismal failure to regulate access is the European flat Oyster (*Ostrea edulis*). This long-lived species once abounded in the Wadden Sea and the shallow waters of the North Sea coastal zone. Due to severe overfishing the species went extinct in the region somewhere between 1940 and 1950. Dijkema (1997) describes the chain of events for the Dutch Wadden Sea, suggesting that "in addition to stock depletion, hydrographic changes caused by the closure of the southern Zuiderzee in 1932 may have played a role". As early as 1714 imports of seed oysters from Denmark are recorded, indicating that already in those years exploitation sometimes exceeded recruitment. Dijkema estimates that annual landings amounted to roughly 14 million oysters in the second half of the 18th century. After 1850, landings began to decline sharply and after 1856 rarely more than 300,000 oysters were landed per season. This caused great poverty among the fishermen. Several restocking attempts in areas where public fishing was banned, using imported seed oysters, failed due to a combination of natural causes and poaching. Reise (1998) provides a vivid description how the oysters disappeared from the German part of the Wadden Sea. Annual landings steeply declined from 5 million oysters per year to around 1 million oysters per year between 1859 and 1875. Restocking attempts failed and the oyster disappeared around 1930. The well-known scientist Möbius warned in 1877 that "*Wenn die Austernbänke zum allgemeinen Nutzen der Staatsbevölkerungen und zum besonderen Vorteil der Küstenbewohner dauernd ertragsfähig bleiben sollen, so darf das jährliche Maass ihrer Befischung nicht nach den Ansprüchen der Consumenten und nach der Höhe der Austernpreise bestimmt werden, sondern einzig und allein nach der Menge des Zuwachses*", but his advice was not taken. In fact, Olsen (1883) describes in the Piscatorial Atlas of 1883 that huge oyster beds had recently been discovered in the southern part of the North Sea, i.e. just north of the Wadden Sea, and that new ships were specifically built to harvest this rich bounty. The North Sea oysters went extinct at about the same time that the Wadden Sea oysters went extinct.

Why did the fishermen fail to develop a sustainable exploitation scheme for the oyster in the Wadden Sea? One important cause is technological development. Oysters must be transported alive, so they could only be sold on markets close to the sea. This changed with the advent of railroads. In Europe, the first railroads were built around 1830, but the network fully developed between 1850 and 1900. Railroads allowed a sudden huge expansion of the market, which led to an immense economic incentive to fish many more oysters than could be harvested in a sustainable manner.

The oyster is not the only species that suffered from overfishing. Reviewing the literature, Wolff (2000) concludes that overexploitation contributed to the extirpation of 17 out of 32 animal species that became extinct during the past 2000 years from the Dutch Wadden Sea.

If oysters disappeared from the Wadden Sea due to overfishing, we must ask why mussels *Mytilus edulis* and cockles *Cerastoderma edule* did not disappear at the same time of railroad expansion. I can only offer some speculations. One part of the answer could be that mussels and cockles are short-lived species, compared to oysters and whelks. Long-lived species have lower population growth rates and are therefore much less resistant to overfishing than short-lived species. Another part of the answer could be that oysters were much higher valued than mussels and cockles. At the time of tsarina Catherine II oysters were already so much of a delicacy that a special delivery of fresh Wadden Sea oysters was organised for her birthday meal on 2 May 1764 (Reise, 1998). To my knowledge, mussels and cockles never acquired such a high status. Dijkema (1997) describes that mussels were inexpensive protein-rich nutrition for the inhabitants of the growing big cities during the industrial revolution and that mussels were also sold as fodder to duck farms and manure on farmland. Cockles are even less valued than mussels. This would have meant that the economic incentive to overfish was much higher for oysters than for cockles and mussels.

Part I: stock sustainability

Present-day shellfishery in the Dutch Wadden Sea

Above we described the forces that make it extremely difficult for fishermen to achieve sustainable exploitation (in the narrow sense) of a shellfish stock under conditions of open access. We also described the oyster as a victim of overfishing and a historical testimony of this problem. Until very recently, 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. 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 so that nature values could be 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, 1993). This policy document sets the direction for the national fisheries policy until 2003, when the policy will be evaluated. The policy is aimed at an integration of fishing activities and conserving natural values, where possible, and a separation of these two activities where necessary. Thus, the present policy incorporates the recent requirement that the fisheries should not cause significant harm to the natural values of the Wadden Sea.

The reason that the shellfishery came into conflict with nature conservation is not solely due to increasing environmental awareness of the general public. The shellfishery itself also changed dramatically. Sailing boats were replaced with engine-powered ships with ever-increasing fishing power. This continuing mechanization leads to a continuous change of the rules of the game, i.e. the way shellfishing interacts with the shellfish stocks and the habitats in which the shellfish occur (Hall, 1999). The speed of this change is so high and the potential risks are so great that there seems simply no time for local fishing communities to develop rules for sustainable exploitation on the basis of trial and error learning. This means that the only way left to ascertain whether a modern-day fishery employing sophisticated technology is sustainable in both the narrow and the broad sense is through scientific investigations. Below we will review from this perspective what we know and what we should know about the shellfish fisheries in the Dutch Wadden Sea.

Mussel culture and fisheries

Nowadays, in the Netherlands there is no fishery of wild mussels that are directly sold on the market. Instead, seed mussels are fished and sown on culture plots. Only after they have grown to a marketable size they are sold on the market. Mussel culture developed after 1865 in Zeeland and from the very beginning most mussel seed was collected from the Wadden Sea (Dijkema, 1997). The first steam-powered dredger appeared in 1910 and by 1932 the mussel fleet was fully motorised. Mechanisation did not stop there as the engine power of the boats quadrupled from 90 kW in 1960 to 351 kW in 1991 (Dijkema, 1997). Between 1994 and 1999 the engine power increased from 377 kW to 461 kW (Productschap Vis, 2000). Seed fishing may occur in both spring and autumn and during the last ten years most seed was taken from the sublittoral. The combined fishing power of the current mussel fleet is so high that it takes only a few weeks to fish the seed. Between 1991 and 1997, no seed was fished in the spring of 1991 and the autumn of 1993 (van Stralen, 1998). In the 11 seasons in this period where fishing took place and for which data are available, on average 73% of the fishable sublittoral stock was fished. In those years, on average 81% of the sublittoral stock was considered fishable.

On the face of it, the tragedy of the commons might potentially afflict current mussel culture practices in two main ways: (1) overfishing of mussel seed, (2) overstocking of the culture lots. Once mussels are put on a culture lot, they are clearly owned by individual mussel farmers. However, seed mussels are a common pool resource. Similarly, the culture lots are owned, but the water that passes over the culture lots, containing the algae on which the mussels feed and transporting the excreta of the mussels, is a common pool resource. Below, we will describe current practices in more detail, to see if these practices suffice to avoid the tragedy of the commons. As explained above, we will use the design principles of Ostrom as a yardstick for this.

Mussel seed fishery and the 7 design principles. Nowadays, mussel seed is collected on the basis of annual fishing plans and quota per mussel farming company. The annual fishing plan is based on a mussel fisheries management plan, both of which are produced by the Mussel Producers' Organization (PO-Mussels). Management plans cover five-year periods and the first came into effect in 1993. The aim of the Dutch PO-Mussels is to produce 100 million kg fresh weight of consumption sized mussels on an annual basis, requiring 65 million kg fresh weight of mussel seed (Smaal *et al.*, 2000a). In other words, the Total Allowable Catch (TAC) of mussel seed from the Dutch Wadden Sea is presently set at 65 million kg fresh weight. As the target of 65 million kg mussel seed is not generally referred to as a TAC, the use of this word may seem inappropriate. According to the definition of the OECD (Organisation for Economic Co-operation and

