Common eiders Somateria mollissima in the Netherlands
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Chapter 1

General introduction
The NWO research program ‘Sustainable use and conservation of marine living resources’

The seas and coastal areas of the world have a long history of human exploitation, which contributed to the degradation, alteration, destruction and collapse of marine ecosystems (Jackson et al. 2001). At present, marine living resources are still declining all around the globe coinciding with an increase in damage to marine ecosystems (Roberts 1997). Although management systems for sustainable exploitation of natural resources have been developed, only a few of them have actually been put into practice (Hilborn et al. 1996). These alarming observations result from a combination of three causes:

1. lack of understanding of essential ecological processes in the sea, resulting in a mismatch between scales of ecological processes and scales of human exploitation systems;
2. deficiencies in the international legal regime, resulting from a spatial mismatch between the distribution of legal authority over jurisdictional (geographical) zones and ecological subdivisions, in combination with limited possibilities to oblige states to comply with internationally agreed management policies;
3. the fact that human behaviour is traditionally based on self-interest and short-term goals (i.e., a mismatch between ecological and economic time scales) which tends to neglect environmental effects and external costs passed on to others and to the future.

Therefore, the multidisciplinary PRIORITEIT programme ‘Sustainable use and conservation of marine living resources’ (SUSUSE) was initiated and financed by the Dutch Organisation for Scientific Research (NWO) between 1998 and 2006. SUSUSE aims to fill up the gaps in knowledge on exploitation, conservation and management of marine living resources in the Wadden Sea area resulting in new guidelines for the practical application at sea.

The focus of the programme is on the ‘mismatch of ecological and human processes’ hypothesis that populations of marine organisms and human exploitation and management systems act at different spatial and temporal scales. The SUSUSE programme is an attempt to investigate the predicted mismatch and centred around three themes:

1. spatial scales of populations of marine organisms in relation to the spatial scale of human exploitations systems,
2. analysis of temporal scales of development of populations of marine organisms and the possible mismatch with the temporal scales of humans exploitation systems, and
3. integrated approach of marine biodiversity.
One of the central themes of PRIORITEIT and SUSUSE is the integration of biological and socio-economical sciences in order to develop new theoretical concepts for sustainable use and conservation of marine living resources. The outcomes of this programme should result in new guidelines for the practical application at sea by policy makers based on a workable and scientifically sound strategy for sustainable use and conservation of marine living resources.

The aim is to examine the temporal variations in marine bivalve stocks in relation to time scales of bird predation and shellfish fisheries, and investigate the economic and other consequences of the observed ecological time scales for exploitation and conservation of marine living resources in the Dutch part of the international Wadden Sea. The total effort of multidisciplinary research of SUSUSE theme 2 is focused on (Figure 1.1):

1. recruitment of shellfish (Bos 2005),
2. settlement of shellfish (Hendriks 2004),
3. long-term population dynamics of the main avian predator of shellfish, the Common Eider Somateria mollissima (this thesis), and
4. building bio-economic models for sustainable use and conservation of marine bivalves (Hoekstra in prep.).

**Figure 1.1** Schematic overview of the multidisciplinary research of SUSUSE theme 2 ‘Analysis of the temporal scales of development of populations of marine organisms, and the possible mismatch with scales of human exploitations’ and their contributing partners in the Dutch Wadden Sea with respect to predators, prey stocks and economics. The shaded areas are the six participants within the four research fields of SUSUSE theme 2 project and non-shaded areas are recent and ongoing external research, for example continuous monitoring of populations of shellfish and oystercatchers within the project of the Evaluating the Effects of Shellfishery part II (EVA II), which is sponsored by the government and shellfishery. (Taken from SUSUSE-proposal).
Introducing the shellfish scene and its main players

The Wadden Sea area
The Wadden Sea area (including the adjacent North Sea) is an internationally important natural area, which is safeguarded for its characteristic habitats and inhabitants (i.e. the birds) by the EU Habitat and Birds Directives, and the Bonn and Bern Conventions on migrating animals. These habitats are important for a wide variety of bird species, such as terns, gulls, wildfowl and waders, which use the Wadden Sea area throughout their annual cycle for wintering, breeding, moulting or as a stopover site to refuel during migration from and to the breeding grounds (Van der Kam 1999). For some species of birds, the numbers exceed the level of 1 % of the total population indicating that the Wadden Sea area is of great importance for those species at a given moment in time.

