Is Food Shortage the Cause of Eider Duck Mortality?

Shellfish and Crab Abundance in the Dutch Wadden Sea 1994 - 1999

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Introduction

Increased Eider duck (*Somateria mollissima*) mortality in winter 1999/2000 raised questions about food abundance and availability. Eiders found dead showed clear signs of starvation and it was hypothesized that there was a lack of available food (Camphuysen, 2000). Other potential causes, such as diseases or pollution, have also been considered (van den Berk et al., 2000). Some authors have presented parasite infestation as a possible cause of mortality (Borgsteede, this volume).

The dynamics of important prey abundances over a period of 6 years are presented in this paper and are based on annual surveys conducted over the entire Wadden Sea and near shore coast. The dominant prey species are mussels (*Mytilus edulis*), cockles (*Cerastoderma edule*), trough shells (*Spisula subtruncata*) and shore crabs (*Carcinus meanus*) (Leopold et al., 2000). This paper addresses the question as to whether the abundance and quality of prey species showed abnormalities in 1999/2000 and to what extent this could be considered a possible explanation for increased Eider duck mortality. As no extensive information is available on food preferences of starving Eider ducks (Leopold et al., 2000), data on the total amount of shellfish and additional data of year or size class and quality, are presented here as an indication of the amount of prey available.

Materials and Methods

In the framework of an analysis of Eider duck mortality causes, shellfish and crab data from the Wadden Sea and near shore coast were worked out for the period 1994 -1999.

Mussels

Data on mussel stocks were derived from annual surveys of wild sublitoral and litoral mussel beds, and from market delivery data of consumption-sized mussels. Sublitoral mussel surveys are carried out in March on a quantitative basis in the framework of mussel seed inventory. In Septem-

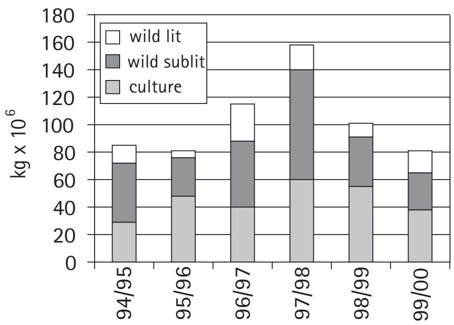

Figure 1: Standing stock of mussels 1994 – 1999: wild sublitoral stocks, estimated stocks on culture plots and wild litoral stocks.

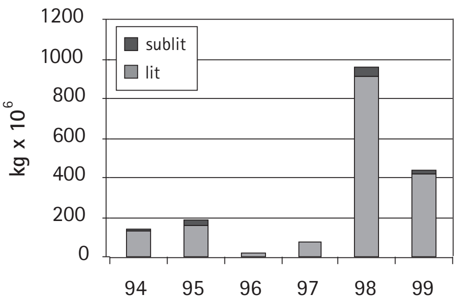

Figure 2: Standing stock of cockles 1994 – 1999 in litoral and sublitoral Wadden Sea areas.

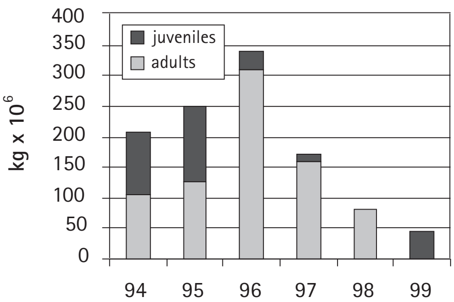

Figure 3: Standing stock of juvenile and adult Spisula 1994 – 1999 in sublitoral off-shore beds, including the North Holland coast.

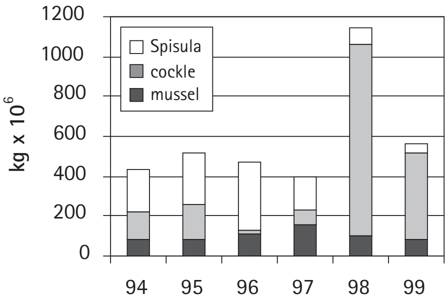

Figure 4: Total shellfish standing stock 1994 – 1999 in the Wadden Sea area.

ber, a qualitative check for mussel seed is carried out. Sampling is done from a commercial vessel using a suction dredge with a sampling width of 20 cm, and a mesh width of 5x5 mm, to a sediment depth of 10 cm, a distance of 100 m. The sampling surface is 20 m^2. Samples are sieved onboard over a 5x5 mm mesh, then sorted by size and finally, their fresh weight is determined. The surveys in the subtidal areas are restricted to the western part of the Dutch Wadden Sea as no subtidal mussel stocks of any importance occur in the eastern part. Litoral mussel stocks are surveyed along with the annual cockle survey in April-May on all tidal flats in the Dutch Wadden Sea. Dispersed stocks are sampled as part of the cockle survey, while mussel beds are quantified on the basis of aerial photography, followed by work carried out on the ground. Data concerning the stock of mussels on culture plots are calculated on the basis of both market delivery and mussel seed fishery data. As limited information is available on the activities of mussel farmers who transplant their stocks, standard conversion factors were used for growth from seed to half-grown mussels to consumption mussels. As these conversion factors may differ in time, the presented estimates of the stock of mussels on plots should be interpreted with care. All mussels are traded through an auction, where data are collected on the total deliveries, size range, flesh content, amount of barnacles on the shells and other tarra; hence, an extensive database is now available on consumption mussels.