Development) a TAC sets a maximum level of catch in a fishery for a specific species, areas and time periods and is meant to prevent overfishing. Without going into the details of the negotiating process that led to the maximum catch of 65 million kg seed mussels, it can be safely assumed that the prevention of overfishing was the primary goal. Using the word TAC to describe this maximum level is therefore appropriate. Since this TAC is divided beforehand among the mussel farming companies a system of Individual Fishing Quotas (IFQ's) is actually implemented by the PO-Mussels. Reviewing successes and failures in fisheries management, Iudicello *et al.* (1999) conclude that a system of IFQ's may well be the most effective management tool to stop rent dissipation and overcapitalization and to achieve a sustainable exploitation of (shell) fish stocks. When the current mussel seed fishery is compared to the 7 design principles of Ostrom, it would seem that criterion 1, 3 and 6 are met (Table 2). With the introduction of a black box, which monitors each and every move of each ship, and the fact that each ship with newly caught mussel seed must pass a registration boat, it would seem that criterion 4 is also met. Keus (1994) describes the introduction of fishing plans in 1991 and concludes that the main introductory difficulties proved to be the dividing of the TAC into IFQ's and the enforcement of the regulations. The latter suggests that criterion 5 was not met until the PO-Mussels was put in charge of the fishing plan. Whether or not local fishermen are allowed to design their own institutions with regard to exploitation of the shellfish (criterion 7) is a matter of debate. The fishermen are organised in local and regional fishery organisations, which they designed themselves. However, the PO-Mussels is in charge of the quota and this organisation is designed according to European law. Furthermore, the fishermen are confronted with institutions and rules imposed on them by the Dutch government. An example of the first is the Productschap Vis, which levies taxes from the fishermen on the basis of their catch. An example of the second is the need for the fishermen to obtain a nature conservation law permit when they want to fish in areas designed as nature reserves. Last, but not least, the official Dutch policy is co-management. Co-management consists of consultation between the fishermen and the Dutch government and of a delegation of some of the tasks of the government to the fishermen.

Are current exploitation practices sustainable? The most important question is whether criterion 2, which deals with the congruence between appropriation and provision rules and local conditions, is met. For our case of mussel fishery this general question can be rephrased into two questions: (1) Is the TAC of mussel seed set at a level that the mussel stock in the Dutch Wadden Sea can sustain in the long run, (2) Are culture lots stocked in a way that maximizes the production of consumption-sized mussels? Various authors mention the TAC of 65 million kg mussel seed (e.g. Smaal *et al.*, 2000a) and the relationship to the target production of 100 million kg consumption-sized mussels (Steins, 1999; Verbeeten, 1999; Kamermans *et al.*, 2001). In none of these papers reference is made to a scientific document where the level of the TAC is derived from ecological considerations. In the first part of the first planning document for the Wadden Sea, it is stated that since the 1960's the Dutch Wadden Sea has become the primary producer of "Zeeuwse" mussels and that the annual production of mussels for Dutch coastal waters fluctuates between 80-100 million kg (Ministerie van Volkshuisvesting en Ruimtelijke Ordening, 1976). In the final part of this first planning document it is stated that the policy aim is to continue the current Dutch mussel production at least at the current level (Ministerie van Volkshuisvesting en Ruimtelijke Ordening, 1980). According to J. van Dijk (pers. comm.) the target production in the Dutch coastal waters of 100 million kg fresh weight of consumption sized mussels was calculated in 1983 on the basis of the landings during the years 1967-1973. According to J. de Vlas (pers. comm.) the value of 65 million kg seed mussels being necessary to achieve the target production was determined from discussions between civil servants and mussel farmers. In the absence of a scientific document deriving the TAC from ecological considerations, we are forced to investigate the available information on this matter ourselves. This will not result in a clear answer to the question whether the TAC of mussel seed is set at a level that the stock can sustain, but in more specific questions as well as hypotheses that need testing. One of these hypotheses deals with the stocking of the culture lots.

Landing statistics of consumption-sized mussels. Good landing statistics exist, because all mussels are marketed through the mussel auction in Yerseke (Fig. 1a). Between 1973 and 1983, the realised production fluctuated around the target production of 100 million kg fresh weight. In 1992 the lowest production occurred since 1951. This low production was due to a shortage of mussels, following a series of years with poor recruitment. The resulting conflict between fishermen and conservationists led to the new fishing policy in 1993. Since this new fishing policy came into effect, the target production was achieved only once, namely in 1995. This directly followed the only year in the period, i.e. 1994, when fishing of seed mussels on the intertidal flats of the Wadden Sea was allowed, as there had been a significant spatfall on some of the flats (van Stralen, 1998). The low production in 1992 and the high production in 1995 can both be related to the extent of mussel spatfall in the preceding years. This suggests, but by no means proves, that limited availability of mussel seed, and not reduced growth or increased mortality of mussels on culture lots, explains the drop in the production of consumption-sized mussels. The Dutch government guarantees sufficient space for culture lots to achieve the target production, but it cannot guarantee sufficient spatfall. The landing statistics do not tell us where the mussel seed was fished and where most of the growth of the seeded mussels occurred. Thus, a mussel classified as a Zeeland mussel may well have been fished in the German Wadden Sea and spent most of its growth period on a culture plot in the Dutch Wadden Sea. For an assessment of the impact of the mussel fishery and culture it is important to know where the seed was fished and where the mussels were cultured. Furthermore, lacking data, we do not know if at some period in time, not only seed and half-grown mussels, but also mussels of large size were taken from mature mussel beds.

Mussels on culture lots. Civil servants of the ministry of Agriculture, Nature and Fisheries monitor the type (seed, half-grown, consumption-sized) and amount of mussels on the culture lots in the Dutch Wadden Sea, but these data have not been published. Even better data are possessed by the individual mussel farmers, but these data are not published either. What we do have are estimates, which are back calculated from the landing statistics and data on the seed fishery (Fig. 1b). The back calculations are based on assumptions with regard to: (1) the amount of spatfall on the culture lots (which can be considerable in the Dutch Wadden Sea), (2) the amount of medium sized mussels from

Germany sown on the culture lots, (3) growth and mortality of the mussels on the culture lots, (4) extra damage from storms and (5) the export of mussels from the culture lots in the Wadden Sea to culture lots in the Oosterschelde (Smaal *et al.*, 2000b). Both a gradual increase from 1950 until the eighties and wide fluctuations between years are noticeable. An all-time low is reached in the years 1990 and 1991, which are exactly the years that the conflict between shellfisheries and conservationists started. These conflict years preceded the year 1992 when production of mussels reached an all-time low. This is logical, as it takes on average two years for seed mussels to reach marketable sizes (Smaal *et al.*, 2000b).

A clear suggestion from the data is that since the crash in 1990-1991 the amount of mussels on culture plots in the Dutch Wadden Sea is structurally reduced. However, it should be realised that the data before the crash come from a different source than the data after the crash: (Smit, 1994), versus (Smaal *et al.*, 2000b). Thus, it cannot be ruled out that the difference is partly or wholly due to a difference in the details of the back calculation. The maximum error would occur if the pre-crash data set refers to stocks at the beginning of the mussel season, while post-crash data refers to stocks left at the end of the season, i.e. after all consumption-sized mussels have been shipped to the market. Luckily, additional insights can be gained. First, if there really is a structural reduction in the amount of mussels on the Wadden Sea culture lots, it could be due to more mussels being shipped to culture lots in Zeeland, before being sold. If this is true, there should be a structural increase in landings from Zeeland since the crash years. When the twenty years preceding the crash are compared to the ten years following the crash, a slight but significant increase from 33.9 to 41.6 million kg fresh weight did indeed occur (Table 3). At the same time the annual landings from the Wadden Sea declined from 67.3 to 36.6 million kg fresh weight (Table 3). Second, if we add these average landings of 36.6 million kg to the post-crash data set in Fig. 1b it is clear that the values remain below the values of the pre-crash data set. Thus, there can be little doubt that stocks of mussels on the culture lots in the Wadden Sea are structurally reduced since the crash in 1990-1991.

Why has the production of consumption-sized mussels declined? A decline in production of consumption-sized mussel can be due to a reduction in annual catch of mussel seed, a reduction in the growth rate of the mussels on the culture lots, an increase in the mortality of mussels on the culture lots, or a combination of these. At least seven different hypotheses can be put forward to explain why changes in recruitment and/or growth and/or mortality might have occurred:

1. **Global warming**. Severe winters are often followed by a good spatfall of mussels. There is increasing evidence that global warming is taking place, which will lead to fewer severe winters. This in turn may lead to a decrease in the frequency of good spatfall of mussels, which we are perhaps already witnessing.
2. **Decline of eutrophication**. Eutrophication may stimulate the growth and production of algae. Since mussels feed on algae, we expect eutrophication to stimulate mussel production. In recent years, eutrophication of Dutch coastal waters has decreased, which in turn may have caused a decline in mussel production.
3. **An increase in silt content of the water in the Western Wadden Sea**. Silt negatively influences the food quality for mussels and human activities, like dredging

and the dumping of this material near Hoek van Holland, may increase the silt load of the water transported to the Wadden Sea.