The shellfish
The total stock of shellfish in the Dutch part of the Wadden Sea area is currently represented by only a few species of shellfish, mainly mussels *Mytilus edulis*, cockles *Cerastoderma edule*, Soft-shelled Clam *Mya arenaria* and Baltic Tellin *Macoma balthica* in the Wadden Sea (Beukema 1982, Beukema et al. 1993, Zwarts 1997, Van Stralen & Kesteloo-Hendrikse 1998, Van Stralen & Kesteloo-Hendrikse 1999, Bult & Kesteloo 2001, Beukema & Dekker 2005) and Cut-trough Shells *Spisula subtruncata* and American Razor Clam *Ensis directus* in the coastal zone of the North Sea (Craeymeersch & Perdon 2006). In general, shellfish undergo large natural fluctuations in numbers, relative densities and reproductive success (Van der Meer 1997). Most of these species of shellfish serve as the principle food for several species of shellfish-eating birds in the Wadden Sea and coastal North Sea, but some of them are also of commercial interest for the fishery.

The shellfish-eating birds
Shellfish are preyed upon by a variety of shellfish-eating birds and predation by birds differs in relation to the species of shellfish and/or size (small or commercial). In general, shellfish-eating birds swallow their prey whole, except for the Oystercatcher, and therefore the maximum size they can take is limited by their gape width. The list of bird species preying on small shellfish is long and includes for example Turnstones *Arenaria interpres*, Bar-tailed Godwits *Limosa lapponica* and Grey Plovers *Pluvialis squatarola*, but substantial reductions in the stocks of small shellfish was only documented for Herring Gulls *Larus argentatus* (Zwarts & Ens 1999) and predicted for Knots *Calidris canutus* (Van der Meer 1997). The birds preying upon large shellfish of commercial size are Common Scoter *Mellanitta nigra*, Common Eider *Somateria mollissima* and Oystercatcher *Haematopus ostralegus*. The Common Scoter specializes on *Spisula*, whereas Eiders and Oystercatchers primarily feed on mussels and cockles.
The shellfish-fishing industry

A long history of shellfish exploitation exists in the Wadden Sea area and involved shellfish species such as Periwinkle *Littorina littorea*, Whelk *Buccinum undatum*, European Flat Oyster *Ostrea edulis*, Blue Mussel *Mytilus edulis*, Cockle *Cerastoderma edule* and Cut-trough Shells *Spisula subtruncata* (Dijkema 1997, Wolff 2005). Two recently invaded exotic species of shellfish in the Wadden Sea area have also become of commercial interest, i.e. Pacific Oyster *Crassostrea gigas* and the American Razor Clam *Ensis directus* (Dijkema 1997, Wolff 2005). The mechanical shellfishery has primarily concentrated on Mussels, Cockles and *Spisula*.

Mussel cultures were introduced in the western part of the Dutch Wadden Sea in 1950 when a parasite (*Mytilicola intestinalis*) decimated the traditional mussel cultures in the SW Netherlands (Dijkema 1997). Each year seed mussels up to 65 million kg fresh weight were fished in the tidal (until 1993) and sub-tidal parts of the Wadden Sea to stock culture lots in both the Wadden Sea and SW Netherlands (Ens 2003). The stocks of seed mussels experienced large annual fluctuations resulting in a shortage of seed mussels, for example after three successive mild winters in 1988-1990. In order to stock the cultures lots, nearly all tidal mussel beds were fished in the Wadden Sea (Ens *et al.* 2004). To date, recovery is not yet complete.