Cockles

Annual surveys of cockle stocks are carried out in April-May at approximately 1,500 stations in the intertidal and shallow subtidal zones of the Wadden Sea. A stratified survey design is applied, which is based on information from fishermen on the occurrence of cockle beds. Data from sampling stations are multiplied with the surface corresponding to the stratum of that station. Cockles, together with mussels, *Macoma balthica* and other bivalves, are sampled with a special device, which collects 0.1 m^2 of sediment to a depth of 10 cm, then sieves it over a 5x5 mm mesh, and finally, the fresh weight is measured per year class. A new sampling device has been used since 1998 that collects samples of 0.4 m^2. Extrapolation of standing stock data from spring to September is based on conversion factors for growth and mortality per year class. For conversion from total fresh to flesh weight, a flesh weight of 15% is assumed. Additional data on the flesh content were derived from routine measurements of harvested cockles in the final fishing period at the end of November.

Spisula

Surveys of *Spisula* have been conducted in May-June in the coastal zone since 1995. The islands in the Wadden Sea's offshore, ca 300 stations, are sampled on a grid system with various density strata, using sampling equipment that dredges over 150 m to a sediment depth of 7 cm and a width of 10 cm, i.e. the sample surface is 15 m^2. The mesh width is 5 mm. Samples including Spisula and other benthos are sorted per year class and fresh weight is then determined. The standing stock is calculated according to the surface belonging to the various sampling strata. Results of the surveys from the following spring season are used to determine the autumn data.

Shellfish quality

Data on shellfish quality are only available for harvested mussels and cockles. Meat yields and average sizes are available from landing statistics for cockles, while for mussels, information is also available on the presence of barnacles and other tarra.

Crabs

Annual demersal fish surveys have been carried out in September-October along the North Sea coast since 1970. Beam trawls are 3 m wide, sampling period is 15 min. and on average 200 stations are sampled in the Dutch Wadden Sea and offshore of the islands. Fishing is done at different depths and samples are clustered in 3 depth strata. The mesh size is 20 mm (Boddeke, 1970) and samples are sorted onboard. Data on *Carcinus maenas* and *Liocarcinus holsatus* have been used for the purpose of this study. The data are expressed per m^2 as the method does not allow extrapolation to total area, hence no standing stock data are available.

Results

Standing stocks

The total standing stock of mussels consists of sublitoral mussels in wild beds and on culture plots, predominantly located in the western Wadden Sea, and littoral mussel stocks in the eastern Wadden Sea. In autumn 1999, a stock of $38*10^6$ kg fresh weight of mussels on culture plots, $27x10^6$ kg wild sublitoral mussels and $16x10^6$kg littoral mussels was observed. The total amount was similar to the 1994 and 1995 figures, but below the average of $103x10^6$kg over the study period (Fig. 1).

In autumn 1999, the stock of cockles (Fig. 2) was relatively high at $434x10^6$kg. Almost all cockles are littoral and distributed on tidal flats along the whole

Wadden Sea. The highest densities are found in the east.

The Spisula stock (Fig. 3) that extends along the North-Holland coast has shown a decrease over time, and in autumn 1999 it consisted almost completely of juveniles. These are considered to be 'uninteresting' to Eider ducks. Spisula stocks offshore from the islands also showed low values in 1995 and stocks along the North-Holland were dominant between 1994-1996.

These results show that in autumn 1999, the total stock of shellfish (Fig. 4) had relatively high values, in comparison with the previous period and that cockles were the dominant species.

Fig. 5a shows the average densities of crabs in the Wadden Sea and the offshore area over time. The shore crab's highest densities were in 1999. This was especially the case in the western Wadden Sea and the adjacent part of the North Sea (Fig. 5b). This figure also shows that the distribution of crabs over the depth strata followed a similar pattern throughout the study period.

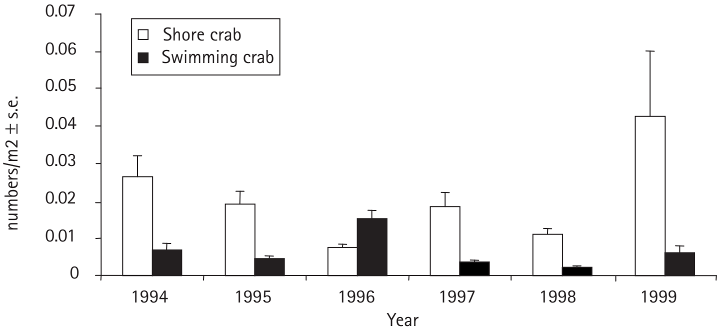

Figure 5a: Densities of shore crabs and swimming crabs 1994 - 1999 as sampled during demersal fish surveys at ca 200 stations in the Wadden Sea area.

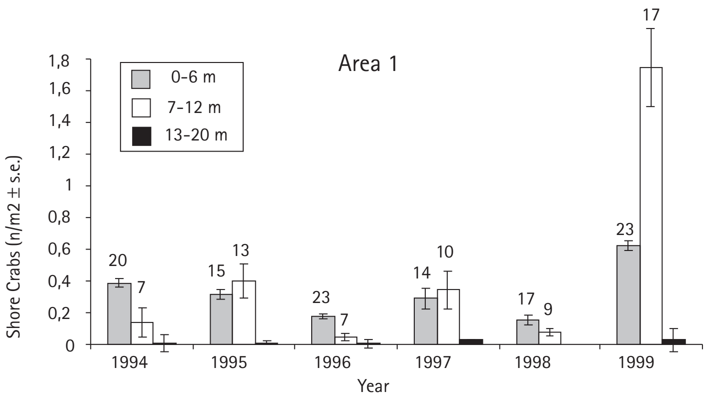

Figure 5b: Densities of shore crabs at stations in different depth strata in the western Wadden Sea in the period 1994 - 1999, with number of stations per stratum.

Shellfish quality

The flesh content of mussels harvested in autumn 1999 from the main production area was 28%. This is close to the average value of 29% over the period 1994-1999. In 1994 and 1995, higher values of flesh content were recorded. Market deliveries from the most westerly area, which is predominantly used for the culture of juvenile mussels, showed a flesh content of 22% in 1999. This value was lower than in previous years. In 1999, mussels from both areas had a higher than average fresh weight (including the shell) of about 20 gram per mussel. Fouling with barnacles on mussels harvested in autumn 1999 amounted to 35 - 45 grams per 2,5 kg of mussels in comparison with values of 3-33 grams that were recorded in previous years.

