DONG
energy

Horns Rev II
Offshore Wind Farm
Food Basis for Common Scoter

Baseline Studies 2007-08

DHI
WATER · ENVIRONMENT · HEALTH

Orbicon

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Contents

1   SUMMARY

DONG Energy has commissioned a consortium of Orbicon and DHI in association with Marine Observers to model the distribution of prey to Common Scoter *Melanitta nigra* by means of a habitat model as part of the monitoring program for the planned Horns Rev 2 offshore wind farm. The establishment of the Horns Rev 2 offshore wind farm (HR2 OWF) was granted by the Department of Energy on the 19th March 2007 on the basis of DONG Energy's application of 13th October 2006. The location of the HR2 OWF is planned for the outer part of Horns Rev, and it consists of a total of 91 turbines, each 2.3 MW which are placed with 13 east-west oriented rows of 7 turbines.

Common Scoters feed almost exclusively on filter-feeding bivalves, and in the Danish part of the North Sea they are known to feed on both cut trough shells *Spisula subtruncata* and American razor clams *Ensis americanus*. The preference for razor clams seems to be of recent origin, and this preference has been suggested as a possible reason for the dispersal of scoters in the Horns Rev area experienced during the PSO-related monitoring programme. This dispersal pattern of razor clams possibly may affect the presence of scoters near the Horns Rev 2 site. As both primary prey species to Common scoter in the North Sea occur commonly in the region knowledge of the available supply of both razor clams and trough shells in the site and on Horns Rev in general is critical to the application of a BACI design for monitoring the impact of the wind farm on scoters. Lack of detailed hydrodynamic and geo-biochemical model to construct physiology-based growth models for standard knowledge about the distribution of prey can lead to ambiguous interpretations of monitoring results, and even bias conclusions on possible impacts.

The modelling work integrated dynamic model data on the potential carrying capacity of the two potential prey species in the area and field data on benthos and surface sediments and the relief of the sea floor. The carrying capacity models were developed using the output from a local combined hydrodynamic and geo-biochemical model to construct physiology-based growth models for standard individuals with an advection term that replenish the food ingested by filter-feeders.

Existing knowledge of food selection and prey dynamics by Common Scoter in the Horns Rev area could not be corroborated. Both additional dietary investigations in the main feeding area of the scoters, the linked benthos sampling programme and the model results unambiguously point at two rather well-defined prey communities of razor clams and trough shells, which are both utilised by the scoters. The community of through shells is related to the area of fine sediments and very high food supply in terms of near-seabed chlorophyll concentrations found in the Esperance Bugt and at the ground Cancer. Most of the areas over the reef are unsuitable to the trough shells, due to the sediment structure and the frequent turn-over of sediments as a result of periodic strong currents over the reef. The community of Razor clams, on the other hand, prefer the medium-sized sediments over the reef and to the northwest of the reef, including the planned wind farm site, and are due to their deep penetration into the sediment able to survive the frequent sediment re-bedding in these areas. Although this community is also found in the eastern part of the area the fine sediments seem to be unsuitable to the

species, and prevent the razor clams to utilise the higher concentrations of food found just off the Danish coast. Rather than an ecosystem dominated by one prey species, American razor clams, our results indicate that both prey species are important at Horns Rev, and that most birds now and historically have been feeding on trough shells in the area.

The change in the historic distribution of Common Scoter recorded after 1999 showed a relocation of a proportion of 10-25 % of the birds along the reef into the offshore areas shallower than 15 m on the reef as well as on the plains northwest of the reef. These areas can now be identified as suitable habitat for razor clams and as mainly unsuitable for trough shells. Thus, it is highly likely that Common Scoters mainly feed on razor clams in the 'new' area of their distribution. As the birds collected in the area in 2006 and in 2008 all were in excellent condition the most probable function of this dual prey system is that razor clams provide a supplementary source of food for scoters which are generally experiencing a rich supply of food in terms of trough shells. This is supported by the fact that scoters seem to use the razor clam habitats more during the later part of the season, when food availability in their primary feeding area may become scarce as a result of their own predation.

The distribution model for razor clam for the period 2000 to 2008 clearly shows that most of the footprint area of the HR2 OWF is prime habitat for this species, and hence that concentrations of Common Scoters may occur regularly in the wind farm site, as found during the surveys from 2005 to present. Based on the model results it is questionable whether scoters will use the existing HR1 wind farm site frequently, as the area does not seem to be highly suitable to razor clams.

Data on surface sediments and benthos are lacking in the areas to the west of Fanø and the whole area northeast of Horns Rev, - areas which are important to describe in terms of potential food supply to Common Scoter. Equally important, the available data on the *Spisula* and *Ensis* do only allow for a break-down of habitat suitability based on presence/absence. Quantitative data are needed to base suitability estimations on biomass levels rather than presence/absence patterns, as such estimations most likely will result in better spatial information on gradients and patchiness in the distribution of the two species on Horns Rev.

2 DANSK RESUME

Et konsortium bestående af Orbicon og DHI i samarbejde med Marine Observers har på vegne af DONG Energy gennemført modellering af udbredelsen af føden for sortænder *Melanitta nigra* som en del af overvågningsprogrammet for den planlagte Horns Rev 2 havvindmøllepark. Tilladelsen til at bygge Horns Rev 2 havvindmølleparken blev givet af Energistyrelsen den 19. marts 2007 på basis af DONG Energy's ansøgning af 13. oktober 2006. Placeringen af vindmølleparken er planlagt til at være på den ydre del af Horns Rev, og mølleparken består af 91 møller på hver 2.3 MW, som er placeret i 13 øst-vestgående rrækker med hver 7 møller.

Sortænder spiser næsten udelukkende filtrerende muslinger, og i den danske del af Nordsøen er de kendte for at fouragere på både Hvælvet trugmusling *Spisula subtruncata* og Amerikansk knivmusling *Ensis americanus*. Præferencen for knivmuslinger synes at være af nyere dato, og den har været foreslået som en mulig årsag til udbredelsesmønstret af sortænder på Horns Rev, som blev fundet i forbindelse med det PSO-relaterede moniteringsprogram. Dette udbredelsesmønster af knivmuslinger kan påvirke forekomsten af sortænder ved Horns Rev 2 mølleparken. Da begge byttearter forekommer almindeligt i regionen vil kendskab til den tilgængelige fødemængde af både trugmuslinger og knivmuslinger i mølleparken og på Horns Rev generelt være kritisk for anvendelse af et BACI design i moniteringsprogrammet. Manglen på detaljeret viden om udbredelsen af bytte kan føre til tvivlsomme fortolkninger af overvågningsresultater, og kan tilmed føre til forkerte konklusioner omkring mulige påvirkninger.

Modelarbejdet integrerede dynamiske modeldata på den potentielle bærevne for de to byttedyr i området sammen med feltdata på muslinger, overfladesediment og havbundsrelief. Modellerne for bærevnen blev udviklet ved brug af output fra en lokal kombineret hydrodynamisk og geo-biokemisk model. Fysiologisk-baserede vækstmodeller blev etableret for standardindivider med en beskrivelse af advektion til fornyelse af føden.

Resultaterne af undersøgelserne støtter ikke den eksisterende viden om fødevalg og byttedyrsdynamik hos Sortand ved Horns Rev, idet såvel supplerende fødeundersøgelser fra sortændernes vigtigste fourageringsområde, det koblede indsamlingsprogram for muslinger og modelresultaterne alle entydigt pegede på forekomsten af to relativt veldefinerede byttedyrssamfund af knivmuslinger og trugmuslinger, som begge udnyttes af sortænder. Samfundet af trugmuslinger er knyttet til området med finere sediment og høje fødekoncentrationer i form af bundnært klorofyl i Esperance Bugt og ved grunden Cancer. De fleste områder på revet er uegnede for trugmuslinger p.g.a. sedimentstrukturen og den hyppige sedimentomlejring som et resultat af perioder med kraftig strøm. Samfundet med knivmuslinger er på den anden side knyttet til det lidt grovere sediment over revet og nordvest for revet, inklusiv mølleområdet, og er på grund af deres dybe forankring i sedimentet i stand til at overleve den hyppige omlejring af sedimentet i disse områder. Selvom knivmuslingesamfundet også findes i den østlige del af området synes det finere sediment at udgøre et uegnet substrat for knivmuslinger, og som forhindrer arten i at udnytte de højere fødekoncentrationer tættere på den danske kyst. Snarere end et økosystem domineret af én byttearter for sortænder tyder disse resultater således

på, at begge arter er vigtige for sortænder på Horns Rev, og at den største del af fuglene nu som tidligere fouragerer på trugmuslinger.

Ændringen i den historiske udbredelse af sortænder observeret efter 1999 viste en omgruppering af omkring 10-25 % af fuglene langs revet til offshore-områderne på dybder mindre end 15 m på og nordvest for revet. Disse områder kan nu identificeres som egnet habitat for knivmuslinger og som generelt uegnet habitat for trugmuslinger. Det er derfor sandsynligt, at sortænder især spiser knivmuslinger i de 'nye' områder offshore. Eftersom fuglene indsamlet i 2006 og 2008 alle var i fin kondition er den mest sandsynlige funktion af det dobbelte byttedyrssystem, at knivmuslingerne udgør en supplementær fødekilde for sortænderne, som generelt finder en rigelig fødekilde i form af trugmuslinger i det kystnære område. Dette støttes af det faktum, at sortænderne især anvender knivmuslingehabitaten offshore sidst på vinteren, når fødetilgængeligheden antageligt mindskes i deres primære foragerinsområde som følge af deres egen prædation.

Udbredelsesmodellen for knivmuslinger for perioden 2000 til 2002 viser tydeligt, at hovedparten af Horns Rev 2 mølleparken er velegnet habitat for arten, og at det derfor må anses for sandsynligt, at koncentrationer af sortænder vil forekomme regelmæssigt i vindmølleområdet, som dokumenteret i perioden fra 2005 til i dag. På basis af modelresultaterne er det tvivlsomt om sortænderne anvender den eksisterende HR1 vindmøllepark i særlig høj grad, eftersom området synes at være mindre egnet som habitat for knivmuslinger. Fremtidige kørsler af habitatmodellerne vil vise hvorvidt udbredelsesmønstrene for trugmuslinger og knivmuslinger har været stabile over hele perioden for overvågningsprogrammet for Horns Rev 1, og hvorvidt konsekvensvurderinger for denne møllepark i relation til habitattab hos sortænder bør revurderes.