Cockles were traditionally hand raked, but the cockle fishery was mechanised during the 1960’s resulting in hydraulic suction dredging (Ens 2003) and as a consequence, the catch increased from 1–2 million kg fresh weight prior to 1960 to a maximum of 80 million kg fresh weight in 1989. An all-time low in the stock of cockles in the Wadden Sea was observed after the mild-winters in 1988-1990 due to intensive cockle fishery in previous years and low recruitment during subsequent years (Smit *et al.* 1998). At the same time, large stocks of *Spisula* were discovered in the coastal areas of the North Sea, which served as a welcome replacement of the low stocks of Cockles. However, during the course of this thesis research, the Dutch government decided that some forms of the fishery were not sustainable and as a consequence the mechanised cockle fishery was terminated in 2005.

The shellfish policy

The extremely low stocks of both mussels and cockles in the Dutch Wadden Sea around 1990 were caused by unrestricted shellfishery. A heated public debate was triggered when increased mortality among shellfish-eating birds (Oystercatchers and Common Eiders) was observed and as a consequence new management rules were introduced in 1993 (LNV 1993) and further adjusted in 1998 (LNV 1998). In short, some tidal areas characterized by a high probability of re-settlement of mussel beds or eelgrass beds were closed to the fishery. Moreover, a food-reservation policy was introduced for shellfish-eating birds (Oystercatchers and Common Eiders) designed to intervene in years with low stocks of shellfish. The aim was to ensure that shellfish stocks (post-fishery) would be adequate to support the birds.
The shellfish problem
The life history of shellfish eating birds differs in two important respects from the life history of their prey. First, the shellfish remain at a fixed location after settlement, while birds move between different feeding areas or move away when local conditions deteriorate. Second, comparing one year to the next, bird populations are much more stable than shellfish populations, due to the higher life expectancy of the birds and the much lower variability in their recruitment. As a consequence, the birds will experience years with an overabundance of food and years with poor food stocks. Local studies on bivalve exploitation by birds in the Dutch Wadden Sea confirm this prediction (Zwarts et al. 1996a, Van der Meer 1997). However, the extent to which the populations of the shellfish eating birds are hit by low stocks will depend on the geographical scale over which the shellfish stocks vary in synchrony. Winter weather is a large-scale phenomenon and severe winters often lead to mass mortality among the shellfish and high recruitment in the next year. As this applies to many shellfish species, despite differences in vulnerability, this means that shellfish stocks will vary in unison over a large geographical scale so that the shellfish eating birds will have limited possibilities for escape, despite their wings (Beukema et al. 1993). Low stocks of shellfish are a threat to both players in the shellfish-scene, because fishermen see their activities restricted and birds can only starve, migrate or ultimately die. Since the well-being of birds has been accorded priority in international treaties, the low stocks of shellfish should not be fished to a level that might become detrimental to the birds.

Outline of the thesis
Common Eiders are the most important consumers of commercially exploited shellfish in the Wadden Sea and coastal North Sea, and as a consequence potential conflicting demands exist between the shellfishery and Common Eiders. Quantitative knowledge on the dependence of Common Eiders on shellfish is lacking and is of crucial importance for the development of a management strategy in the Wadden Sea area, which attempts to reconcile the demands of both shellfishery and nature protection. This thesis is a first step to fill up these gaps in knowledge of the dependence of Common Eiders on shellfish during two important periods in the annual cycle, i.e. wintering and breeding.