The flesh content of cockles was approximately 15% by the end of November 1999, and this showed no significant difference when compared to other years. These data show that there was no abnormality in the quality of the cockles. For the mussels on the other hand, there are indications of relatively high barnacle fouling and lower flesh content in the most westerly area.

Discussion

The total shellfish stock did not show abnormally low values in autumn 1999, and the stock was dominated by cockles. In conjunction with their large abundance, the distribution of cockles was not restricted to specific areas of the tidal flats. Densities were in fact higher in the eastern Wadden Sea (Smaal et al., 2000). There was no difference in the quality of the cockles compared to other years. The dominant year class was 3-year-old cockles from the 1997 cohort but there is no evidence that this is a possible limitation for Eider ducks (Leopold et al., 2000). It is therefore concluded as unlikely that the cockle stock in 1999 proved to be a limited food resource for the Eider ducks in comparison to previous years.

The largest mussel stocks are found in the western Wadden Sea. Wild sublitoral beds and culture plots for seed mussels are dominant in the most westerly part, while the area near the island of Terschelling is most important for the culture of consumption mussels. The total amount of harvested mussels from the Wadden Sea in 1999/2000 was $45x10^6$ kg. This is a higher value than between 1995/96 -1997/98, similar to 1994/95 and lower than in 1998/99 (Smaal et al., 2000), and it shows that there are no abnormalities in both total stock and harvest. Not all mussels are harvested, as the culture cycle is two years. The amount left over during wintertime can be estimated on the basis of the harvest of the following season. Until December 2000, a total amount of $27x10^6$ kg was registered at the auction as harvest from the Wadden Sea. These data show that this amount of mussels has survived the 1999/2000 winter, thereby we can assume that growth has compensated for mortality loss. The flesh content of mussels harvested from the western area was lower than before and there were more barnacles on the shells. The question therefore, is whether the quality of the mussels may have limited their availability as prey for the Eider ducks. The flesh content of 22% may be lower than before, but it is higher than in natural mussel stocks. The larger amount of barnacles can be considered a limiting factor, as shown by Swennen (1976). However, it should be considered that the average value of 1.6% can be based on one market delivery with relatively high values of barnacle fouling and other deliveries with lower values or no fouling at all. In addition, an average amount of 0.3 grams of barnacle per mussel can be considered as low and it has been observed that Eider ducks are able to consume mussels with limited barnacle fouling (G. Nehls, pers. comm.). It can therefore be concluded that the mussel stock has shown no dramatic abnormalities during the winter of 1999/2000. The Spisula stock consisted of juveniles, which are not considered to be suitable prey for Eider ducks (Leopold et al., 2000). There is an abnormality for the Spisula stock in autumn 1999. Low Spisula stocks offshore from the islands have been observed between 1994-1996, but prey was available along the North Holland coast during this period. Eider ducks were regularly observed offshore from the Wadden Sea islands, in 1999/2000 (Berrevoets et al., 2000). Owing to their small size, however, it seems likely that Spisula stocks could not serve as a primary food resource for the Eider ducks in 1999/2000. The total stock of shellfish was high in 1998 and 1999, and dominated by cockles. As there is limited information on food preferences of Eider ducks, it can only be concluded that our data do not show clear signs of limited shellfish stocks in 1999/2000 in comparison to previous years.

For the shore crab, the data clearly show high values in autumn 1999. This species is considered as prey for the Eider ducks, particularly juvenile ducks that prefer prey with a relatively weak shell or cuirass. Crabs also host the parasite *Profilicollis botulus*. High crab abundance in autumn may induce extensive parasite infestation of Eider ducks evolving into an epidemic and subsequent mass mortality (Borgsteede, this volume).

Conclusions

As no dramatic abnormalities in shellfish abundance and quality could be found in autumn 1999, food shortage is not the most likely cause of the increased Eider duck mortality episode in 1999/2000. An alternative explanation for the mass mortality may be found in the abnormal crab abundance and subsequent high risk of parasite infestation.

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Food Selection by Eiders – Why Quality Matters

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Introduction

Eider ducks are bivalve specialists. They feed on a variety of bivalve species, ranging in size from a few millimeters up to several centimeters. They are captured by head dipping or diving up to depths of over 30 meters. Eiders are able to feed on buried bivalves such as cockles or baltic tellins, which may be dug out of the sediment with the bill, even when the birds are diving. The shallow waters of the Wadden Sea with their productive benthic communities dominated by bivalves therefore seems to be an ideal habitat for eiders. In the Wadden Sea, the main food of eiders are mussels and cockles, two widely distributed species, which contribute a high share to the total macrozoobenthic biomass. Eiders are the most important avian predators in the Wadden Sea, however, their consumption is low in relation to the annual production of mussels and cockles. On average, only 10% is taken by eiders each year. It therefore appears that the Wadden Sea is a suitable habitat, with a rich food supply for eiders. Food limitation or competition with other species or fisheries seems to be unlikely, so how can eiders suffer from food shortage?

A special habit of eider ducks is to swallow mussels and cockles whole and crush the shells in their stomach, where they are then ground into small fragments. Eiders have a large and very strong stomach, which enables the birds to exploit a wide size range of molluscs. However, it is obvious, that such a feeding habit is expends much energy. The ducks have to crush the shells, then heat the mussel flesh and the water locked between the valves to body temperature and finally, excrete the salt from the mussel flesh and water. As part of the ecosystem research project, I studied food selection and the costs and benefits for eiders feeding on mussels (Nehls 1995). The results show that mussel quality is of high importance when eiders decide where and what to feed on and they indicate, that only a part of the mollusc stock within the Wadden Sea may be suitable for eiders.