Data på overfladesediment og benthos mangler generelt for områderne vest for Fanø og fra hele området nordøst for Horns Rev, - områder som er væsentlige at beskrive i relation til potentiel fødemængde for sortænder. Et andet vigtigt problem er, at de tilgængelige data på knivmuslinger og trugmuslinger kun tillader estimering af habitatkvalitet ud fra om arten er tilstede eller ikke tilstede. Kvantitative data behøves for at estimere habitatkvalitet ud fra data på biomasse, idet disse formodentlig vil resultere i mere detaljeret information om gradienter og fordelingsmønstre af de to arter på Horns Rev.

3 INTRODUCTION

3.1 Background

DONG Energy has commissioned a consortium of Orbicon and DHI in association with Marine Observers to establish a model of the distribution of potentially available food supply to non-breeding Common Scoter *Melanitta nigra* on Horns Rev in terms of cut trough shells *Spisula subtruncata* and American razor clams *Ensis americanus*. The food supply model should be used as a basis for modelling the dynamic habitat selection of Common Scoter in the area, and thus gain important insight in relation to the potential impacts envisaged on scoters from the planned Horns Rev 2 offshore wind farm. The establishment of the Horns Rev 2 offshore wind farm (HR2 OWF) was granted by the Department of Energy on the 19th March 2007 on the basis of DONG Energy's application of 13th October 2006.

This report contains the results of the development of the food supply model and the habitat model for Common Scoter on Horns Rev. The implementation of the habitat model is covered by a report dealing with the distribution and abundance of Common Scoter during the baseline monitoring of waterbirds related to the HR2 OWF (Skov et al. 2008).

3.2 The Horns Rev II Project

3.2.1 Location

The location of the HR2 OWF is planned for the outer part of Horns Rev, a sand bank which stretches from the coast of Denmark (Blåvands Huk) and 40 km westwards, Figure 3-1.

The distance from the HR2 OWF to Blåvands Huk is 30 km. The minimum distance between the existing OWF on Horns Rev and the planned HR2 OWF is 14 km. The water depth at the site of the HR2 OWF varies between 6 and 18 m. The HR2 OWF has been designed as an arc north of the shallow ground VovVov on the western Horn Rev.

The HR2 OWF consists of a total of 91 turbines, each 2.3 MW which are placed with 13 east-west oriented rows of 7 turbines. Due to the design of the OWF the distance between the rows will vary from 700 m in the eastern part to 900 m in the western part, Figure 3-2. The distance between individual turbines is 550 m.

Figure 3-1 and Figure 3-2 also show the proposed placement of three 15 MW test mills. The transformer station will be located 1 km east of the wind farm. 16-20 m northeast of the transformer station an accommodation platform will be installed with a gangway connecting the two platforms.

The turbines will be connected by east-west running 34 kV cables, which will be collated into a single cable in the eastern part of the OWF, which then is connected to the transformer station, Figure 3-2.
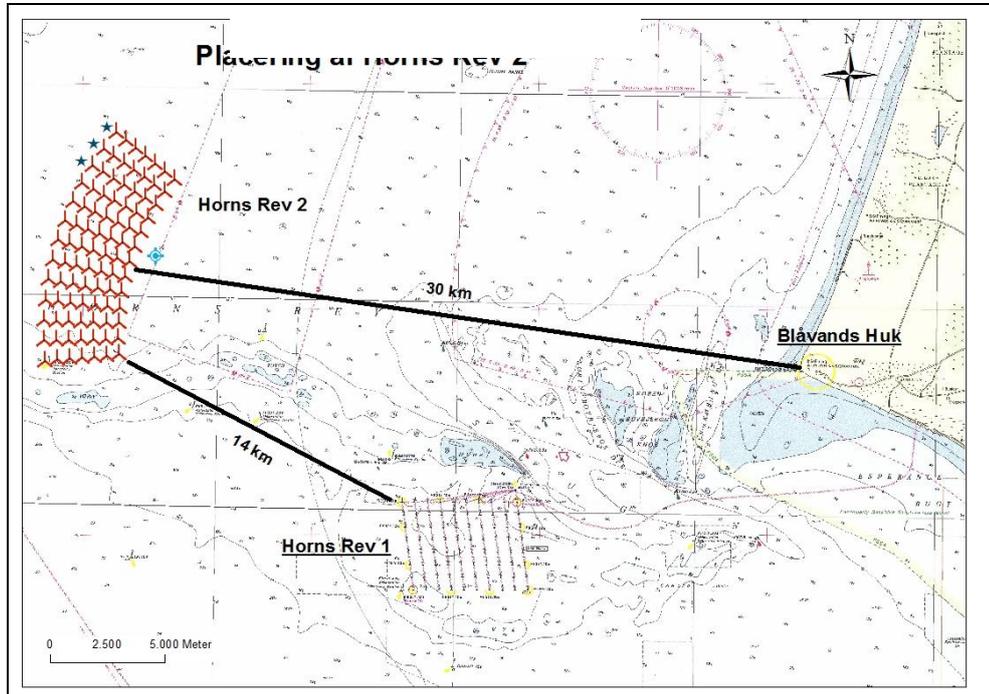

Figure 3-1. The location of the HR2 OWF relative to Blåvands Huk and the Horns Rev 1 OWF.
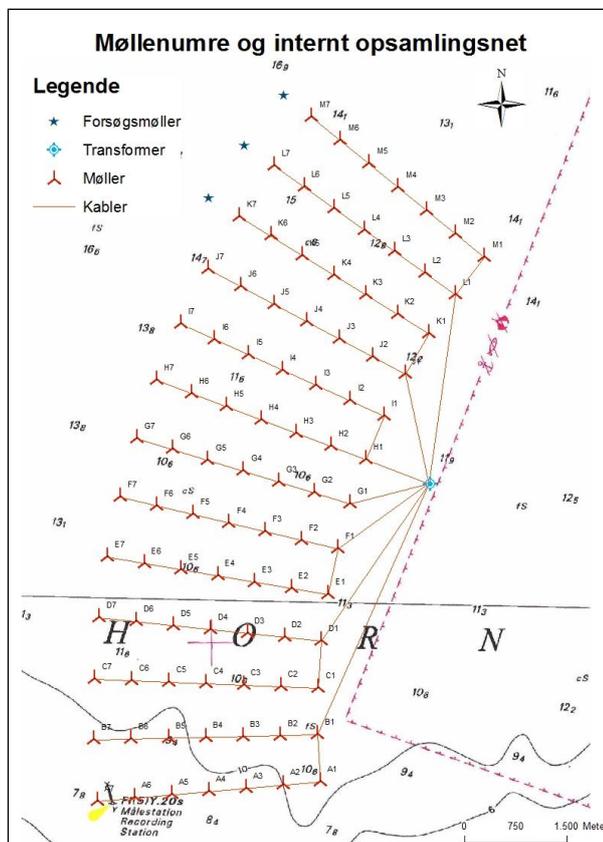

Figure 3-2. Turbine numbers and planned cables for the HR2 OWF.

3.2.2 Free zone

A free zone of 4 km towards the south and west and 2 km towards the north and east has been granted to DONG Energy for this OWF.

3.3 Monitoring requirements for Common Scoter and the need for modelling available food supply

This modelling study is intended to assist the monitoring of Common Scoters. Common Scoters feed almost exclusively on filter-feeding bivalves, and in the Danish part of the North Sea they are known to feed on both *Spisula subtruncata* and *Ensis americanus* (Durinck et al. 1993, Freudendahl & Jensen 2006). The preference for American razor clams seems to be of recent origin, and this preference has been suggested as a possible reason for the dispersal of scoters in the Horns Rev area experienced during the PSO-related monitoring programme. This dispersal pattern of razor clams possibly may affect the presence of scoters near the Horns Rev 2 site. As both primary prey species to Common Scoter in the North Sea occur commonly in the region knowledge of the available supply of both razor clams and trough shells in the site and on Horns Rev in general is critical to the application of a BACI design for monitoring the impact of the wind farm on scoters. Lack of detailed knowledge about the distribution of prey can lead to ambiguous interpretations of monitoring results, and even bias conclusions on possible impacts. The lack of key co-variables is likely to be the single most important obstacle to the use of monitoring data on Common Scoters in relation to offshore wind farm development.

The infauna of the Horns Rev area has been subject of several field campaigns during the PSO-supported programme 2000-2005 (Leonhard 2000, Leonhard & Pedersen 2005, 2006) and during the EIA for the HR2 OWF (Leonhard 2006). As a result the distribution of razor clams and trough shells is relatively well known except for the easternmost part of the area on the western and eastern slopes of Slugen and in Esperance Bugt, where most of the Common Scoter historically has been concentrated. It was therefore decided to supplement the historic infauna data for Horns Rev by quantitative samples from these areas.

Ensis americanus

The knowledge of the selection of razor clams by Common Scoter on Horns Rev stems from only one investigation of the stomach content of 26 individuals of Common Scoter shot at the western edge of the existing Horns Rev 1 OWF in March 2006. This investigation showed that all sampled birds had eaten razor clams (Freudendahl & Jensen 2006). To validate these results supplementary sampling of scoters was organised with a focus on the areas frequented by the majority of the birds during the winter of 2007-2008.

4   METHODS

4.1   Study period

As the statistical power of the BACI design for Common Scoter at the HR 2 OWF to a large degree depends on the use of data from the PSO-programme the food supply models need to cover the period from the onset of the PSO programme in winter 2000 to the termination of the HR 2 monitoring programme in 2013.

4.2   Study area and dynamics of benthic prey organisms

The Horns Rev area is an extension of Blåvands Huk extending more than 40 km towards west into the North Sea. Horns Rev is considered to be a stable landform that has not changed position since it was formed (Danish Hydraulic Institute, 1999). The width of the reef varies between 1 km and 5 km. Blåvands Huk, which is Denmark's' most western point, forms the northern border of the European Wadden Sea, which covers the area within the Wadden Sea islands from Den Helder in The Netherlands to Blåvands Huk. The Horns Rev area has a highly distinctive oceanographic setting, which is characterised by the convergence of estuarine and North Sea water masses and tidal currents and the presence of a striking bathymetry,

Larsen (2003) gives a detailed review of the geological formation of the Horns Rev area. In terms of geo-morphology Horns Rev consists of glacial deposits. The formation of the reef probably took place due to glacio-fluvial sediment deposits in front of the ice shelf during the Saale glaciation period. The constituents of the reef are not the typical mixed sediment of a moraine but rather well sorted sediments in the form of gravel, grit and sand. Huge accumulations of Holocene marine sand deposits, up to 20 m thick, formed the Horns Rev area as it is known today with ongoing accumulations of sand (Larsen 2003). Horns Rev can be characterised as a huge natural ridge that blocks the sand being transported along the coast of Jutland with the current. The annual transport of sand amounts to approximately 500,000 m^3 (Danish Hydraulic Institute, 1999) or even more (Larsen, 2003).