4. **Overfishing of the total mussel stock**. Even though we currently lack precise data, there can be little doubt that the total stock of mussels (littoral mussel beds, wild sublittoral stocks, mussels on culture lots) in the Dutch Wadden Sea, was higher before 1990 than after 1990. Perhaps this reduction in stock has caused a reduction in recruitment of young mussels in the Wadden Sea as a whole.
5. **Depletion of the littoral mussel beds**. Before 1991 mussel seed was regularly fished from the intertidal flats. This stopped when the intertidal mussel beds disappeared. Thus, it cannot be excluded that the high production in the period 1964-1991 may be partly or wholly due to fishing away the mussel beds from the intertidal.
6. **Fishery-induced deterioration of the sublittoral mussel habitats**. During recent years most of the mussel seed was fished from sublittoral areas in the Wadden Sea and the fishing intensity has been quite high. Perhaps this high fishing pressure has caused a decline in the quality of the sublittoral areas for recruitment of mussels.
7. **Deterioration of the mussel culture lots**. A decline in production may be due to a general decline in the quality of the culture lots. Conditions for growth might have declined, or mortality of mussels might have increased, due for instance to an increase in the susceptibility to storms or an increased predation of mussels by natural predators, like eider ducks.
8. **Suboptimal stocking of the culture lots**. The combined stocking decisions of the individual farmers do not necessarily lead to the maximal production of consumption mussels from a given amount of seed mussels. It could well be that a redistribution of mussels between the Wadden Sea and the Oosterschelde, or redistribution within those areas, would lead to a higher production.

Space does not permit us to elaborate and test these hypotheses in any detail, except for the suggestion that culture lots are perhaps stocked suboptimally, the second way in which mussel growers might fall victim to the tragedy of the commons.

Suboptimal stocking of culture lots? Compared to the period 1971-1991 landings of mussels from Dutch coastal waters have decreased from ca. 100 million kg fresh weight per year to ca. 80 million kg fresh weight during 1991-2001 (Table 3 and Fig. 1). Yet, landings from Zeeland have increased in the same period. According to Smaal *et al.* (2001a) the culture lots in the Oosterschelde in Zeeland must be considered overstocked. This implies that a higher yield (production of consumption-sized mussels per kg of seed mussels) could be achieved through a reduction of the total stock of seed mussels in the Oosterschelde. The important question is to which extent the culture lots in the Wadden Sea are similarly overstocked. If the Wadden Sea culture lots are not overstocked, the total production of consumption-sized mussels from Dutch coastal waters would increase if fewer seed mussels were shipped to the culture lots in Zeeland.

Cockle fisheries

Until the early 1960's fishery for cockles on the tidal flats of the Wadden Sea and in Zeeland was small scale and only performed with a "beugel" or "wonderklauw", a rake dragged through the top of the sediment by the fisherman (Dijkema, 1997). Then the mechanical dredge was developed, which was gradually perfected and replaced by the suction dredge. The incentive to invest in the development of these ships arose from the development of a substantial market for cooked deep-frozen cockles in Spain and the fact that the ships could also be successfully deployed in the seed mussel fishery (Dijkema, 1997). During the period of expansion the government, on request of the fishermen, took several restrictive measures: a maximum number of 36 licenses, a maximum of 2 dredges of 1 m wide per ship or one dredge of 1.25 m wide, and a minimum mesh width of 15 mm of the sieves. Nonetheless, the fishing power of the fleet increased considerably between ca. 1980-1990 due to (1) ships getting bigger (they are now 40 m long and 10 m wide), (2) the draft getting smaller (the draft is only 45-50 cm so the boats can fish high in the tidal range), (3) an increase in the engine capacity, increasing the fishing speed from 2.5 to 4 knots, i.e. from 4.6 to 7.4 km per hour (Dijkema, 1997). As a result, the landings of cockles steeply increased from the early 1960's onwards (Fig. 2). For the years 1984, 1985 and 1986 the landings reported by the Productschap Vis (Productschap Vis, 2000) considerably exceed the landings reported by (Dijkema, 1997). The cause of this discrepancy is not clear and requires further study into the reliability of the data. In the following analysis, which aims to highlight the increase in the fishing efficiency of the cockle fleet, we have selected the data provided by the Productschap Vis to represent the years in which the two data sets overlapped.

The total number of permitted fishing days of the cockle fleet has decreased from 3500 in 1976 and now fluctuates between 500 and 1000 since 1991 (Fig. 3a). Sometimes, boats did not use all the permitted fishing days (J. Holstein, pers. comm.). However, this will not greatly affect the following analysis, as long as the fraction used is small or does not vary greatly during the period of interest. Dividing the cockle landings by the total number of fishing days yields the average capture of cockles per boat per day (Fig. 3a). This daily capture steadily increased from 1976 onwards and peaked at 60 ton of fresh cockles in 1988 and 1989. A low value of less than 10 ton was reached in 1991 and since that time the average daily capture has fluctuated. We expect the daily capture to depend on both the total stock and the efficiency of the boats. When the daily capture is plotted in the same graph as the cockle stocks in Wadden Sea and Oosterschelde it seems likely that before 1990 the increase in daily capture is due to an increase in efficiency of the boats (Fig. 3b). This conclusion follows from a steady increase in the daily capture, which bears no relationship to the size of the combined stock in Oosterschelde and Wadden Sea. After 1990 the fluctuations in daily capture follow the fluctuations in the stock, suggesting that no additional improvements in the efficiency of the boats occurred. The increase in efficiency could be due to:

1) An increased ability on the part of the fishermen to locate the most profitable cockle beds.
2) An increase in the area fished per unit time, which could be due to:
   a) an increase in the width of the dredges
   b) the switch from mechanical dredges to suction dredges, which made it possible to fish continuously
   c) an increase in the fishing speed

We know from the publication of Dijkema (1997) that fishing speed increased from 4.6 to 7.4 km per hour, but it cannot be excluded that the other factors also contributed to the improved efficiency.

Table 2 compares the current organisation of the cockle fishery to the design principles identified by Ostrom for long-enduring, self-governing CPR institutions. Many criteria are fulfilled, but in some cases important doubts remain. As with the mussel fishery, the most important unanswered question is whether the current intensity of exploitation can be sustained on a long-term basis by the Wadden Sea ecosystem. The TAC of 10 million kg cockle flesh for years with high stocks was decided in court without reference to detailed scientific studies specifically dealing with the question which harvesting level can be considered sustainable in both the narrow and the broad sense.

Spisula fisheries

Suction dredges used for fishing cockles can easily be modified to fish the cut trough shell *Spisula subtruncata* by elongating the pipes. This species occurs in dense banks in the North Sea coastal zone and the fishery commenced in 1985. However, the fishery only fully developed when cockles were scarce in the early 1990's (Dijkema, 1997). No annual landing data are available, but according to the recent Wadden Sea Quality Status Report (de Jong *et al.*, 1999), the annual Dutch market is 3000-4000 t meat, which corresponds to 19 – 25 million kg fresh weight, assuming a flesh content of 16% (J. Holstein, pers. comm.). In the years 1994-1999 the stock of adult *Spisula* varied around 130 million kg fresh weight, with extreme values of 0 and 310 million kg fresh weight (Smaal *et al.*, 2001b). Two species of birds feed in large numbers on *Spisula*: the common scoter *Melanitta nigra* (Leopold *et al.*, 1995) and the eider duck *Somateria mollissima* (Leopold *et al.*, 2001). Common scoters sometimes feed on small *Spisula* (M.F. Leopold, pers. comm.), but eider ducks depend on the large specimens, which are also preferred by the fishermen. Combining these various bits of information, it seems quite likely that the fishery can and sometimes does take a sizeable portion of those *Spisula* which are most profitable to both the birds and the fishermen. This brings us to questions on the ecological sustainability of the various fisheries, which is the topic of the next section of this paper.