Food Selection

Eiders prefer certain sizes of mussels and cockles. Size selection in eiders feeding on mussels was studied over four years in Königshafen, Sylt. Eiders much preferred certain size classes out of a wide range of mussel sizes found on the mussel beds (Fig. 1).

Mussel sizes consumed by eiders changed in the course of the year. In winter, eiders took a wide size range of mussels, with median sizes between 40 and 50 mm. Mussels larger than 60 mm were rarely taken. In late spring, a sharp drop occurred in the size of mussels consumed. In May, the smallest mussels were taken and eiders focussed on a rather narrow range of mussel sizes. In the course of the summer, eiders took increasingly larger mussels and a wider size range was selected. The seasonal pattern in size selection was consistent throughout the period of the study. Although eiders are able to consume mussels up to 80 mm in size, 80% of the mussels consumed in Königshafen were between 30 and

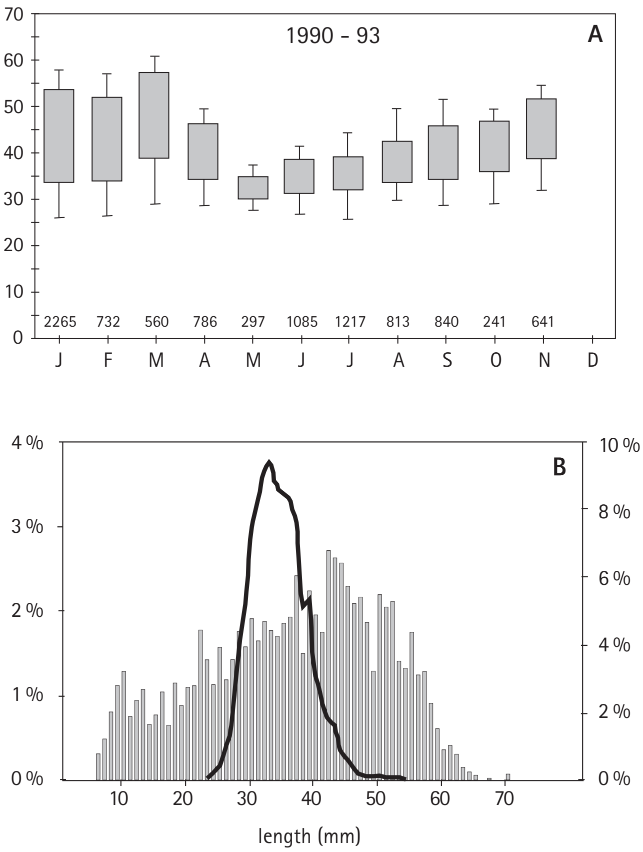

Figure 1: Size selection in mussel feeding eiders. A: Seasonal variation in mussel sizes taken by eiders in Königshafen / Sylt 1990-1993. B: Frequency distribution of mussels on a bed in Königshafen (bars, left Y-axe) and sizes taken by eiders on this bed (black line, right y-axe) (Nehls 1995).

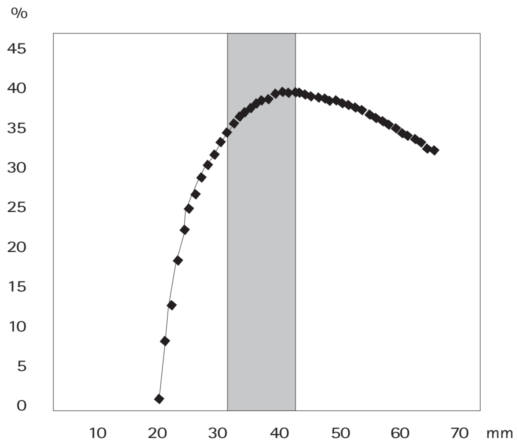

Figure 2: Energy utilization of eiders in relation to mussel size. The graph gives the proportion of energy gained versus energy spent in foraging for eiders feeding on mussels by diving. The shaded area indicates the mussel sizes taken by eiders at this time (June 1990) (Nehls 1995.)

52 mm. Size selection was not influenced by the eiders' feeding technique. Eiders, which fed at low tide by head dipping, and eiders feeding at high tide by diving on the mussel bed consumed the same size ranges.

Cockles are much smaller than mussels and do not grow out of the size range consumed by eiders. Cockles are mainly taken by head dipping when the tide is low. Size selection has been studied less intensively, but occasional observations show, that all sizes of cockles are taken by eiders, with a preference for the larger ones (Nehls 1991).

Processing the Food – Hard Work on Hard Shells

An eider, which has completed a feeding session and consumed 10 to 20 mussels, will start preening and resting for 20 to 30 minutes and even sleep for a short while before it resumes feeding. Experiments with captive eiders showed, however, that the birds – although sometimes motionless – are working hard during this time. Their metabolic rate, which was measured in a respiratory chamber, may double in response to a single meal of a dozen mussels and remain elevated for two to five hours. The reason for this is the internal processing of the food. It has long been known that digestion is an energy consuming process and the same is true for shell crushing, warming the food to body temperature and the excretion of the salt from the isoosmotic bivalves. Shell crushing is an especially demanding task. The energy costs for shell crushing increase exponentially to mussel's length, reflecting that shells get much thicker as mussels grow larger. Almost 20% of the assimilated energy of a mussel is spent crushing the shells. The digestion of the mussel flesh requires energy of the same magnitude as shell crushing. The heating of the mussels to body temperate and the excretion of the salt expend less energy, but these costs also contribute to the budget. Diving and the processing of the mussel clumps until a mussel can be swallowed further increases the energy costs of foraging. Eiders select mussels, which offer the highest energy efficiency, but even in the most suitable mussel sizes, 50 to 60% of the assimilated energy is spent during foraging and digestion (Fig. 2). This means that foraging efficiency in mussel feeding eiders is very low. The ratio of energy assimilated versus energy spent is about 2:1, which is much lower than in most other species. Foraging and digestion are the most important energy consuming activities for eiders, comprising of about half of their daily energy budget. Variations in flesh content and shell weight will considerably influence the energy gain. Thick-shelled mussels with low flesh content will not allow an energy gain, in fact, eiders feeding on poor mussels may starve despite having a full stomach. This highlights the fact, that food quality is of paramount importance to eiders when they are deciding where and what to feed on.