Despite the overall stability, Horns Rev is subject to constant changes due to continuous hydrographical impacts such as currents, waves and sedimentation of sand; the latter of which causes the surface of the reef to rise over time (Larsen 2003). In the HR2 OWF area as well as in most of the Horns Rev area, the sediment consists of almost pure sand with no or very low content of organic matter (<1%) (Leonhard 2006). Formations of small ribbles are seen all over the area, caused by the impact from waves and currents on the sandy sediment. Tidal currents create dunes and ribbles, showing evidence of sand transport in both northerly and southerly directions. Larsen (2003) gives a more detailed review of the sediment flow at and around Horns Rev. All structures in the area apart from those in the tidal channels indicate that the prevailing sediment transport direction east of the reef is towards south and southeast (Larsen 2003). A large spatial variation exists regarding the sediment grain size distribution. Effects of strong currents are found on the slopes facing larger depths, where coarser sand can be found (Leonhard 2006), while the eastern-most parts of the area is dominated by finer sands with

relatively high content of organic matter (this study). Several shallow bank areas are found within the area, of which VovVov is located in the southern part of the planned wind farm, Figure 4-1. An updated model of the horizontal distribution of surface sediments in terms of median grain size is shown in Figure 4-2.
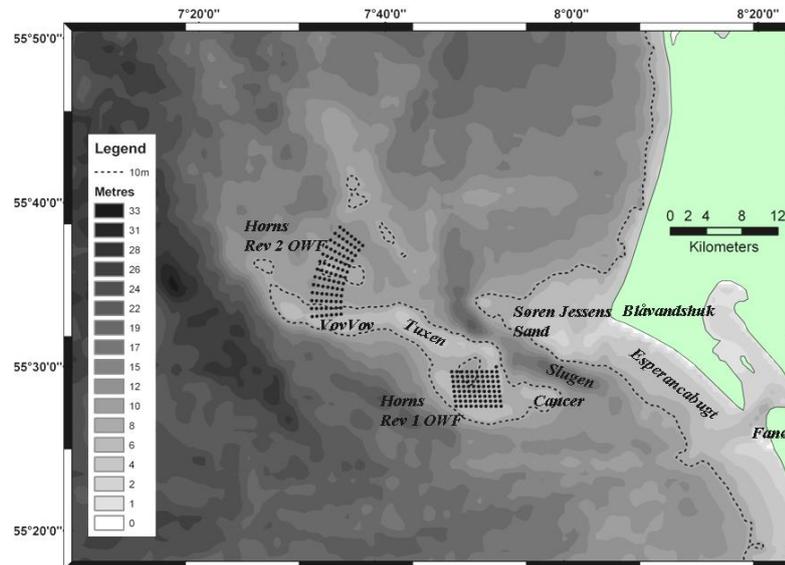
Figure 4-1. Map showing the location of HR1 and HR2 OWFs and places mentioned frequently in the report.

The available data on the presence or absence of both target prey species on Horns Rev, including the data collected during this study are depicted in Figure 4-3. The two species display rather different distribution patterns with trough shells being found mainly in the eastern-most part of the area from Cancer to Esperance Bugt, which is characterised by fine sediments. American razor clams, on the other hand, are found on the reef from Cancer to VovVov and over the sandy plain north of VovVov, including the planned wind farm site. These areas are characterised by medium-sized sediments, and relatively few razor clams inhabitat the fine sand of Esperance Bugt or the coarser sediments on the southwestern slopes of the reef. Overlap in the distribution of the two species seems to be limited to the lower to medium range of sediments. As the razor clams are almost impossible to sample quantitatively due to their ability to escape the sampling equipment the knowledge about their abundance in the above-mentioned areas is very limited. Thus, the empirical data on the distribution of razor clams have been used qualitatively as an indication of either presence or absence, whereas the data on trough shells have been used semi-quantitatively to indicate absence, presence of small or medium abundance or high abundance.
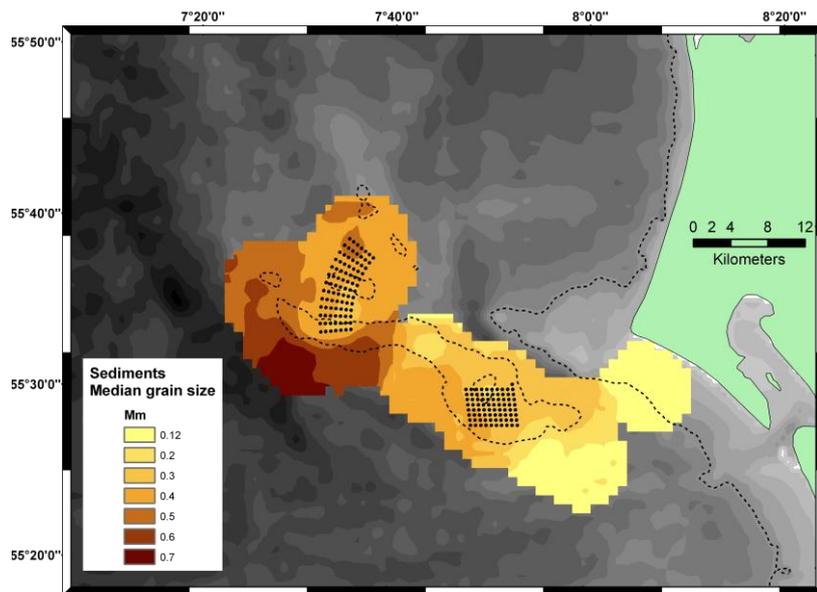
Figure 4-2. Model of the coarse-scale sediment structure on Horns Rev determined by existing data and data collected during this study on median grain size of the surface sediments. The model has been developed using kriging on the basis of an experimental variogram. Areas of Horns Rev excluded from the model were inadequately sampled.

Common scoters sampled at Horns Rev.
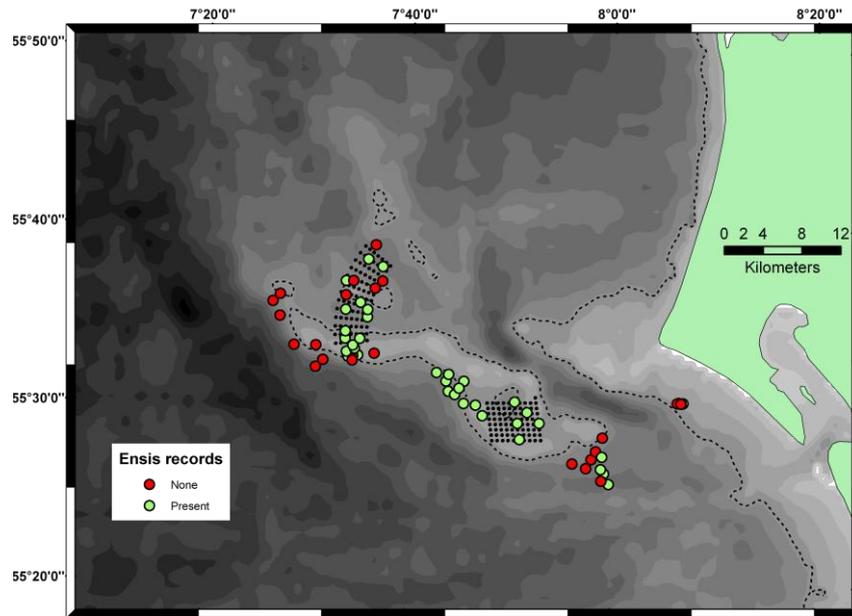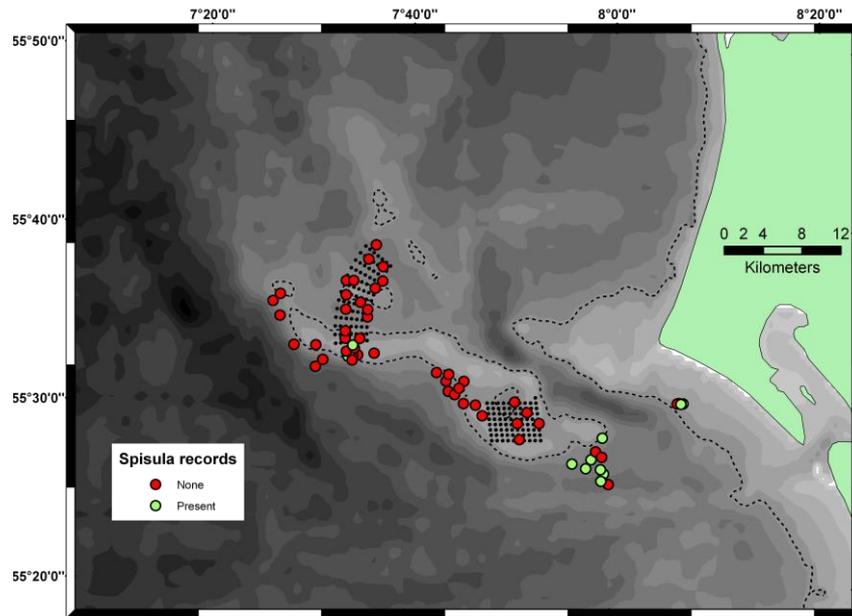
Figure 4-3. Available data on the presence/absence of cut trough shells (top panel) and American razor clams (bottom panel) on Horns Rev from existing data and data collected during this study.