Part II: Ecological Sustainability

Shellfish fisheries and nature conservation

Apart from seals and birds being disturbed by fishermen walking over the mudflats, which is generally considered a minor problem, fishing for shellfish may affect nature in two main ways. First, it is self-evident that shellfish are removed, which leads to an immediate reduction in the stock. When the harvesting intensity is too high, this may lead to a "permanent" reduction in the stock in the long term, which will negatively affect species feeding on the shellfish, like eider ducks and oystercatchers. Second, shellfishing and shellfish culture may affect the habitat where the shellfish occur. If such habitat changes occur, they may imperil the shellfishery itself and lead to conflicts not only with nature conservation, but also other fisheries. For example shrimp beam trawling (and suction dredging) is not allowed on mussel culture lots. Furthermore, suction dredges are only allowed to cook cockles at locations where the piles of empty shells do not pose a problem for shrimp beam trawlers. In the following we will not be concerned with such interfishery conflicts over space use, but focus on the scientific discussions regarding the effect of shellfishing on important natural habitats and the food supply of shellfish eating birds.

Effects on habitats and non-targeted species

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.

Their general conclusion is that intuition about how fishing ought to affect benthic communities is generally supported, but that substantial gaps in the available data remain. They give high priority to the identification of habitats that show long recovery times (i.e. times exceeding 15 years) – the most likely candidates being habitats containing a high proportion of structural fauna. On the basis of the above we would predict a great initial effect of dredging on intertidal mussel beds. This prediction is supported by a comparison of fished and unfished young mussel beds in Lower Saxony (Herlyn *et al.*, 2000) – the only study known to me that deals with the impact of dredging on the mussel bed itself. The majority of the fished young beds disappeared one year after recruitment, whereas none of the unfished beds disappeared. Since most of the losses occurred after the fishery had taken place, the authors hypothesize that fishing damages the structure of the beds, making them less resistant to storms and ice rafting. Further support for this scenario is provided by the studies of Widdows and co-workers (in Earll 2001; Widdows *et al.*, 2001) and on the effects of current velocity on mussel bed stability and erosion. On both sand and cohesive mud fragmentation of mussel colonies makes them more susceptible to erosion at higher current velocities. Remarkably, fishermen in both the Netherlands and Germany claim exactly the opposite, namely that fishing has a positive effect on the stability of fished beds, but so far there is no supporting scientific evidence for this claim. A point of concern is that Herlyn *et al.* (2000) had to work with the fishing regime as it occurred. Future studies would benefit from carefully controlled experiments, where beds to be fished or left untouched are selected beforehand by the scientists.

Since intertidal mussel beds are a biogenic habitat dominated by structural fauna (i.e. the mussels themselves), we also predict a long recovery time on the basis of the review by Collie *et al.* (2000). I am not aware of studies that specifically set out to measure the recovery time of mussel beds that were fished away. There is a clear need for such studies.

Whereas the review of Collie *et al.* (2000) does not list a single study of mechanical dredging of mussels, it lists several studies of mechanical cockle harvesting. To this we can add the very recent study of Ferns *et al.* 2000) on a tractor-towed cockle harvester, which lasted 174 days. Noticeable decreases occurred in the most common non-targeted invertebrates and several species had not fully recovered by the end of the study period. In line with the conclusions of Collie *et al.* (2000), recovery took more time in the area with the more muddy sediment and a more structured community. Two "old" studies dealing specifically with the effects of suction dredging of cockles in the Dutch Wadden Sea are not included in the review of Collie *et al.* (2000), probably because these studies were not published in a scientific journal with a proper system of peer review. The first study was conducted in the years 1979 and 1980 by de Vlas (1982). Considerable mortality among non-target species occurred, and for several species a difference between fished and unfished areas remained after more than a year. Since de Vlas (1982) observed no clear effects on recruitment of shellfish and calculated that each year only 3% of the flats was affected, he more or less concluded that mechanised fishing for cockles was relatively harmless. However, as described above, the fishing power of the suction dredges used in the Wadden Sea improved considerably after his study period. In fact, suction dredging may have replaced mechanical emptying of the dredges after de Vlas finished his study. This may be one explanation why the results of the study of Piersma *et al.* (1997), which was initiated in 1988 and still continues, seem much more alarming. On the basis of their detailed long-term observations around the island of Griend, they suggest that suction dredging may not only harm non-target species, but also lead to fine sediments being washed away, not only during the fishing episode itself, but also during subsequent storms. The resulting sandy substrate will be less attractive for small bivalves to recruit. Such long-term changes would be quite dramatic, both from the point of view of the cockle fishery and from the point of view of nature conservation. Therefore, testing this hypothesis in a decisive manner is one of the core projects of the current EVA II research program, which must allow a proper evaluation in 2003 of the current Dutch shellfishing policy (Ens *et al.*, 2000). The hypothesis is controversial and for instance Duiker *et al.* (1998) conclude that there is insufficient scientific evidence. A major weakness in the study of Piersma *et al.* (1997) is that it refers to only one geographical location, but this has been remedied. According to Piersma *et al.* (2001a) historical information from other sites in the Dutch Wadden Sea supports their hypothesis that suction dredging has a long-lasting negative impact on bivalve recruitment.

Last, but not least, suction dredging may negatively affect important biogenic habitats like seagrass beds and mussel beds. This may happen directly, when the cockles are fished from areas with seagrass beds (de Jonge *et al.*, 1992; van Katwijk, 1993; Philippart, 1994) or mussel beds. It may also happen indirectly, when suction dredging alters the sediment in such a way that establishment of new seagrass beds or mussel beds is impaired. Peterson *et al.* (1987) studied the effects of intensive mechanised fishing for clams in shallow seagrass meadows. It took more than two years before the seagrass beds started to recover and recovery was not completed after 4 years when the study ended. The authors suggest that perhaps seagrass beds and sand flats exist as alternative stable states. Once the seagrass beds are removed, the sediments are more open to disturbance and it may be more difficult for the seagrass to become re-established. This could also apply to mussel beds. The severity of the problem will depend on the extent to which the habitat requirements of cockles, mussels and seagrass overlap. So far, only the habitat requirements of seagrass have been modelled quantitatively (Philippart, 1994), but work on mussel beds is in progress (Brinkman *et al.*, 1999). Still, static habitat descriptions must be treated with caution to answer our questions, because, as said, seagrass beds and mussel beds are biogenic structures that affect the habitat in which they occur.

Effects on the food supply of shellfish eating birds

In the Dutch Wadden Sea, several bird species feed on shellfish that are too small to be of direct interest to the fishermen. Shellfish fishery may affect these species through the effects on the habitats where they find their food. Only two species prey heavily on cockles and mussels of a size that are also of commercial interest: the oystercatcher and the eider duck. Both species breed in the Wadden Sea, but numbers are much higher during the non-breeding season when large numbers of birds breeding elsewhere join the local birds. Hence, the following discussion will focus on the non-breeding season.

For oystercatchers, we cannot analyse population size and mortality as a function of food supply, without considering the effect of winter severity. During severe winters the mudflats become covered with ice, so the oystercatchers cannot feed, while their energy demands are at a maximum due to the low temperatures. Some birds leave the Wadden Sea, while others stay behind attempting to survive on the basis of their fat reserves. Both options are risky and mortality during severe winters may exceed 25%, which is very high for a long-lived species like the oystercatcher. Fig. 4a shows that many oystercatchers are found dead on the beach during severe winters. However, when winter severity is accounted for, there is clear evidence that mortality is also increased in years with a low food supply (Camphuysen *et al.*, 1996; Zwarts *et al.*, 1996). Especially young birds suffer from food shortages (Nève *et al.*, 1997). Thus, both winter severity and food stocks will determine the long-term equilibrium population size of oystercatchers (Goss-Custard, 1996). Shellfish fisheries could have a considerable impact on that part of the shellfish stock that is harvestable for the oystercatchers. Shellfish have a much shorter life span than oystercatchers and the stocks of shellfish are much more variable than the bird populations. It is therefore not surprising that model calculations indicate that the long-term population size of the oystercatchers is primarily determined by the occasional years with a very low food stock and not by the average size of the food stock (Goss-Custard, 1996). Unlimited fishing for shellfish during years with a low stock, as occurred in the winter of 1990/1991 (Beukema *et al.*, 1996), is bound to have a negative effect on the oystercatcher population size. Indeed, since 1990 the number of oystercatchers wintering in the Dutch Wadden Sea appears to be declining (Fig. 4b). To see the trend we must take into account that counts in January preceded by a frost period result in lower numbers because many oystercatchers leave the Wadden Sea during frost periods. The graph is also corrected for the incompleteness of the counts by systematically excluding sites that were often missed during counting. Thus, the number depicted is a minimum.