Consequences

In Königshafen, eiders carefully selected the mussel sizes, which provided the highest energy efficiency. What about differences in the mussel quality between sites? The growth conditions of filter feeding bivalves in tidal waters vary in relation to environmental parameters, such as water turbidity, composition and amount of phytoplankton, emersion period and current velocity. Two main gradients have been identified for mussels: 1. Growth conditions on the tidal flats improve with decreasing emersion time. Culture plots are consequently situated in the subtidal zone. 2. Growth conditions are better close to the inlet to the North Sea and decrease towards the mainland, probably as a consequence of increasing turbidity and decreasing algae content (Ruth 1994). On good sites, mussels do not only grow faster, but they also have higher flesh contents and lower shell weights. The ratio between shell weight and flesh content varies by more than factor 2. On productive beds, mussels contain 0,5 g flesh per 1 g shell, on poor beds it is only 0,2 g flesh per 1 g shell (Nehls unpubl.). From an eiders point of view, differences in the quality of mussels between beds must therefore be large. They have to decide whether to feed on beds where mussels are lean and thick shelled or fat and thin shelled. The large differences in the quality of mussels and probably also for cockles from different locations within the Wadden Sea will considerably restrict the amount of mussels and cockles, which may serve as a food resource for eiders. In many locations, flesh content will be too low and shells too thick to allow a sufficient energy gain. Other mussel beds are almost ignored by eiders, although the exploitation on some mussel beds is as high as the annual production.

Can these findings help us to understand the mass mortality of eiders? First, it has to be stated, that only a fraction of the bivalve stocks in the Wadden Sea can be exploited by eiders and that food limitation might be common, even though eiders take only 10% on average of the bivalve stock. This will increase the risk of competition with fisheries, if these were interested in the same mussels and cockles as the eiders. As fisheries will be interested in dense stocks of high quality, competition with mollusc eating birds such as eiders is very likely to occur. Second, natural fluctuations may affect the mollusc stock in quantity and in quality. It has been noted, that the conditions of bivalves in the Wadden Sea is low in mild winters (Zwarts 1991), probably as a result of a higher metabolic rate of the bivalves at mild temperatures. This may severely reduce the proportion of mussels and cockles, which can be profitably exploited by eiders. As the winter 1999/2000 was very mild, it can be assumed, that prey quality was rather poor. In combination with a low mollusc stock and a high fishing intensity this has probably led to a very poor feeding situation in the Dutch Wadden Sea.

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What Can Peak Mortalities of Eiders Tell us about the State of the Dutch Wadden Sea Ecosystem?

Two mass mortality events of Common Eiders *Somateria mollissima*, which occurred in the Dutch Wadden Sea in the 1990s can be considered either trivial (if in proportion to the total breeding population size of eiders: c. 1% died in 1999/2000), or enormous (if in proportion to the size of the Dutch wintering population: c. 15%). What is most critical, however, is not the magnitude of the mortality events, but the ecological reasons behind the enhanced mortality. We put forward the hypothesis that gross overfishing in the early 1990s resulted in permanently reduced food resources, a reduced foraging area and an increased use of secondary prey such as *Spisula subtruncata* in the North Sea coastal zone, all of which led to increased interference competition among eiders. A further decrease in food quality in the winter of 1999/2000, coupled with the removal of major *Spisula* banks in late summer 1999, induced starvation and concomitant parasite problems that led to spectacularly increased mortality rates in an otherwise long-lived bird species. The eider story tells us that early warning signals of the continuing 'ecological erosion' of the Wadden Sea were largely ignored, thus leading to a loss of biodiversity and structural food shortages for molluscivorous birds. In any case, the limited additional conservation measures that were introduced shortly after the first increased eider mortalities in 1990/91 have proven inadequate.

Introduction

Unprecedented mass mortality of Common Eiders was observed in the winter 1999/2000 in the Dutch Wadden Sea (this issue). Between November 1999 and June 2000, at least 21,000 Common Eiders died representing c. 15% of the national wintering population. At least 7,500 individuals were adults. Dissected birds were all severely emaciated and 94% were infested with the acanthocephalan parasite *Profilicollis botulus*.

This mortality is worrying for conservationists, managers and government officers alike, as the Dutch Wadden Sea is designated a wetland of international importance (e.g. RAMSAR Site), where nature conservation is the first and foremost policy concern. Nevertheless, extensive human use of the area is allowed. Mussel cultures occur in subtidal areas while mechanical cockle fisheries are licensed annually after evaluation of the available resources. Of the intertidal areas, c. 31% is now used solely by fisheries, while the remaining 69% are open and potentially fished by mechanical cockle fisheries.

The official estimate of annual requirements of shellfish-consuming waders and ducks amounts to 12.6 million kg of flesh in high densities, of which 60% (7.56 million kg) may not be harvested in 'poor years'. However, the specific requirements of the predators in terms of profitability and availability of prey are not taken into account in this policy (Ens, 2000) and their energetic requirements are underestimated (Camphuysen et al., MS). The winter of 1999/2000 was the third mild winter in a row, leading to a series of summers with low recruitment and generally reduced shellfish condition ('quality'). Food shortage involving both the primary prey (mussels and cockles) and the secondary prey (*Spisula subtruncata*) may have been the principal cause of the observed starvation (Camphuysen et al., MS).