4.3   Hydrodynamic model software

In the following the set-up of the dynamic model of the supply of the two prey species to Common Scoter has been outlined. The model design is based on four model elements:

1.   A regional and local hydrodynamic model

2.   A bio-geochemical model

3.   A deterministic filter-feeder model, and

4.   A habitat suitability model.

The applied hydrodynamic model has been developed on the basis of DHI's model software MIKE 3 HD, which is a fully three-dimensional, non-hydrostatic, primitive equation model (Rasmussen 1991). It is based on the Reynolds-averaged Navier-Stokes equations and the conservation of mass, salinity and temperature. The prognostic variables are fluid pressure, the three velocity components and the two scalar quantities salt and temperature. The partial differential equations are separated onto a C-grid using a second-order accurate finite difference technique. The solution is advanced in time using an ADI technique combined with the artificial compressibility method proposed by Chorin (1967).

MIKE 3 HD includes different turbulence closures of which the standard k-ε model is the most advanced. In this model setup the k-ε model is applied for the vertical description and the Smagorinsky eddy viscosity formulation were employed for the horizontal description. The scalar quantities, salt, temperature and also the state variables of the bio-geochemical module ECO Lab are modelled using the accurate third-order advection-dispersion scheme QUICKEST proposed by Leonard (1979) and extended to three dimension by Vested et al. (1992), combined with the SHARP scheme (Leonard 1988). The SHARP scheme is used wherever steep gradients in the scalar fields are encountered, to avoid spurious over- and undershooting.

At open boundaries a Dirichlet or Neumann boundary condition is applied whereas a zero-flux boundary is applied to solid walls. At the seabed a quadratic drag law is applied assuming a logarithmic velocity profile just above the seabed. A similar quadratic drag law is employed at the surface where a balance between the wind stress and the ocean stress is assumed.

4.4   Bio-geochemical software

For this study a bio-geochemical model has been developed and adapted into the DHI integration module ECO-Lab. The state variables included in the model are phytoplankton carbon (C), nitrogen (N) & phosphorous (P), zooplankton C, detritus C, N & P, inorganic N & P, dissolved oxygen and chlorophyll-a. The fluxes of C, N & P are presented in Figure 4-4.

The most important element in the model is the growth of phytoplankton. The growth of phytoplankton is mainly controlled by nutrient availability, sedimentation, turbidity, temperature and solar radiation. Bacterial degradation of organic matter in the water phase and in the sediment releases inorganic nutrients which then become available for new primary production in the photic zone.
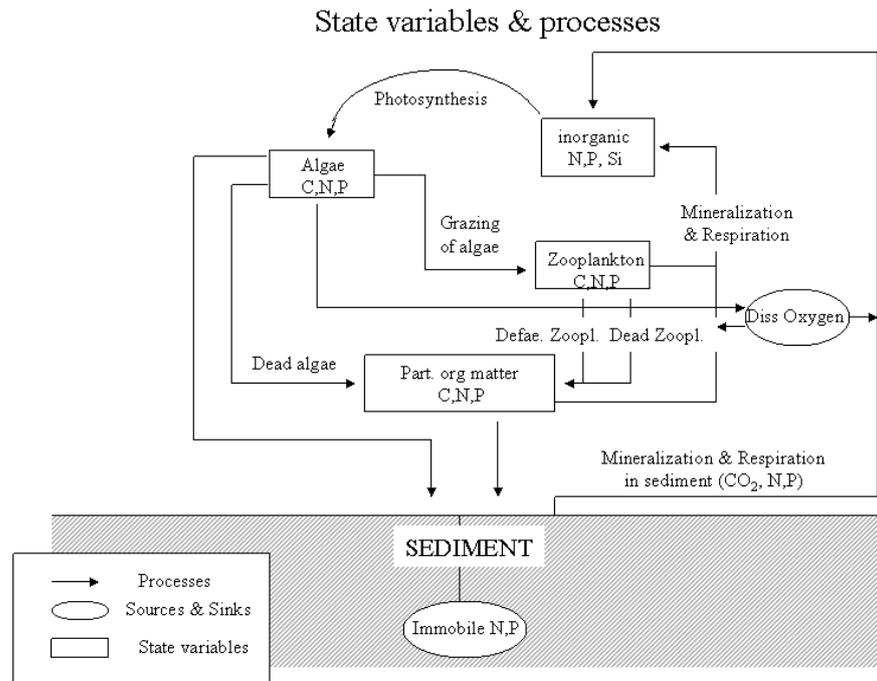
Figure 4-4. A schematic flow diagram of state variables and processes in the standard eutrophication model.

Grazing on phytoplankton by zooplankton (including other filtrators) can have a regulating effect on the phytoplankton biomass; hence, grazing on algae is modelled explicitly. The model does not include secondary producers at a higher level than zooplankton. Grazing (e.g., by fish) on zooplankton is handled indirectly by applying a higher death rate for zooplankton. Grazing and decay transforms phytoplankton to zooplankton and detritus, respectively. The processes involved do however also transform a small part of the phytoplankton N & P directly into inorganic N & P, the latter accounting for an internal microbial loop.

The organic material produced in the surface (or subsurface waters) will settle with time. The bacterial degradation of this material in the sediment and in the water column utilizes oxygen and can depending, among other things, on the strength of the pycnocline, result in anoxic conditions. The model does not specifically include bacterial biomass, but the effects of bacteria are parameterized mainly based on temperature. In the biochemical model the dependency of nutrients on growth of phytoplankton is described in a two-step process. Firstly, the inorganic nutrients are taken up into an internal pool in the algal cells. Secondly, nutrients from this pool are utilized in production of organic matter. This approach has proven to be very strong in modelling growth of phytoplankton.

The release of nutrients from the sediment is simulated in the model by a relationship between the actual sedimentation rate and the water temperature. Thus, the model describes the system in a situation with equilibrium with respect to input-output to the sediment. The basic module and the different governing processes included are described in more detail in (DHI, 2000).

4.5 Model set-up

The model setup was developed and used in Edelvang et al. (2005) and Edelvang et al. (2001). Subsequently, the model area was enlarged and the bio-geochemical model refined as part of the NOCOMMENTS project (DHI 2001) and establishment of an operational water forecast service (www.waterforecast.com), see also Sørensen et al. (2002) and Erichsen & Rasch (2001). The model was furthermore refined in (DHI 2003). The model area covers the entire Baltic Sea, the transition area and the North Sea, with an open boundary to the north between Stavanger and Scotland (latitude app. 59°) and an open boundary to the south-west in the English Channel (latitude app. 51°). The model area is shown in Figure 4-5.

The applied model is set up with a horizontal resolution of 9 nm (nautical miles). However, in the transition area between the Baltic Sea and the North Sea, including the coastal areas west of Denmark and Horns Rev, an interactive two-way nesting technique is applied allowing a grid resolution of 3 nm in this area, Figure 4-5. The bathymetry of the model domain is based on available surveys. However, some adjustments have been made in the narrow Danish Straits to ensure an appropriate representation of the deeper trenches, which are very important for the formation of the stratification in the Belt Sea.

MIKE 3 is a z-layered model, and the vertical resolution in this setup is 2 meters between –6 and –220 m, giving 110 z-layers. Below –220 m a bottom-boundary fitted approximation is applied to the remaining part of the local water column. The surface layer varies with the free surface elevation and extends down to level –6 m (or local depths at shallower depths). The model is run with a time step of 300 sec.
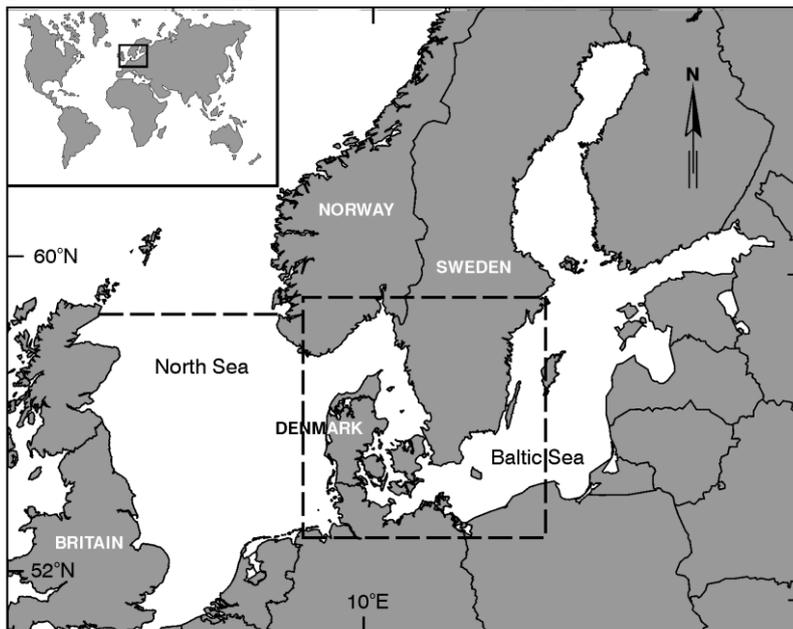
Figure 4-5. The regional model area. The dotted line between Scotland and Norway indicates an external boundary whereas the dotted square shows the area with the finer grid resolution.

4.6 *Boundaries and forcings*

To run the hydrodynamic model, external forcing, boundaries, and initial conditions are required. The required data and their origin are listed in Table 0-1.

Table 0-1. Data required to run the model.

HYDRODYNAMIC MODEL	Data origin
Open marine boundaries	
Astronomical tides (corrected for actual atmospheric pressure)	
Climatological[1] values of temperature and salinity distribution in sections (linearly interpolated to cover the entire sections)	ICES[2] database (on request)
Initial fields	
North Sea and Baltic Sea; Salinity, temperature	ICES database (on request)
Interconnecting Seas; Salinity, temperature	NERI[3] (MADS database)
Run-off	
Actual monthly values of flow for Danish, Swedish, Norwegian rivers to Skagerrak, Kattegat, and the Belt Sea	NERI SMHI[4] (on request) IMR[5] (on request)
Actual daily, weekly or monthly values of flow, water temperature and nutrients (N and P) for German, Dutch and English rivers[7]	HYDABA1[8] (on request) NLWKN[9] (on request) Service Desk Data[10] CEH[11] (on request) Environment Agency[12] (on request) SEPA[13]
Climatological[1] values for the remaining rivers (Belgium, Germany, Poland, Norway, Russia, Finland, Sweden)	HELCOM/OSPAR
Air-sea exchange	
Climatological[1] values of net precipitation	
Actual 3-hourly 10 m wind and air pressure fields	HIRLAM, DMI[6]
Actual 3-hourly 2 m air temperature fields	HIRLAM, DMI[6]
Climatological[1] clearness information	

1) 10 years of monthly mean.
2) International Council for the Exploitation of the Seas, see http://www.ices.dk for further information.
3) National Environmental Research Institute, see http://www.neri.dk for further information.
4) Swedish Meteorological and Hydrological Institute, see http://www.smhi.se for further information.
5) Institute of Marine Research, see http://www.imr.no for further information.
6) Danish Meteorological Institute, see http://www.dmi.dk for further information.
7) These data were updated in this study (Table 4-2).
8) Hydrological database. Federal Institut of Hydrology.see. http://www.bafg.de for further information
9) Niedersächsischer Landesbetrieb für Wasserwirtschaft, see http://www.nlwkn.de for further information.
10) Rijkswaterstaat Centre for Data and ICT, see http://www.waterbase.nl for further information.
11) National River Flow Archive. Centre for Ecology & Hydrology, see http://www.ceh.ac.uk.
12) Environment Agency, see http://www.environment-agency.gov.uk for further information.
13) Scottish Environment Protection Agency, see http://www.sepa.org.uk for further information.