Two independent estimates lead to the conclusion that in the 1980's circa two thirds of the food needs of the oystercatchers were covered by mussels (Smit *et al.*, 1998). Thus, the disappearance of the intertidal mussel beds from the Dutch Wadden Sea and their slow recovery is a likely explanation for the ongoing decline in oystercatcher numbers. At present, no good data (measurements or reconstructions) are available documenting the decline of the intertidal mussel beds on a yearly basis. This makes it difficult to investigate via multivariate analysis the relative contribution of intertidal mussel stocks, intertidal cockle stocks, cockle fishery, mussel fishery and winter severity to changes in the number of oystercatchers. The alternative approach is to ask what size of intertidal food supply is needed to sustain the oystercatcher numbers present in the Dutch Wadden Sea in the 1980's. This question can be answered on the basis of the extensive literature on the feeding ecology of the oystercatcher. Drawing on this literature, Ens (2000) calculates that at least between 50 and 100 million kg (fresh weight) of mussels should be present on the intertidal flats. To date, the stocks of littoral mussels have not recovered to the levels that were present in the Dutch Wadden Sea in the 1980's. The most recent published estimate amounts to less than 20 million kg fresh weight for the winter of 1999/2000 (Smaal *et al.*, 2001b). If this situation persists, we may expect further declines in the oystercatcher population. However, in the summer of 2001 a massive spatfall of mussels occurred on the intertidal flats of the eastern part of the Dutch Wadden Sea.

Similar calculations are much more difficult for the eider duck. For oystercatchers we know that between 25 and 50% of the intertidal shellfish stocks can be harvested by the birds in the course of one winter (Goss-Custard, 1996). Such information is lacking for eider ducks. However, in contrast to oystercatchers, eider ducks do not suffer high mortality during severe winters: there is no correlation between winter severity and mortality (Fig. 5a). As a result high mortality of eider ducks also does not correlate with high mortality of oystercatchers (Spearman $r=0.11$, $P=0.60$, $N=23$). This difference with oystercatchers can be explained by the fact that the subtidal areas where the ducks obtain a lot of their food take much longer to freeze than the intertidal flats on which the oystercatchers depend. Eider ducks are also much bigger birds than oystercatchers, so they experience less heat loss during cold weather. Fig. 5a shows that the first time that high mortality of eiders occurred in the Netherlands was in the winter of 1990/1991 when shellfish stocks were already low and shellfish fishery was nonetheless continued (Beukema *et al.*, 1996). Since that time large numbers of eider ducks are counted in the North Sea Coastal Zone, where very few were counted before (Fig. 5b). One possible explanation is that since the winter of 1990/1991 the stocks of mussels on the subtidal culture plots are structurally reduced (Fig. 1b). Subtidal mussels have thinner shells than mussels from the intertidal, so subtidal mussels are almost certainly the most profitable food for the eider duck (Nehls, 1995). Within the Dutch Wadden Sea, eider ducks have tended to be most common in the western part (Camphuysen, 1996), where the subtidal culture plots of mussels occur. In the North Sea Coastal Zone, the eider ducks dive for *Spisula subtruncata*. These North Sea eiders experienced a dramatic food shortage during the winter of 1999/2000 as there were very few *Spisula* and the few *Spisula* present were small (Smaal *et al.*, 2001b)and very likely unprofitable (Leopold *et al.*, 2001). According to (Camphuysen *et al.*, 2001) this may explain the very high mortality that occurred in the winter of 1999/2000 (Fig. 5a). The very recent fishery on *Spisula* certainly contributed to the low stocks, but in the absence of published figures on the catch, the magnitude of the contribution remains unknown. Presented in this way, the case seems clear: structural food shortage in the Wadden Sea since 1990/1991 caused the eider ducks to move to the North Sea Coastal Zone, where they were hit by another food shortage in the winter of 1999/2000 (Camphuysen *et al.*, 2001; Piersma *et al.*, 2001b). Two objections have been raised against this explanation. First, many eiders found dead were full of parasites, so it is suggested that a parasite outbreak caused the massive mortality in 1999/2000 (Borgsteede, 2001). Second, stocks of cockles in the Wadden Sea were rather high in the winter of 1999/2000 (Smaal *et al.*, 2001b) and cockles are an important food item for the eider duck. This brings us back to the start of our discussion on eider ducks: we simply do not know which part of the cockles was actually available to the eider ducks. Most cockles were old, which means that they were large and that the ratio of flesh to shell was unprofitable. Furthermore, the cockles occurred primarily in the intertidal, which means that the potential feeding time of the ducks was restricted to the stages of the tidal cycle where the flats were covered with a thin layer of water. There is a clear need for more studies on the feeding ecology of the eider duck, to determine which prey are available.

Conclusions

According to several authors, the conflict between shellfish fishermen and conservationists in the Dutch Wadden Sea started around 1990 due to shellfish stocks being especially low as a result of a series of years with failing recruitment (Keus, 1994; Steins, 1999; Verbeeten, 1999). While it is true that recruitment was poor for a number of years, it should be realised that variable recruitment is a basic aspect of the life history of both cockles and mussels (Beukema *et al.*, 1993). To invoke recruitment failure it is therefore needed to demonstrate that the period of recruitment failure was abnormally prolonged. To my knowledge, this analysis has not been performed to date. The alternative explanation is that the conflict occurred because continuing mechanisation of the fishing fleet during the previous decades had led to such a high fishing power that the associated exploitation rate of the shellfish had reached unsustainable levels, in both the narrow and the broad sense. This alternative explanation receives support from evidence that mechanisation and other technological improvements considerably increased the fishing power of the ships. In addition, shellfish fishery in the Dutch Wadden Sea was *de facto* open access until 1990 and an open access regime may easily lead to overexploitation.

New regulations have been put into place since then, but it is too early to tell if these regulations suffice to prevent overexploitation of the shellfish stocks. When the current regulations are compared to the design principles of self-governing institutions of long-enduring fisheries (and other common pool resources), they score positively on many, but not all, accounts. The most important unanswered question is whether current appropriation and provisioning rules are sufficiently in line with the local conditions (design principle 2 of Ostrom), i.e. can current harvesting rules (like the TAC of 65 million kg seed mussels) be considered ecologically sustainable for the Dutch Wadden Sea ecosystem? This question can only be answered through scientific investigations. This seems trivial, but it is not. In the old times, a community of fishermen could learn through trial and error how to exploit the shellfish, while surviving through periods of hardship. Nowadays, technological developments are so fast and the potential impact of sophisticated technologies is so high that learning through trial and error is not a good option. The risks are too high and it takes too much time. Instead, learning should be through properly devised scientific studies, preferably in close co-operation with the fishermen. From this, three recommendations follow:

1. The effect of new fishing gear or fishing practices on the ecosystem should be studied before the new gear or practices are introduced on a large scale, instead of afterwards.
2. Good monitoring programs must be put in place to study whether fishing practices are ecologically sustainable. The accuracy and reliability of a scientific evaluation increases with the accuracy and reliability of the available data. Lack of good annual data on the abundance of intertidal mussel beds, sublittoral wild mussel stocks and mussel stocks on the culture plots before 1990, makes it difficult to determine what exactly happened in the years preceding the low shellfish stocks. When the Dutch

government gave permission for large-scale mussel culture in the Wadden Sea, they should also have implemented a monitoring program of the previously mentioned parameters. Similar arguments apply to mechanised fishing for cockles.