Chapter 2 reviews the present status and most recent changes in the Baltic/Wadden Sea Common Eider flyway population based on data on breeding, migrating, moulting, and wintering numbers in the flyway and summarises the causes of mortality observed in recent years throughout the flyway. Several geographic populations of Common Eider are present within the flyway throughout the annual cycle, and the Netherlands are used by two populations, i.e. wintering and breeding, which are presented separately.
The diet and prey preferences of Common Eiders in the Wadden Sea (Chapter 3 and 4) provide the background for the analysis of the wintering population (Chapter 5–8) and breeding population (Chapter 9–10) in the Netherlands. Chapter 3 provides an overview on the actual diet and prey preferences of Common Eiders. The reconstruction of the diet of the ingested shellfish was based on the analysis of shell fragments found in stomachs of oiled scoters, and in faeces from eiders roosting on an offshore sandbank. The primary prey in the diet of Common Eiders in the Wadden Sea area is the mussel followed by cockles and *Spisula*. Common Eiders are selective with respect to size and take only those sizes with the highest energy return indicating that not all prey species and sizes can be taken. Chapter 4 shows that Cut-trough Shells *Spisula subtruncata* and American razor Clams *Ensis americanus* are the staple food in the diet of Common Eiders, but also in Common Scoters *Melanitta nigra*, wintering along the coastal North Sea in the Netherlands.

Chapter 5 describes the patterns of mass mortality observed among Common Eiders in the Dutch Wadden Sea area in the winter of 1999/2000, when approximately 21,000 individuals died. Data on the dissection of beached birds, number and distribution of wintering eiders and the available food stocks was presented and it was hypothesised that over-fishing of mussels and cockles in the Wadden Sea in the early 1990s resulted in drastically reduced food resources. These reductions in food had impacts on the eiders causing mortality, shifts in distribution, and increased use of secondary prey.

Chapter 6 investigates the role of two parasites, *Profilicollis botulus* and *Amidotomum acutum*, in the recent mortality events of the Common Eider (1999/2000 and 2001/02). Three hypotheses were advanced to test whether mortality was caused by food shortage, parasite outbreak or that food shortage increased mortality among heavily parasitized individuals. Parasite loads were compared in beached (starved) and shot (healthy) eiders in order to test whether body condition was dependent on parasite loads. Evidence indicated that mass mortality was not caused due to an outbreak of parasites and the parasite outbreak hypothesis was rejected.

Chapter 7 analyses the size of the wintering population, the shift in distribution and mortality in relation to the total stocks of tidal and sub-tidal mussels, cockles, *Spisula* and *Ensis*, and winter severity in the Dutch Wadden Sea area. Although variation in the total wintering population in the Wadden Sea was related to the Winter Severity Index (explained by influxes of birds from the Baltic Sea area during severe winters) mortality was closely related to the stocks of sub-tidal medium-sized mussels. Variations in this primary food stock also explained shifts of wintering Eiders to the North Sea.

Chapter 8 links the distribution at various scales of wintering Common Eiders to the distribution of the tidal and sub-tidal shellfish in the Wadden Sea and evaluates the importance of sub-tidal cultured mussels.
Chapter 9 reveals the existence of widespread non-breeding by adult females, which was observed in 1990-1993 and 2003, and was calculated in a population trajectory for a single breeding colony (Vlieland) using data on annual number of breeding females and fledglings, and estimates on the probability of breeding in 2\textsuperscript{nd} and 3\textsuperscript{rd} year old females, and annual survival of juvenile, immature and adult females, using 25-year data of ring recoveries.

Chapter 10 investigates the relationship between the Dutch breeding population and the dependence on the local feeding conditions near the breeding colony. The importance of local feeding conditions is indirectly revealed by showing that at colony saturation the number of nesting females was related to the tidal area near the breeding colony. For Vlieland, the incidence of non-breeding was found to be negatively related to the total density of profitable food. For a series of years when cockles of appropriate size were lacking, breeding numbers on both Vlieland and Rottum were shown to be related to the stocks of tidal mussels near the colony.

Chapter 11 contains a general discussion of the main findings of this study and discusses future threats and perspectives. Although quantitative insights on the relationship between Eider populations, demography and distribution in relation to the stocks of shellfish have been obtained, there are still important gaps in our knowledge of the feeding ecology of the Common Eider. Until these gaps have been filled, we will be unable to implement a realistic science-based management plan in the Wadden Sea.