What does the limited hindsight that we now have tell us about the state of the Wadden Sea ecosystem? In this article, we outline a hypothesis of the coincidental human and environmental factors that may have lead to the mass mortality of eiders in the winter of 1999/2000 based on the recent assessment by Camphuysen et al., (MS). This may have also triggered other events that took place in the 1990s, such as widespread population declines of Oystercatchers *Haematopus ostralegus* (Smit et al., 2000), and perhaps also of molluscivorous long-distance migrants such as Red Knots *Calidris canutus* (Piersma & Baker, 2000).

Food Abundance

During a series of three unusually mild winters (1989-91) there was no spatfall of cockles and mussels. This led to very low stocks in the Dutch Wadden Sea. These low stocks were then depleted further in 1990 by mechanical cockle dredging and mussel seed fishing (Van Berkel & Revier, 1991; Dankers, 1993). In addition, virtually all mature mussel beds were removed from the intertidal areas of the Dutch Wadden Sea (Van Berkel & Revier, 1991; Beukema, 1993; Beukema & Cadeé, 1996; Piersma & Koolhaas 1997; Piersma et al., in press). Mature mussel beds, removed in the early 1990s, have so far only marginally recovered (Van Berkel & Revier 1991; LNV 1998).

Prior to this, Swennen et al. (1989) concluded that eiders obtained c. 20% of their prey from mussel culture plots. Since then, the significance of mussel cultures for wintering eiders has increased (Baptist et al., 1997; Berrevoets et al., 2000). Based on Smit (1994) and Smaal et al. (2000), a reconstruction of the mussel stocks showed a structurally low level since the early 1990s.

In winter 1999/2000, both quality (body mass index; BMI) and stocks of cockles were on the low side, according to broad-scale inventories by in the Wadden Sea by the Dutch fisheries Institute (RIVO; Van Stralen & Kesteloo-Hendrikse, 1998) and previously unreported data (Camphuysen et al., MS). The autumn 1999 mussel census indicated a stock of 5 million kg fresh flesh mass of cockles in subtidal areas, 60 million kg cockles in the intertidal zone, 17.5 million kg mussels in the subtidal zone (no data for mussels in the intertidal zone). If these prey were all suitable, accessible and profitable for eiders as exclusive consumers, this would amount to six times the winter requirements of c. 97,000 birds (Camphuysen et al., MS). However, as the greater part of cockle resources were in the intertidal areas of the eastern Wadden Sea (utilized largely by species such as Oystercatchers), and as between autumn 1999 and spring 2000, the mussel stock was reduced by 63% as a result of mussel harvesting and mortality, while 70% of the remaining mussels were 'seed mussels' of sizes too small for eiders (Nehls, 1995), we may safely conclude that the mussel resource was also on the low side.

A final potential prey is *Spisula*, which was utilized during the last decade of the 20th century in response to low shellfish resources after the overfishing of the early 1990s. *Spisula* banks north of the Wadden Sea islands were intensively fished in late summer 1999 by a large fleet (c. 20) of modified cockle vessels, followed by two vessels from small-scale fisheries throughout most of the following winter. Dedicated inventories of shellfish stocks prior to and following the fishery indicated that 85% of the stock in an area with >250 *Spisula* m^{-2} were removed (Camphuysen et al., MS). Some 1-year old molluscs remained but these small *Spisula* are unsuitable for eiders due to their low profitability. Also, the remaining *Spisula* occurred in far too low densities to allow successful exploitation.

Could Eiders Cope?

Eiders (for two consecutive years, autumn 1989 to spring 1991, c. 3x background levels; Camphuysen, 1995) as well as Oystercatchers (winter 1990/91; Camphuysen et al., 1996) experienced peak mortality levels following the depletion of shellfish stocks in 1988-1990. Wintering numbers of Oystercatchers have declined ever since and breeding stocks of Oystercatchers utilizing the Wadden Sea have also declined (Smit et al., 2000). The wintering population of eiders in 1990/91 (103,000 individuals) was c. 20% lower than the average for the 1970s and 1980s (132,000). Of more significance that this possible decline was the food-induced shift in the wintering distribution since the early 1990s as compared to the 1970s and 1980s (Baptist et al., 1997). Camphuysen et al. (MS) found a significant negative relationship between mussel stock and the proportion of eiders utilizing North Sea coastal waters.

Since 1990, the use of *Spisula* in the North Sea coastal waters has become a permanent feature. Considering that North Sea coastal waters only provide foraging opportunities in the form of banks of *Spisula* (a secondary prey, which can be considered difficult to obtain), the shift must be indicative of a structural reduction in the carrying capacity of the Wadden Sea area since 1990.

The Possible Role of the Commercial Fisheries

Eiders and fisheries overlap in their requirements. Diving eiders experience threshold values with respect to a required minimum density (catch per unit effort; De Leeuw, 1997; 1999), a factor that is of equal significance for economically viable fisheries. Size selection studies confirm that eiders select considerable quantities of potentially marketable shellfish (Leopold et al., 2000), while the reverse is obviously also true: fisheries harvest suitable prey for eiders.

Mussel fisheries harvest mussel seed in most of the Wadden Sea to translocate this to mussel culture plots for further growth under largely controlled conditions. Seed mussels are too small to be profitable for eiders (Nehls, 1995). Culture plots of more mature mussels are excellent feeding sites for eiders and may even favorable because of better growing conditions for mussels. The same fisheries have depleted the wild mussel stocks in the Wadden Sea, automatically leading to a reduction of wintering eiders on mussel cultures (interpreted by fishermen as an 'increased population'). Systematic chases of eiders, to scare them away from plots, became routine in the 1990s (M.R. van Stralen, pers. comm.).