3. It should be recognised that closed areas are an important tool to study the long-term effects of fishery on the ecosystem. Since 1993 26% of the intertidal flats of the Dutch Wadden Sea are permanently closed for fishery, but the primary objective of this closure is to restore important habitats like mussel beds and seagrass beds.

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Tables

Table 1: The distribution of the most common types of fisheries over the different parts of the international Wadden Sea according to the most recent Quality Status Report (de Jong *et al.*, 1999). Per region the number of ships (or licenses) is given for each of the major fisheries.

	Netherlands	*Lower Saxony*	*Schleswig-Holstein*	*Denmark*
surface (km2)	2500	2100	2500	850
Mussel ships/licenses	85	4	8	5
Cockle ships/licenses	22[1]	1	0	1
Spisula ships/licenses	8	0	6	1
Shrimp & Flatfish ships/licenses	90	107	121	27

[1]According to J. Holstein (pers. comm.) there are 37 licenses for mechanical cockle fishing in the Netherlands

Table 2: Assessment of the extent to which present-day (anno 2000) mussel seed fishery and cockle fishery in the Dutch Wadden Sea comply with the design principles listed by Ostrom (1990) as indicative of long enduring, self-governing CPR-institutions (CPR = Common Pool Resource). Not listed is design principle 8, as it deals with the nesting of large and complex CPR's. It should be noted that long enduring *sensu* Ostrom must be equated to sustainability in the narrow sense. Information to fill the table is drawn from: (Keus, 1994; Steins, 1999; Verbeeten, 1999).

	Design principle	*Mussel seed fishery*	*Cockle fishery*
1	Clear boundaries to the resource and clear memberships of the users.	YES. Mussel seed may be fished from the Dutch Wadden Sea, excluding areas permanently closed for fishery. Only license holders may fish: licenses of 87 bottom growers are individually transferable; 7 firms active in off bottom culture hold a joint license.	YES. Cockles may be fished from the Dutch Wadden Sea and the Dutch Delta area, excluding areas permanently closed for fishery. Only license holders may fish: 37 licenses for mechanised cockle fishing are individually transferable, in contrast to a larger number of licenses for fishermen gathering cockles by hand.
2	Congruence between appropriation and provision rules and local conditions. In former times this encapsulated the accumulated knowledge obtained through trial and error by the local community on the natural variability in the resource and how best to deal with it.	NOT CLEAR. The annual target production is set by the sector at 100 million kg fresh weight of mussels and it is posited that this requires 65 million kg fresh weight of mussel seed on an annual basis. This Total Allowable Catch (TAC) of 65 million kg is divided among the license holders. It is a maximum value, because fishing is restricted in years with poor stocks to reserve food for birds. No scientific data exist to prove that the current level of seed fishery can	NOT CLEAR. In years with low stocks fishing is restricted to reserve food for birds. In such years ca. 6% of the quotum is allocated to the hand gatherers. In years with high stocks the TAC is 10 million kg cockle flesh from the Wadden Sea (12 million kg cockle flesh for the Netherlands as a whole). No scientific data exist to prove that the current level of mechanised cockle fishing can be sustained in the long run by the Wadden Sea ecosystem.

		be sustained in the long run by the Wadden Sea ecosystem	
3	Collective choice arenas, i.e. most users can participate in modifying the rules.	YES. Most users are members of the Producers Organisation of Mussel culture (PO Mussels), which is currently in charge of the 5-year management plan and the annual fishing plans. Meetings of the members must approve changes in regulations.	YES. Most users are members of the Producers Organisation of Cockles (PO Cockles), which is currently in charge of the 5-year management plan and the annual fishing plans. Meetings of the members must approve changes in regulations.
4	Good monitoring of the resource and the amount taken by each user.	YES. The fisheries institute RIVO monitors the stocks of seed mussels in spring and autumn. During the fishing season each fisherman is obliged to pass an inspection ship to have his catch measured, before he can sow the mussels on his culture lot. Each ship is equipped with a black box, which monitors all fishing activity. Some poaching occurs.	YES. The fisheries institute RIVO monitors the cockle stock in spring and uses an extrapolation procedure to gauge the cockle stock in autumn. The Commodity Board for Fish and Fish Products registers all landings. Each ship is equipped with a black box, which monitors all fishing activity. Officers from the ministry of LNV inspect at random whether hand gatherers stick to their designated areas. Some poaching occurs.
5	Graduated sanctions against offenders, e.g. when fishermen taking more than their share are caught for the first time, they are punished only lightly, whereas repeated offenders receive severe punishment.	YES. Originally, the regional fisheries organisation Zevibel was in charge of the fishing plan. However, offenders refused to pay the fines and Zevibel did not cash them. Responsibility for the fishing plan has been transferred to the PO-mussels, which has more	YES. In 1995 the responsibility for the fishing plan was transferred from Zevibel to the PO-cockles, which has more powers to impose fines. Each breach of the rules has a specific fine and the height of this fine increases with the number of times the rule

		powers to impose fines. Each breach of the rules has a specific fine and the height of this fine increases with the number of times the rule has been breached by the specific offender.	has been breached by the specific offender. The hand gatherers organised in Cardium oversee themselves and explicitly specify graduated sanctions: second time offense leads to a doubling of the fine and third time offenders are temporarily excluded from the fishing plan.
6	Conflict resolution mechanisms, as conflicts are bound to occur among users as well as between users and officials monitoring the resource and enforcing the rules.	YES. According to European law the PO-mussels is the competent organisation to take measures to ensure the proper management of catch quotas. Two off-bottom growers lost their claim for a bigger share of the quotum in court.	YES. According to European law the PO-cockles is the competent organisation to take measures to ensure the proper management of catch quotas. Disputes with the government or conservation organisations are settled in court.
7	Recognised rights to organise, i.e. local fishermen are allowed to design their own institutions.	YES AND NO. Growers are organised in local fishery organisations and in the regional fisheries organisation Zevibel. However, the PO-mussels is nowadays in charge of the quota and this organisation is designed according to European law. The official Dutch policy is co-management.	YES AND NO. Fishermen are organised in local, regional and national fishery organisations. However, the PO-cockles is nowadays in charge of the quota and this organisation is designed according to European law. The official Dutch policy is co-management.

Table 3: Average annual landings of consumption-sized mussels (in million kg fresh weight with SD in brackets) from the Wadden Sea and Zeeland for two different periods. For each area the means are compared with the Student t-test. In case of Zeeland the Levene's test for equality of variances indicated unequal variances, so this was taken into account.

	1971-1991	1991-2001	t-value	df	P(2-tailed)
Wadden Sea	67.3(25.2)	36.6(14.7)	3.54	28	0.001
Zeeland	33.9(5.6)	41.6(10.1)	-2.23	11.9	0.046

Figures

Figure 1: (a) Annual landings of marketable mussels at the mussel auction in Yerseke. Landings are classified according to the area of origin. Data from Productschap Vis and previously published in a.o. Smaal *et al.* (2000a). The season 1999/2000 is indicated as 1999. (b) Stocks of mussels (million kg fresh weight) on the culture plots in the Dutch Wadden Sea according to Van Stralen in Smit (1994) and Smaal *et al.* (2000b). The season 1999/2000 is indicated as 1999.