With respect to the North Sea boundary no modifications have been made to account for reference conditions. This might cause some interference in the Skagerrak and potentially in Kattegat. However, the direct transport from the North Sea boundaries is small, and less significant than the loadings from the German and Dutch rivers (which have been reduced properly). The effects from these rivers are regarded as much more important. Furthermore, the northern boundary is close to North Atlantic waters which are less influenced by anthropogenic loadings.

Table 0-2. Names of rivers and measuring stations for data on discharge (Q, m^3 s^{-1}), water temperature (T, ºC) and nutrients (N, mg/l). Location of the river outflows in the model setup and the measuring stations is shown in Figure 4-6.

River	Country	Source no	Station no	Station	Q	T	N
Elbe	DE	S16	16Q	Neu Darchau	X		
			16T	Hohnstorf		X	
				Seemannshöft			X
Weser	DE	S15	15Q	Intschede	X	[2]	
			15N	Uesen			X
Ems	DE	S17	17Q	Versengesamt	X		
			17T	Knock		X	
			17N	Gandersum			X
Rhine	DE	S12	12QT	Rees	X	X	
	NL		12N	Maassluis			X
Maas	NL	S18	18QTN	Haringvliettsluizen	X[1]	X	X
IJssel	NL	S13	13Q	Kornwerderzand Buiten	X		
			13TN	Vrouwezand		X	X
Scheldt	NL	S83	83QTN	Schaar van Ouden Doel	X[1]	X	X
Thames	UK	S19	19Q	39001, Thames at Kingston	X	X	X
Humber	UK	S69	69Q	27009, Ouse at Skelton	X	X	X
Tweed	UK	S71	71Q	21009, Tweed at Norham	X	X	X
Tay	UK	S84	84Q	15013, Almond at Almondbank	X[1]		
			84QTN	Perth at Queens Brirdge		X	X
Spey (Moray)	UK	S85	85Q	8006, Spey at Boat o Brig	X		
			85TN	Spey at Fochabers		X	X
Forth	UK	S70	70QTN	18011, Forth at Craigforth	X	X	X

[1] 2007 missing, data not available yet, filled in with daily average of 2000-2006
[2] no data record of temperature, data from the other German rivers used

4.6.1 Runoff

The runoff to the model domain is represented by 85 source points of which 13 sources to the North Sea were updated in this study, Table 4-1. The position of the runoff sources are illustrated in Figure 4-6.

The Danish sources are actual runoff discharges and nutrient concentrations taken from the annual reporting from NERI (2006 sources are estimated based on actual rainfall). The German, Dutch and English sources to the North Sea are also actual runoff data provided as mentioned in Table 4-1. The Baltic Sea sources are mainly made available via the BANSAI (BANSAI) project and the former NO COMMENTS project (DHI Water & Environment 2001). Load compilation data from around year 2000 from HELCOM and OSPAR has been applied where actual data has not been available.
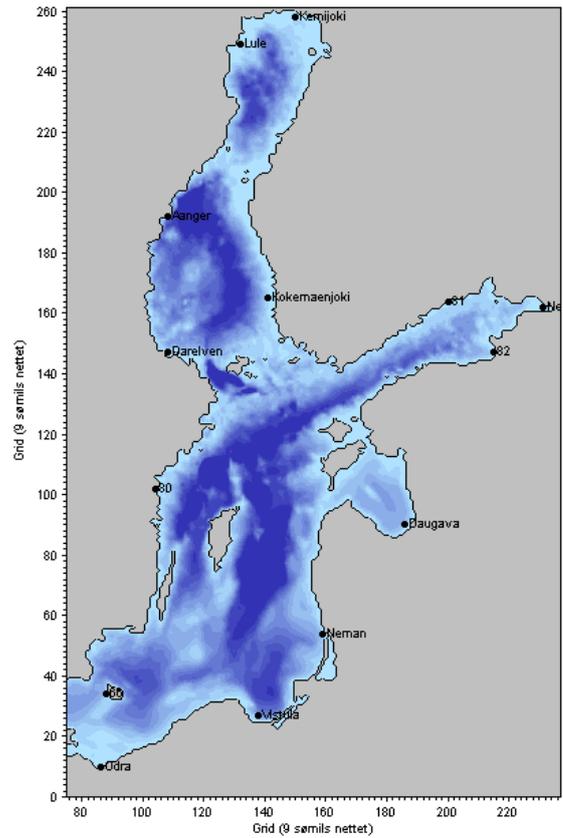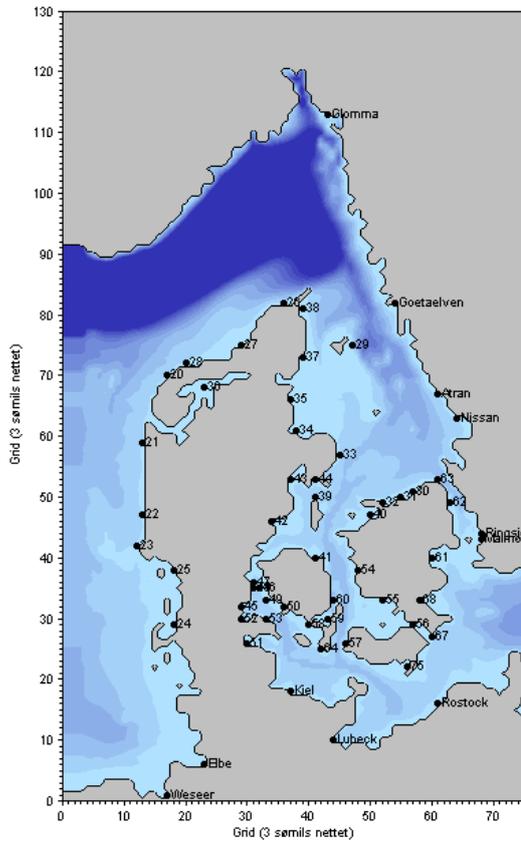
Figure 4-6. Runoff positions for the 85 freshwater sources.
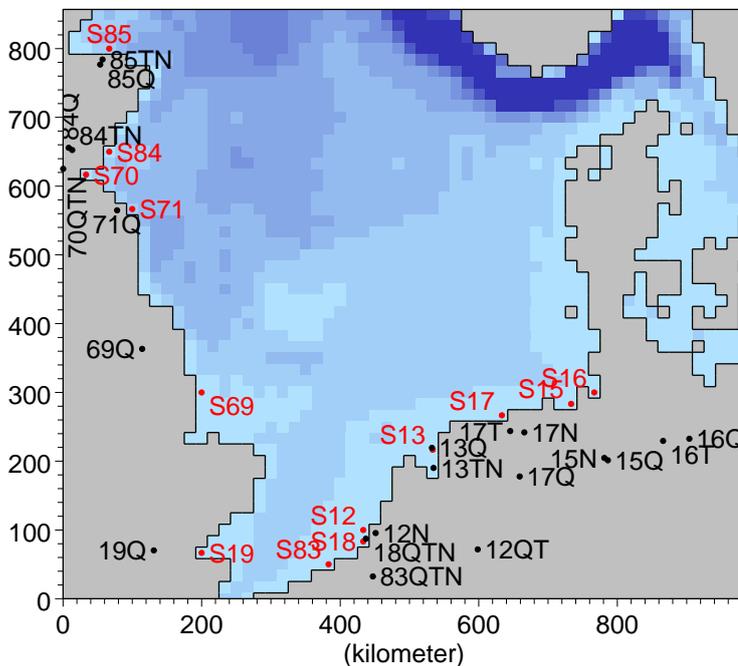
4.6.2 Filter-feeder model

Two different carrying capacity (CC) models were established for razor clams and trough shells using the output from the hydrodynamic and geo-biochemical models. Both CC models build on the same concept by combining a physiology-based growth model for a standard individual with an advection term that replenish the food ingested by filter-feeders. On large scale CC depends on the local primary production and on smaller scale current speed plays an increasing role for CC.

The energy balance of a filter-feeding bivalve can be expressed as: $I = P + R_t + F$, where I = ingestion; P = growth, R_t = total respiration (sum of maintenance respiration, R_m, and respiratory cost of growth, R_g), and F = excretion. Rearranging, growth is expressed as $P = I \times AE - (R_m + R_g)$ or $P = (F \times C \times AE) - (R_m + R_g)$, where $AE = (I - F)/I =$

assimilation efficiency, F = filtration rate, and C = algal concentration. In the individual bivalve growth depends on the quantity (C) and quality of suspended food particles including different species of algae, ciliates and zooplankton organisms along with suspended inorganic material (silt). The maintenance food concentration (which just is sufficient for zero growth) and the maximum growth rate for a standard-sized bivalve differs between species and between populations within species as result of adaptation to local composition and concentration of food (Kiørboe at al. 1981, Kiørboe & Møhlenberg 1981).

Energetic growth models are available for many filter-feeders, including *Spisula subtruncata* (Møhlenberg & Kiørboe 1981), but to our knowledge energetic growth studies have not been published for any razor clam (based on literature survey and consulting of Prof. H.U. Riisgård, University of Southern Denmark). Therefore, the proposed model for *Ensis americanus* has been established based on rather anecdotic information on razor clams (Freudendahl & Nielsen 2005, and references therein) but also including information on growth energetics from other bivalves, especially *Mytilus edulis* (Kiørboe at al. 1981; Kiørboe & Møhlenberg 1981).