The removal of permanent natural mussel beds in the early 1990s may have been the most damaging measure taken by this industry in the Wadden Sea. To date, these mussel beds have not yet recovered. Mechanical cockle fisheries remove suitable prey occurring in high densities. This starts (<1993) mainly in the intertidal parts of the Wadden Sea but recently has also occurred in subtidal areas. These fisheries actively harvest (potential) eider feeding areas and are therefore, at least potentially causing conflict. Recent stock assessments from the fisheries institute combined with blackbox data of the fisheries sector indicated clearly how efficient cockle fisheries remove the subtidal cockle banks with the highest densities (i.e. the most profitable areas for eiders; Van Stralen & Kesteloo-Hendrikse, 1998; 1999).

Spisula fisheries are a recent development in the Wadden Sea area that has rapidly grown into a full-blown fishing industry. Fishing pressure on the limited and patchy resources of *Spisula* is large. Several documented cases of considerable to near-complete (local) stock depletion exist. In February 1993, the first mass-fishery (7-8 ships) was noted off Terschelling, the preferred *Spisula* feeding ground of eiders in that year. Before and after fishery surveys showed that 55% of the stock had been fished (Den Hollander, 1993). Similarly, the largest, concentrated fleet ever recorded, 20 ships working off Texel in May 1999, removed 85% of the fishable *Spisula* within one month.

In conclusion, combined fishery activities in the Wadden Sea seem to have resulted in a reduction of the foraging range of eiders by the removal of old mussel banks, the partial removal of high density cockle and *Spisula* banks and a shift towards mussel cultures. This would then have led to increased levels of interference and a reduction in the carrying capacity of the Dutch Wadden Sea.

Fisheries Management and the State of the Wadden Sea Ecosystem

The current food reservation policy 'guarantees' the availability of only 60% of the energetic requirements of *all* molluscivorous birds in so called 'poor' years. This deliberately risks mass 'die-offs' of birds. It is doubtful whether calculations and assumptions used in this policy were correct. In a recent analysis of the procedures and negotiations underlying this policy, a long list of scientific uncertainties was identified (Ens, 2000). While underestimating the energetic requirements of wintering birds, the reserved quantities are almost certainly too low and the proposed buffer of preserving four times the needs of birds to be at least on the safe side, was applied for some regions, but not for the Wadden Sea. These observations strongly suggest that prey resources are now too small, despite an apparent 'surplus' of five times the energetic requirements of eiders alone.

The evidence so far suggests that the overfishing in 1990, particularly the removal of mature mussel beds, has been a fatal management error. Several bird species were apparently able compensate this for this irreversible loss of prey by seeking alternative foraging areas. In the case of the eider, offshore *Spisula* banks have been a refuge, but only until the late 1990s, when it was the turn of these banks to be overfished. To make the situation much worse, there is now evidence that seafloor disturbance through cockle dredging and other forms of mechanical fisheries have strong long-term negative effects on the recruitment of the bivalves on which eiders and other waterbirds rely (Piersma et al., in press).

In summary, we belief that in an ecosystem under severe and prolonged stress from fisheries and aquaculture (mussel cultures), the wintering eider population collapsed as a consequence of what would otherwise have been a minor dip in prey availability. Damaged intertidal habitats take a long time to recover if they should manage to recover at all (Piersma et al., in press), whereas fished stocks that are currently being overfished have a low likelihood of showing any recovery (Hutchings, 2000). We therefore predict that the Wadden Sea ecosystem as we knew it in the early 1980s, will need a long time to recover especially if immediate stringent protection measures are not taken. Events similar to the mass mortality of eiders may well continue in the near future, eventually inducing structural declines in the populations of molluscivorous and other migrating waterbirds that have made this ecosystem so famous (Van de Kam et al., 1999).

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Consequences

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Mortality of Eiders in the Dutch Wadden Sea 1999/2000: The Search for the Cause of Mass Mortality of Eiders in the Dutch Wadden Sea

During the winter of 1999-2000, large numbers of dead Eider were found in the Dutch Wadden Sea. The birds were very lean and large numbers of parasites were found in their stomachs and intestines. This led to a lot of speculation as to the cause of death, as well as publicity, letters from nature conservation associations and questions raised in Parliament. The Minister of State, Mrs. G. Faber, who is responsible for nature management and fisheries' issues, promised the Parliament that an investigation into the cause of the mass mortality would be conducted before the onset of the cockle fishing season.

The National Reference Center, which is part of the Netherlands Ministry of Agriculture, Nature Management and Fisheries, was asked to co-ordinate this two-month investigation. In short, its function is to liaise between all aspects of government policy, as well as policy implementation, and also includes research. The center is not, however, a research institute itself. Bureau Waardenburg was contracted to support the investigation.

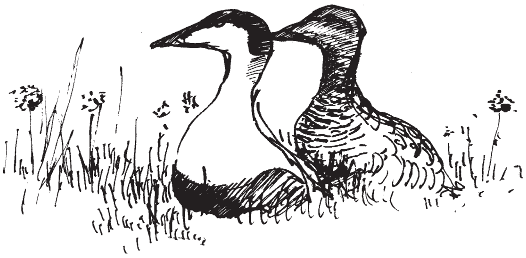
Given the sensitivity and complexity of the subject, the large number of parties and organizations involved, the conflicting interests that the issue raises and the short time available, the organization of the investigation process was as important as the investigation itself. For the same reason, organizations representing both nature conservation and fishery interests were not invited to take part in this investigation phase.

