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).](image)

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.

<table>
<thead>
<tr>
<th>Year</th>
<th>Surface touched by cockle dredge</th>
<th>Area disturbed by cockle fishery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lit (%)</td>
<td>lit (ha)</td>
</tr>
<tr>
<td>1992</td>
<td>4.6</td>
<td>523</td>
</tr>
<tr>
<td>1993</td>
<td>2.1</td>
<td>236</td>
</tr>
<tr>
<td>1994</td>
<td>11.8</td>
<td>1346</td>
</tr>
<tr>
<td>1995</td>
<td>4.3</td>
<td>483</td>
</tr>
<tr>
<td>1996</td>
<td>9.1</td>
<td>1040</td>
</tr>
<tr>
<td>2001</td>
<td>7.0</td>
<td>795</td>
</tr>
<tr>
<td>average</td>
<td>6.5</td>
<td>0.2</td>
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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).
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 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).
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 an 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)
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., 2000).
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.