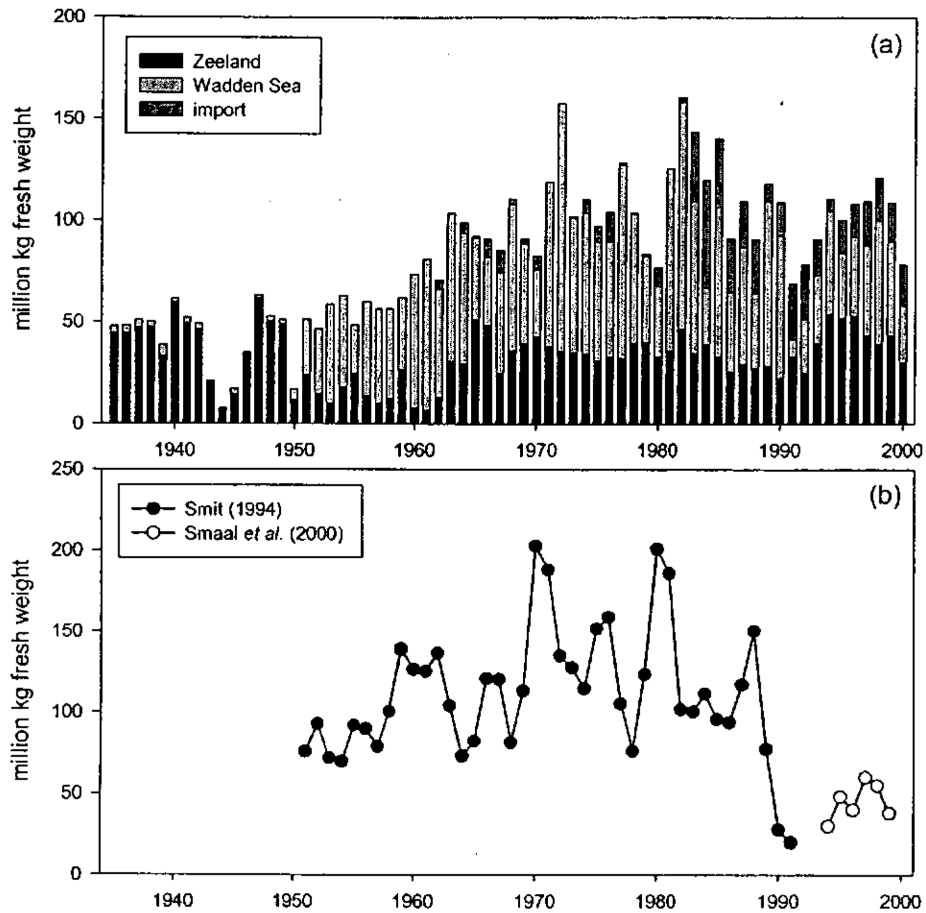
Figure 2: Landings of cockles (million kg fresh weight) in the Netherlands for the period 1949-1991 Dijkema (1997) and the period 1984-1999 (Productschap Vis, 2000).

Figure 3: (a) Total number of fishing days of the mechanical cockle dredges fishing for cockles in the Wadden Sea and Oosterschelde (J. Holstein pers. comm.). (b) Daily capture of cockles (ton fresh per boat per day - calculated from the landings of cockles divided by the total number of fishing days) compared to the total stock in the Wadden Sea and Oosterschelde. The estimates for the total stock are taken from Bult *et al.* (2000) who only give data for the Oosterschelde from 1980 onwards.

Figure 4: (a) Mean number of oystercatchers found dead on the beach (number of dead birds per km beach) during the Beached Bird Surveys. Also plotted the IJnsen index of winter severity (IJnsen, 1988). There is a strong correlation between winter severity and oystercatcher mortality (Spearman $r=0.79$, $N=23$, $P<0.001$). Data Kees Camphuysen (pers. comm.). The winter of 1999/2000 is indicated as 1999. (b) Minimum number of oystercatchers counted in the Dutch Wadden Sea during winter, i.e. excluding counting sites that were counted infrequently. Open circles indicate counts in January and filled circles indicate counts in the preceding autumn. Triangles indicate January counts where a frost period probably triggered a mass exodus of oystercatchers from the Wadden Sea. Such counts are not included in the three-year moving average indicated with the line. Taken from Smit *et al.* (2000). The winter of 1999/2000 is indicated as 1999.

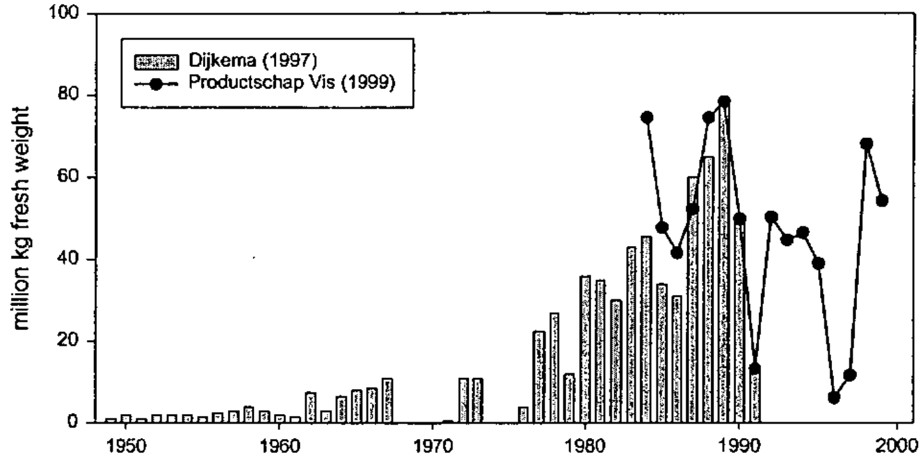
Figure 5: (a) Winter mortality of eider ducks in the Dutch Wadden Sea estimated from dead birds recovered on the shore and expressed as dead eiders per km beach. Oiled birds were excluded. For comparison the IJnsen winter severity index is also indicated (IJnsen, 1988). There is no correlation between winter severity and eider mortality (Spearman $r=-0.06$, $P=0.78$, $N=23$). From Camphuysen *et al.* (2001). (b) Number of eider ducks in the Dutch Wadden Sea (black bars) and the adjoining North Sea Coastal Zone (grey bars) for winters where counts were available. Based on counts from airplanes, ships and from the ground and assembled by M.F. Leopold (previously published in Ens (2000) and Camphuysen *et al.* (2001)). The counts before 1965 are not very reliable. The winter of 1999/2000 is indicated as 1999. In 1991 only the North Sea was counted.

Figure 1



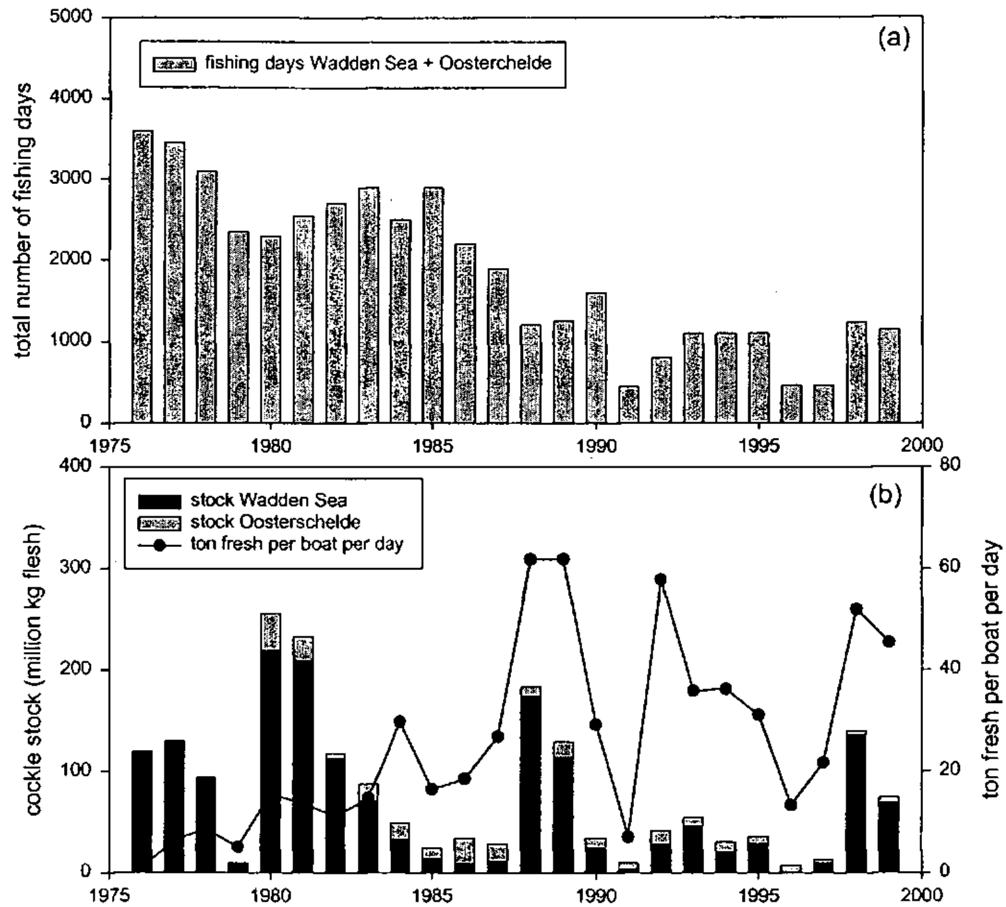
million kg fresh weight
Zeeland
Wadden Sea
import
(a)
0
50
100
150
200
1940
1950
1960
1970
1980
1990
2000
million kg fresh weight
Smit (1994)
Smaal et al. (2000)
(b)
0
50
100
150
200
250