Important documented evidence for food requirements for *Spisula subtruncata* Figure 4-7 include a rather high maintenance food concentration of 0.072 mgC/l, and that suspended bottom material (i.e. detritus) can constitute up to 30% of assimilated food (Møhlenberg & Kiørboe 1981). Based on the modelled detritus concentration in the model area 5% of detritus was assumed to be available for assimilation, hence a growth equation fitted to observed data was developed using non-linear curve-fitting:

For food concentration (PC +0.05*DC) less than 0.072 mg C/l:

Gf = 2.55*(PC+0.05*DC-0.1833

For food concentration (PC +0.05*DC) above 0.072 mg C/l:

Gf = (PC+0.05*DC-0.072)/(PC+0.05*DC-0.057))

Where PC is phytoplankton carbon (mg/l) and DC is detritus carbon (mg/l)
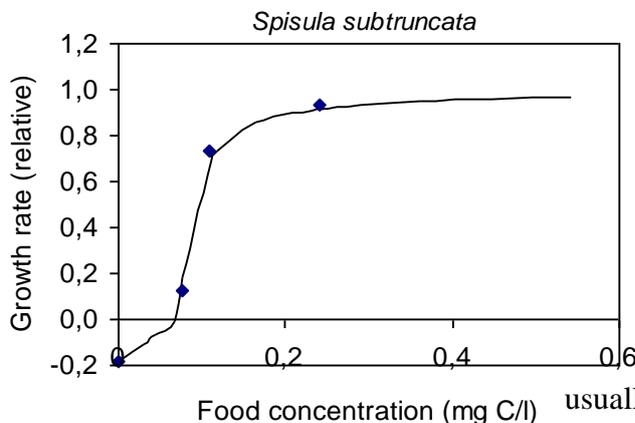
Figure 4-7. Relative growth rate as function for food concentration in Spisula subtruncata. Modelled data and observations (♦) shown.

The growth equation for *Ensis americanus* Figure 4-8 was assumed to differ from the growth equation for *Spisula* in two aspects: (1) "growth of juveniles was reduced at high algal concentrations" (Freudendahl & Nielsen 2005) which usually implies that food sorting capacity is rather low (Kiørboe et al 1981), i.e. detritus plays a minor role as food and, (2) that *Ensis* approaches the maximum growth rate at lower food (algae) concentration compared to *Spisula*, (3) the ventilation rate and oxygen uptake in razor

clams are relatively unaffected by low oxygen concentrations as in cockles (Salánki 1966) which indicate a higher weight loss during starvation. Below is shown the assumed growth function for *Ensis*, but it should be kept in mind that the equation is not based on hard evidence, but an interpretation of observations from different sources.

For food concentration (PC +0.02*DC) less than 0.040 mg C/l:

Gf = 5*(PC+0.02*DC-0.23

For food concentration (PC +0.02*DC) above 0.04 mg C/l:

Gf = (PC+0.02*DC-0.04)/(PC+0.02*DC-0.01))
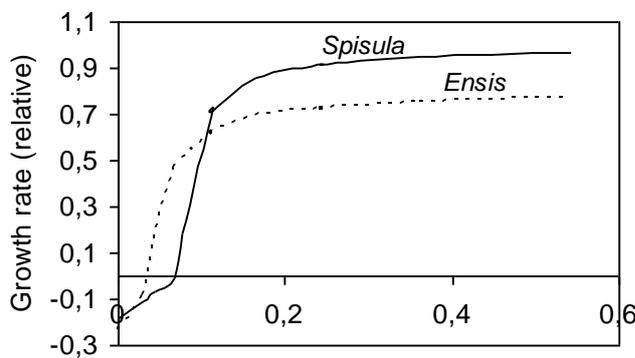
Figure 4-8. Comparison of functional response in Spisula subtruncata and Ensis americanus.

The growth functions, Figure 4-8, described above relate to individual bivalves surrounded by food at constant concentrations. In nature, filter-feeding bivalves aggregate in dense assemblages if current speeds are high, e.g. in tidal areas as the Wadden Sea. In low-current environments plankton algae removed by filtration are only slowly replenished and such environments cannot sustain dense populations. Therefore, the growth functions need to be supplemented by an equation that describes the replenishment of food.
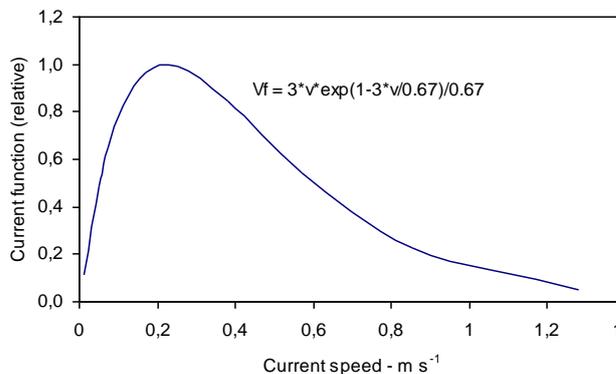
Figure 4-9. Current function to describe food replenishment and physical stress in filter-feeding bivalves.

Effect of current speed on growth in individual filter-feeding bivalves has rarely been studied. One example relates to giant scallop (*Placopecten magellanicus*), where growth rate increased until an optimal speed of 0.15 m s^{-1}, but at larger current speeds the growth decreased as currents interfered with filtration behavior (Wildish et al. 1987). In *Mytilus* in situ growth rate increased with current speed (Riisgård et al. 1994) and wind-induced turbulence (Sand-Jensen et al. 1994). We are not aware of studies where an optimum current speed has been identified, but it is likely that bivalves in benthic environments consisting erodible substrate such as sand cannot maintain their position at current speeds larger than 0.6-1.0 m s^{-1}. To that end we have constructed a bell-shaped current function with an optimum speed at 0.3 ms^{-1}, Figure 4-9.

The individual growth function can then be combined with the current function to a carrying capacity index reflecting both individual growth conditions and the density of bivalves that can be sustained: CC index = Gf * Vf

Controlled experiments of the effects of current speed on growth have only been carried out on oysters, which showed an increase until an optimal current speed of 15 cm s^{-1}, after which the growth started decreasing. Other bivalve species such as blue mussels increase growth in the field with increasing current speed and wind-induced turbulence until a plateau. This is generally interpreted as a consequence of increasing food availability. Mussels which are settled on substrate like cliffs, stones and foundations may survive and grow in even very energy rich environments (e.g. in current speeds > 60-80 cm s^{-1}), while blue mussels on sandy sediments are unable to establish long-living populations at current speeds exceeding 40-50 cm s^{-1}, probably as a result of erosion.

Based on their distribution both bivalve species seem to prefer full salinity even though some razor clams like *Ensis ensis* probably can tolerate some reduction in salinity which occurs during precipitation events on the intertidal flats (Hill 2006). In contrast, *Spisula solida* (unfortunately, no information is available on *Spisula subtruncata*) seems less tolerant to reductions in salinity (Sabatini 2007) even though firm information is lacking. To account for influence of salinity in CC-indices we have applied two different functions based on the information available. Specifically, at salinities below 20 and 25 psu *Ensis* sp. and *Spisula* are excluded and at salinities above 30 and 35 psu they are not influenced by variations in salinity. Linear function is applied between these two extremes.

The carrying capacity index was included in the geo-biological model as a 3-dimensional variable. Following the model simulations the 3-dimensional coarse (9 nm) index was transformed into 2-dimensional and finer grids (1/3 nm or 617 m) describing the actual bottom index-values in the corresponding depth of the 617 m bathymetry.
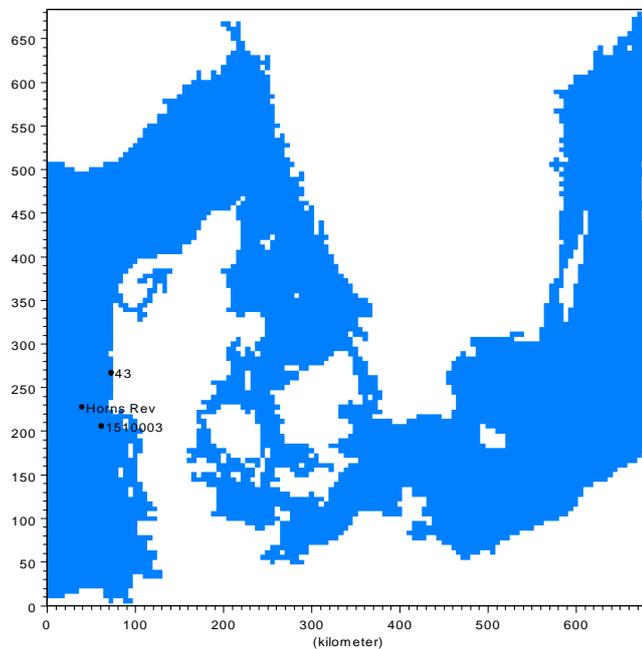
However, since the surface layer in the geo-biological model is 5 m, no variation was found in shallow areas. The index for depth between 0-5 m was therefore corrected with a function describing increasing food availability with increasing depth:

$$CCindex_{0-5m} = CCindex_{0-5m}*1.75*(depth+0.15)/(depth+4)$$

Figure 4-10. Location of the measuring stations and Horns Rev.

4.6.3 Calibration

The model results have been evaluated against measurement north and south of Horns Rev. However, only few measurements are available in the area for the modelled years, and only measurements in the coastal areas. For now, no measurements are available/exist in the more open parts of the North Sea. Measurements applied in the evaluation origins from the two stations: 43 and 1510003, Figure 4-10.

The model results have been compared against measurements of salinity, temperature, chlorophyll-a and dissolved oxygen for the station 1510003 and 43. Station 1510003 is located south of Horns Rev and is located in an area with expected high gradients of nutrients, suspended material, and salinity. Station 43 is located north of Horn Rev and is located rather close coast which will imply some variations when compared with the model results and the resolution of the model alone will not make it possible to meet the measurements exactly.

4.7 Sediment and benthos samples

Collection of calibration data on the distribution of American razor clams *Ensis americanus* was planned performed using a commercial mussel sucking vessel. Only one such vessel is available in Denmark, and this vessel was not mobilised within the time for sampling.