Unfortunately, knowledge on the ecological trade-offs concerning the necessary food intake of shellfish in relation to energetic demands of the Eider are poorly known and the crucial food related aspects of the investigation could only be derived indirectly by analyzing different sets of comparable existing data and desk-studies. These additional analyses were run by the different research institutes and agencies involved in managing these monitoring schemes (Alterra Green World Research, CSR Consultancy, National Institute for Coastal and Marine Management (RIKZ), Netherlands Institute for Fisheries Research (RIVO), Dutch Center for Ornithological Research (SOVON)). A large group of experts in different fields of research also contributed to the project (Erasmus University, Bird Rehabilitation Center Fûgelpits Anjum, Institute for Animal Science and Health (ID-Lelystad), Netherlands Institute for Sea Research (NIOZ), University of Utrecht and several foreign institutes and organizations elsewhere in NW-Europe).

Most of the findings are described in detail elsewhere in this special issue.

The findings of the investigation, including the supporting reports of the research institutes and other agencies, were submitted to an independent scientific audit commission chaired by Prof. Dr. W.J. Wolff, University of Groningen.

In the report (Van den Berk et al., 2000), it is concluded that several hypotheses could in fact be rejected. The only hypothesis which can be supported by evidence from existing data is the following: The mass mortality of Eiders in the Dutch Wadden Sea in 1999/2000 occurred after large numbers of birds could not survive an infection carried by regularly occurring parasites (the intestine parasite *Profilicollis botulus*, which is contracted by the birds while eating the host, namely the Shore Crabs *Carcinus maenas*, and probably also the stomach parasite *Amidostomum spec.*). The birds subsequently starved to death because large enough food quantities could not be consumed. This implies that there was a food availability shortage for the birds. The results from analyses of the available data on the four most important prey species (mussel, cockle, *Spisula* and Shore Crab) showed it to be likely that in 1999/2000, the food situation highlighted various differences when compared to preceding winters. These differences led to a combination of circumstances



which did not occur in the years before (at least not since 1994): Mussels were less attractive, *Spisula* was not available as a prey alternative, cockles were at best a partial alternative and Shore Crabs were available. Based on the data for prey species, the changes in shellfish populations are likely to have led to an unfavorable food situation for Eiders, which in combination with parasite infections caused the mass mortality of Eiders.

A clear relationship between the shellfish fisheries and availability of mussels and cockles as food could not be found. Such a relationship is, however, likely for the prey species *Spisula*. It has been concluded that mechanical shellfish fisheries, which focus on *Spisula*, were fully or partially responsible for the lack of *Spisula* of the right size classes for Eiders in the winter of 1999-2000.

The audit commission endorsed the conclusions of the report in broad outline.

The report and the conclusions of the audit commission were submitted to the policy departments of the Ministry responsible for the Wadden Sea, Fisheries and Nature Management. They organized a hearing with the interest groups to discuss the findings on which the Minister of State based her reply, conclusions and recommendations to the Parliament. Conclusions and recommendations were in line with those described in our report.

The Most Important Findings of the Project

Extent and pattern of the mortality in The Netherlands

1. In the Dutch part of the Wadden Sea, a total of 7,271 dead Eiders were found between November 1999 and June 2000. Based on the numbers found on different transects, the total number is estimated to have been 21,000 birds. In both absolute and estimated figures, this is by far the highest mortality recorded since 1980.
2. From November onwards, the number of dead Eiders gradually increased. The highest numbers were found in March/April after a first peak in December.

Extent of the mortality in bordering countries

3. An exceptionally high mortality of Eiders was also observed in the German Wadden Sea (both in Lower Saxony and in Schleswig-Holstein). The symptoms of the birds were similar, but the numbers (both in absolute and in relative numbers) were lower than in The Netherlands. Clear differences were found in both spatial and temporal patterns in comparison with the Dutch situation.
4. No elevated mortality was observed in Great Britain and Denmark.

Causes of mortality that could be rejected

5. Based on the data from analyses and the discussion with researchers, the following possible causes could be excluded or said to be very unlikely: oil pollution, poisoning with contaminants, infection with bacteria, infection with a virus or chronical stress/deficiency of the immune system.

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Notes for Contributors

Contents

The Wadden Sea Newsletter is a trilateral periodical to inform scientific, nature management and policy-making institutions in Denmark, the Federal Republic of Germany and The Netherlands about research projects, their results, management measures and topical news in the Wadden Sea area.

Length and Structure

"Main theme" articles should be about 3 printed pages (about 1500 words with one figure on each page), short contributions of about one page (about 500 word with one figure) and brief notes are also welcome.

The "main theme" articles should include an abstract of 4 - 7 lines in easy English. The body of the article should be organized in sections with headings.

Only a few (2 - 4) recent references should be added to the contributions. Example: Becker, P.H., S. Thyen & K.R. Schneider, 1998. Monitoring Pollutants in Coastal Bird Eggs. Wadden Sea Ecosystem No. 8, Common Wadden Sea Secretariat, Wilhelmshaven, pp 59 – 101. Reference in text: (Becker et al. 1998) or (Beukema & Vlas 1979).

Authors are advised to consult this issue of the Newsletter and follow the conventions for section headings, tables, captions, references, addresses, quotation marks and abbreviations. (see also: http://cwss.www.de/news/publications/wsnl.html)

Language

The Wadden Sea Newsletter is published in English.

Format

A hard copy of the text, tables and figures and an electronic copy of the manuscript in WORD or WordPerfect format should be submitted, either as a file attached to an e-mail (preferred) or on a diskette.

With the exception of species names (*italics*) the text should not contain any further formats (e.g. bold, underlined, hyphenation, justified setting). Record numbers up to 9999 should be written without a space, for higher numbers, such as 10 000 leave a space at the thousand interval.

Photos, Figures, Illustrations, Tables

Photos, figures and illustrations with useful captions and legends are welcome and should be included wherever possible. Photos should be submitted as slide or photo print. Electronic versions of figures, illustrations and tables should be delivered in black and white and as separate files in the program they have been created with, e.g. MS products (Word, Excel, Powerpoint, Access), Freehand, CorelDraw (version 7.0) or Adobe Illustrator format.

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