Figure 2



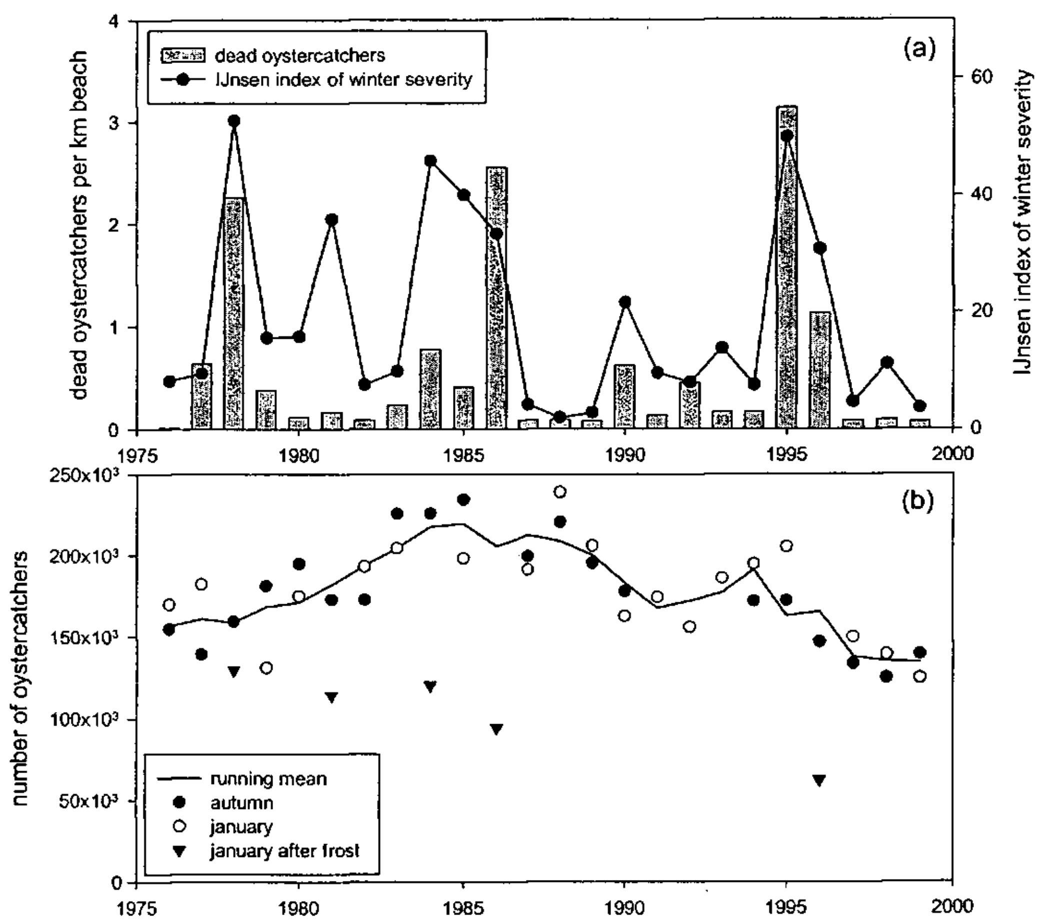
100
80
60
40
20
0
million kg fresh weight
Dijkema (1997)
Productschap Vis (1999)
1950
1960
1970
1980
1990
2000

Figure 3



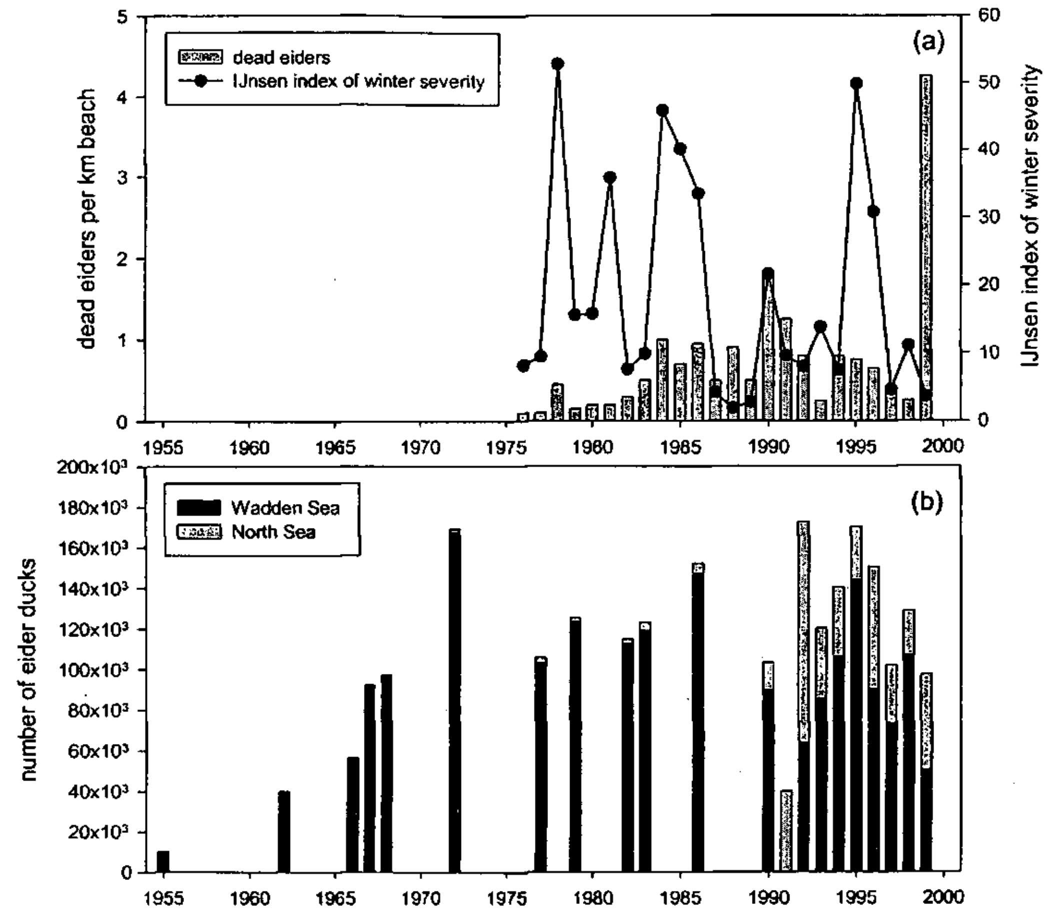
(a)
fishing days Wadden Sea + Oosterchelde
total number of fishing days
0
1000
2000
3000
4000
5000
1975
1980
1985
1990
1995
2000
(b)
stock Wadden Sea
stock Oosterschelde
ton fresh per boat per day
cockle stock (million kg flesh)
ton fresh per boat per day
0
100
200
300
400
0
20
40
60
80

Figure 4



dead oystercatchers
IJnsen index of winter severity
(a)
dead oystercatchers per km beach
IJnsen index of winter severity
0
1
2
3
4
0
20
40
60
1975
1980
1985
1990
1995
2000
(b)
running mean
autumn
january
january after frost
number of oystercatchers
0
50x10³
100x10³
150x10³
200x10³
250x10³

Figure 5



(a)
dead eiders
IJnsen index of winter severity
dead eiders per km beach
IJnsen index of winter severity
0
1
2
3
4
5
0
10
20
30
40
50
60
(b)
Wadden Sea
North Sea
number of eider ducks
0
20x10³
40x10³
60x10³
80x10³
100x10³
120x10³
140x10³
160x10³
180x10³
200x10³
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000