An alternative sampling method was applied during one field campaign 27th March using a standard triangular dredge operated from a RIB. The dredge was operated in the Esperence Bugt and at south of the ground Cancer

Using the standard triangular dredge only mussel data from the most near shore locality in Esperance Bugt was obtained. At the wind farm site (Horns Rev2) no live mussels were collected but more empty shells of razor clams. This was probably caused by malfunction of the dredge due to firmly compacted sand at the wind farm site.
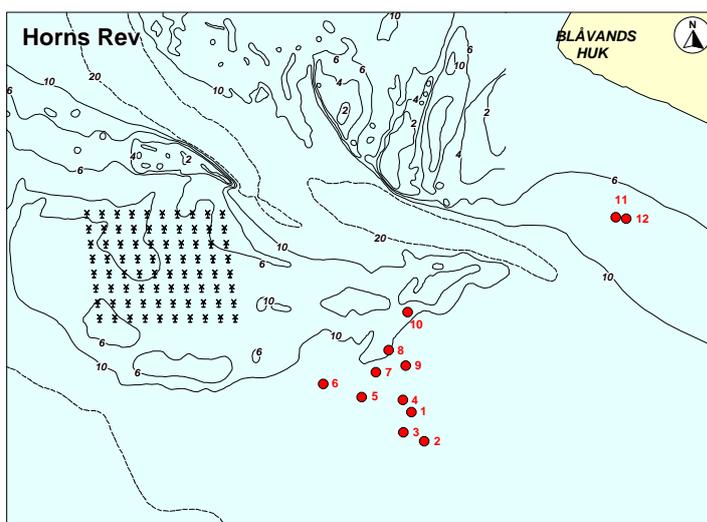
Figure 4-11. Sampling sites for mussels and sediments at Horns Rev using the Van Veen grab.

The 9th April at approximately the same positions for collecting common scoters, Figure 4-11, mussels and sediment were sampled using a Van Veen grab bottom sampler operated from "m/v Salling".

Samples for identification of mussel species and biomass were carefully sieved through a 1.0 mm test sieve and the material retained was preserved in 96% ethanol, which is equivalent to approx. 80% when taking the water content of the sample into consideration.

Each mussel species were numbered and biomass DW was measured for each species. Other benthic species were noted.

The shell length of the mussels, i.e. the longest distance between anterior end and posterior end were measured by means of electronic slide gauge. All mussel data was entered and stored into a fauna database.

Sediment was characterised by analyses for grain size distribution, dry matter content and the amount of organic material measured by combustion loss. Dry matter content was measured as a percentage of the wet weight. The combustion loss was measured as a percentage of the dry weight. The samples were treated according to DS 405.11 and DS 204. The sediment was washed in distilled water to remove any remaining salts and dried at 105°C until constant weight was obtained. The sediment was pre-treated with hydrogen peroxide to remove organic material.

Grain size distribution was determined using a combination of sieve analysis and sedigraph technique. Sieve analysis was used for the sand fraction, i.e. all the material retained by a 63µ sieve according to a modified standard DS 405.9 using a total of 15 sieves.

A sedigraph 5,100 was used for analysis of the silt/clay fraction, i.e. all the material passing through a 63µ sieve. The sediment was pre-treated with a 0.005 molar solution of sodium pyro phosphate and treated with an ultrasound vibrator for 5 minutes.

Cumulative percentage curves of the sieve and the sedigraph analysis data were prepared and their characteristics described by means of median particle diameter and measured as the point at which the 50% abscissa intersects the cumulative percentage curve.

On the basis of sediment statistics, a sorting index was calculated. Sediments with a sorting index less than 0.5 were characterised as well-sorted. A sorting index of 0.5–1 characterises sediments as medium-sorted, while a sorting index of >1 characterises sediments as poorly sorted.

4.8   Dietary studies
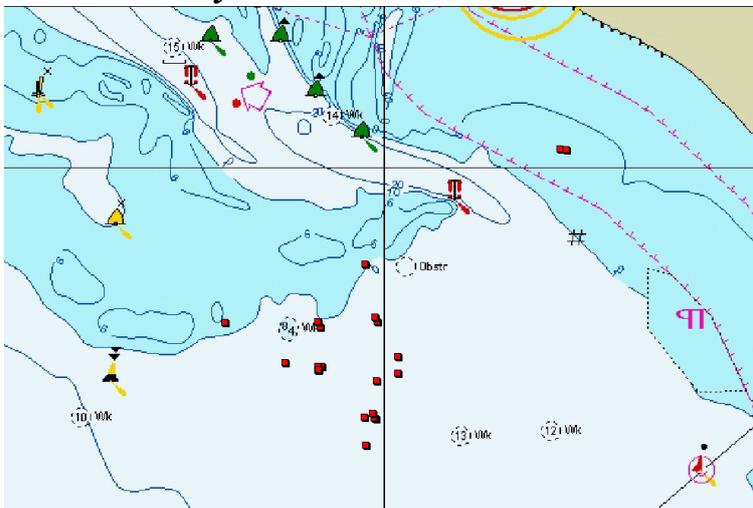
Thirty Common Scoters were sampled in Esperance Bugt and south of Cancer on 27th March and 9th April 2008, Figure 4-12.

Figure 4-12. Sample locations of Common Scoters marked by red squares.

These two areas held approximately 90 % of the birds during the winter 2007-08. This was legally based on a dispensation from the hunting laws given by the Danish Forest and

Nature Agency. The sample consisted of 5 female and 25 male birds. The birds were kept frozen and stomachs subsequently taken out and analysed in a laboratory.

One bird was shot through and the stomach was destroyed. The stomachs of the remaining birds were studied following the methodology described in Durinck et al. (1993). Food remains from the oesophagus and gizzard were gently flushed out, identified and measured.

4.9 Data analyses

4.9.1 Development of habitat suitability model for Ensis americanus and Spisula subtruncata

Although the carrying-capacity models for razor clams and trough shells provide key information on the potential conditions for sustained growth of the species in the Horns Rev area the actual distribution of the two species can only be estimated by the addition of geo-morphological parameters. This was done within the frame of habitat suitability modelling using the modelled sediment data and data on the depth and relief of the sea floor. The presence-absence data on the two species were collated into a GIS layer with 1,000 m resolution in UTM 32 projection. Normalisation of the eco-geographical GIS layers and modelling of covariance matrix, Ecological Niche Factor Analysis (ENFA) and habitat suitability scores were carried out using a combination of ArcGIS version 9.1, Biomapper version 3.0 and Idrisi version 3.2. All variables were normalized through the 'Box-Cox' algorithm (Sokal and Rohlf 1981), although ENFA is not considered very sensitive to the frequency distribution of variables (Hirzel et al. 2002).

Suitability functions were computed by comparing the distribution of the razor clams and trough shells in the multivariate oceanographic space encompassed by the recorded presence data with the multivariate space of the whole set of cells in the study area (Hirzel 2001). On the basis of differences in the bivalve and the global 'space' with respect to their mean and variances, marginality of bivalve records was identified by differences to the global mean and specialisation by a lower species variance than global variance. Thus, for large geographical areas like the part of the North Sea studied here, ENFA approaches Hutchinson's concept of ecological niche, defined as a hyper-volume in the multi-dimensional space of ecological variables within which a species can maintain a viable population (Hutchinson 1957). For reasons of clarity we chose to select only 5 eco-geographical variables for ENFA:

> The modelled filter-feeder index for each of the two species averaged for the entire growth season from March to November between 2000 and 2008;
> Modelled sediment structure;
> Water depth;
> Slope of the sea floor slope (in %) estimated from the formula of Monmonier (1982);
> Complexity of the sea floor calculated for 5x5 kernel: $F = (n-1)/(c-1)$ Where n = number of different classes present in the kernel, c = number of cells.

Marginality (M) was calculated as the absolute difference between the global mean (Mg) and the mean of the bivalve presence data (Ms) divided by 1.96 standard deviations of the global distribution (g)

$$M = \frac{\left| M_g - M_s \right|}{1.96\,\sigma_g},$$

while specialisation (S) was defined as the ratio of the standard deviation of the global distribution to that of the species distribution

$$S = \frac{\sigma_g}{\sigma_s}.$$

To take account of multi-colinearity and interactions among eco-geographical factors, indices of marginality and specialisation were estimated by factor analysis; the first component being the marginality factor passing through the centroid of all bivalve presence records and the centroid of all background cells in the study area, and the index of marginality measuring the orthogonal distance between the two centroids. Several specialisation factors were successively extracted from the n-1 residual dimensions, ensuring their orthogonality to the marginality factor while maximising the ratio between the residual variance of the background data and the variances of the bivalve occurrences. A high specialisation indicates restricted habitat usage compared to the range of conditions measured in the studied part of Horns Rev. Obviously, ENFA is highly sensitive to the location and size of study area, and it is should be born in mind that due to the coverage of the sediment model the entire Horns Rev area could not be included in the habitat suitability model.

A habitat suitability index was computed on the basis of the marginality factors and the first three specialisation factors, as a high proportion of the total variance was explained by the first few factors, by comparison to a broken-stick distribution. The habitat suitability algorithm allocated values to all grid cells in the study area, which were proportional to the distance between their position and the position of the species optimum in factorial space. We used the medians algorithm for habitat suitability computation.

5 QUALITY CONTROL

All routines of the field inventory was checked according to an internal quality plan. Data entry into the database was checked according to an internal quality plan.

General quality assurance and management were conducted and documented in accordance with internationally accepted principles for quality and environmental management as described in the DS/EN ISO 9001 standard.

6 RESULTS

6.1.1 Small-scale patterns of filter-feeder indices
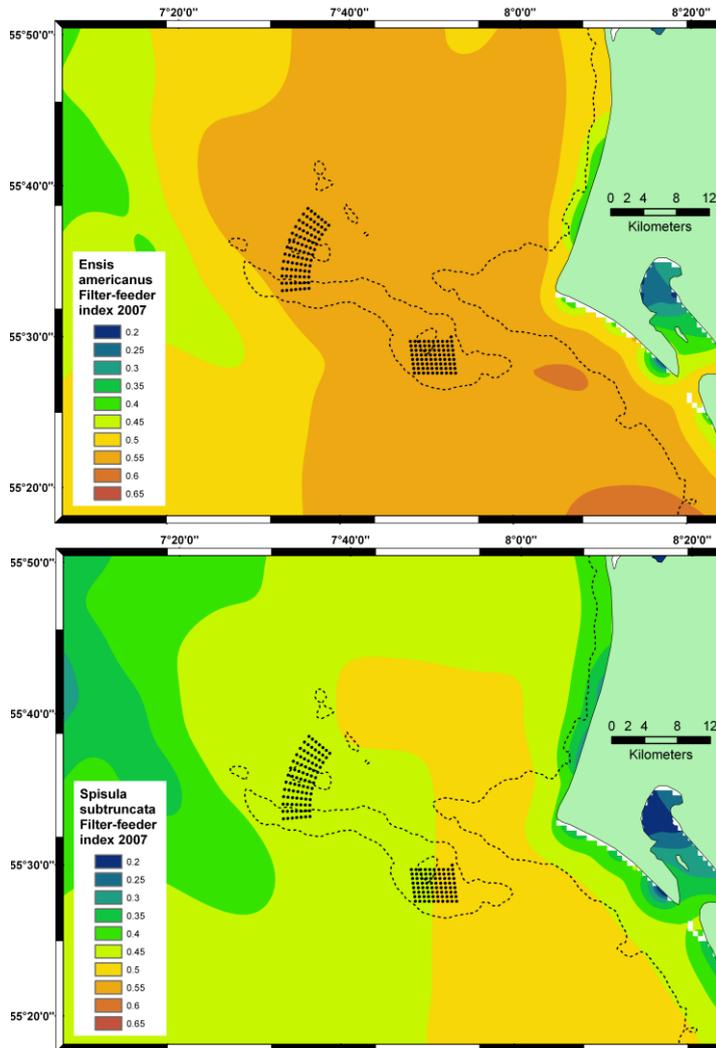
The output from the carrying capacity models elucidated similar spatial trends in the indices over the Horns Rev area both between the two species and between years, Figures 6-1 and 6.2. Both models displayed high index values from the 5 m depth contour to the area west of the HR2 OWF; the *Spisula* model indicating highest index values from the 10 m curve to HR1 OWF. West of Horns Rev the filter-feeder indices dropped to lower values in the whole region. In Figure 6-1 only the results from 2007 are shown.

Figure 6-1. Small-scale patterns of the average filter-feeder indices for American razor clam and cut trough shells for 2007.
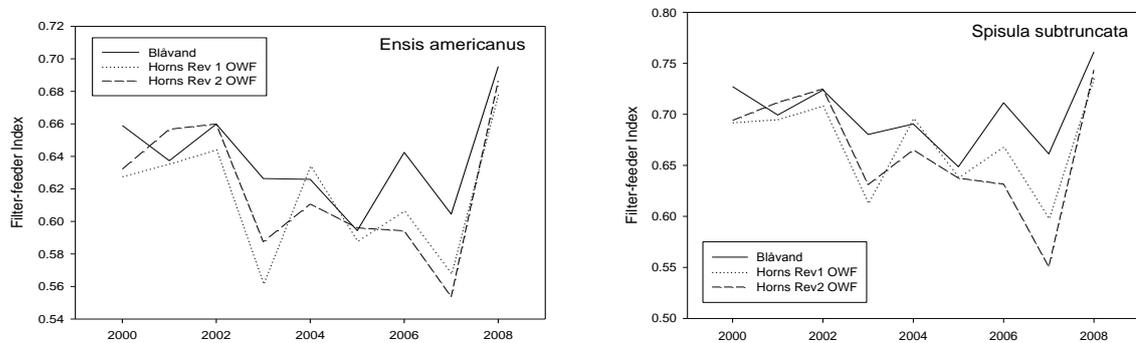
Figure 6-2. Time series of filter-feeder indices for American razor clam and cut trough shell on three selected locations.

6.1.2 Habitat suitability models for *Ensis americanus* og *Spisula subtruncata* at Horns Rev

The combination of the carrying capacity indices and physical habitat characteristics by means of habitat suitability models provided insight into the potential distribution of the species during the period from 2000 to 2008. Although the CC-indices may show strikingly clear patterns it should be born in mind that these do not relate directly to the abundance or distribution of the two species. Application of ENFA provided an overall marginality of $m = 3.92$ and an overall specialization value of $S = 2.734$ for *Ensis* and $m = 0.527$ and $S = 4.654$ for *Spisula*, showing that Horns Rev habitats for the two species during 2000-2008 differed markedly from the mean conditions in the studied part of the North Sea.
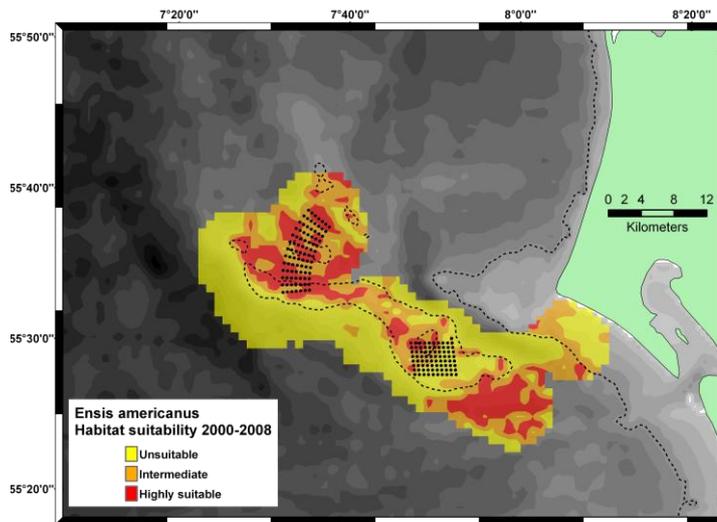
Figure 6-3. Modelled suitable habitat for American razor clam on Horns Rev for the period 2000-2008 (see text for details).

The three factors retained accounted for more than 93 % of the sum of the eigenvalues (that is 100 % of the marginalization and 95 % of the specialization). Marginality accounted for 50.9 % of the total specialization in *Ensis* and 81.6 % in *Spisula*. The two first specialization factors accounted for 41 % of the total specialization in *Ensis* and 11.7 % in *Spisula*, indicating that the two species are moderately restricted in the range of conditions they utilize in the study area, with trough shells being more restricted.

Marginality coefficients showed that razor clams were (positively) linked to water depth, areas with relatively flat terrain and carrying capacity index, while trough shells showed strong links to median grain size (negative coefficient) and carrying capacity index.
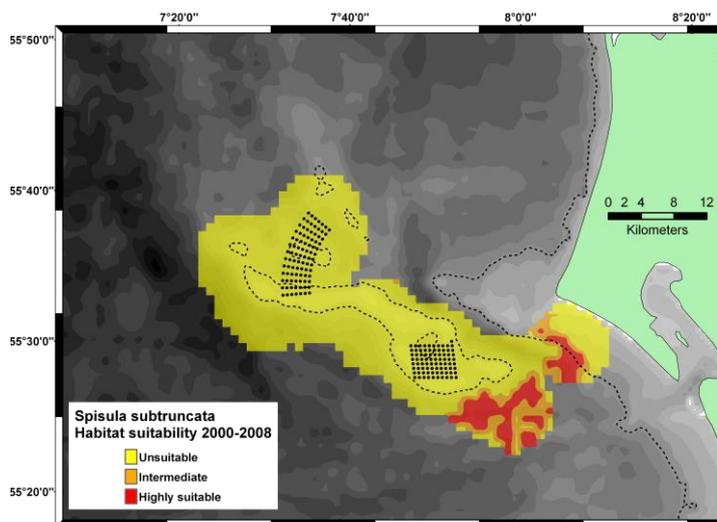
Figure 6-4. Modelled suitable habitat for cut trough shell on Horns Rev for the period 2000-2008 (see text for details).

These scores can easily be interpreted on the basis of the plotted presence/absence data, which indicate that razor clams mainly use offshore areas and are found commonly around and on Horns Rev, whereas trough shells are mainly found in the easternmost, near-coastal areas, Figure 4-3. The marginality and specialization scores lead to habitat suitability scores ranging from 0-100, the upper 33 reflecting suitable habitat, Figure 6-

3 and 6-4. The pixels indicating high habitat suitability for razor clams mainly lie within a coherent zone corresponding to the Horns Rev and moderate slope areas to the northwest and southeast, including the HR2 OWF, Figure 6-33. The pixels indicating high habitat suitability for trough shells, Figure 6-4, are confined to the area of fine sediments and high carrying capacity values in the south-eastern and eastern-most part. On Cancer high habitat suitability is estimated for both species. The areas closest to the coast are estimated as unsuitable.

6.2   Diet of Common Scoter 2007-2008

High condition values and really high fat scores of the Common Scoter collected in the Horns Rev area indicated that these birds were in very good condition, Table 6-1.

Table 6-1. Mean weight of whole birds plus mean sum of fat rankings with standard deviation and range.

	Weight	Fat
All birds	1,157 ± 74 (1,011-1,285)	7 ± 1.2 (4-9)
Females	1,105 ± 62 (1,019-1,194)	8 ± 0.7 (7-9)
Males	1,168 ± 73 (1,011-1,285)	6.8 ± 1.2 (4-9)

All examined stomachs of Common Scoters were almost empty, on average only 10 gram of food items or remains were present indicating that the birds had generally finish eating hours before they were sampled. The sampling took place in the early hours in the morning and hence it is probable that they mainly forage at night. The food remains were generally only found in the gizzard and only two birds had any remains left in the oesophagus. Consequently most food remains were crushed and most of it reduced to sand sized grains unfit for use in analysis.

No *Ensis americanus* shells were completely intact and only 9 measurements of the width were possible. From the width it could be calculated to total length of the shells based on an equation given by Leopold (2002) – length 5.8937*(width) + 2.3859; R^2 = 0.8048; n = 561). This equation was based on measurements of *Ensis directus* but considered valid for *Ensis americanus* as well. The mean length was 65.9 mm, minimum 45.0 mm, maximum 87.8 mm, stdev. 14.1mm. These findings corroborate the findings by Freudendahl & Jensen (2006) who found that "the dominant size group of consumed *Ensis americanus* was between 60 and 90 mm in shell length, corresponding to an age of 1.5 to 2.5 years."

Table 6-2. Food items found in 29 birds (one was shot through).

Food item	N	Frequency of occurrence
Ensis americanus	47	29
Spisula subtruncata	10	3
Nereis diversicolor	6	4

Only a few relatively large razor clams with a minimum length of 80 mm and a maximum length of 150 mm were found at few locations in the bottom grab samples Appen-

dix A. No smaller specimens were found in either the grab samples or in the dredge samples.
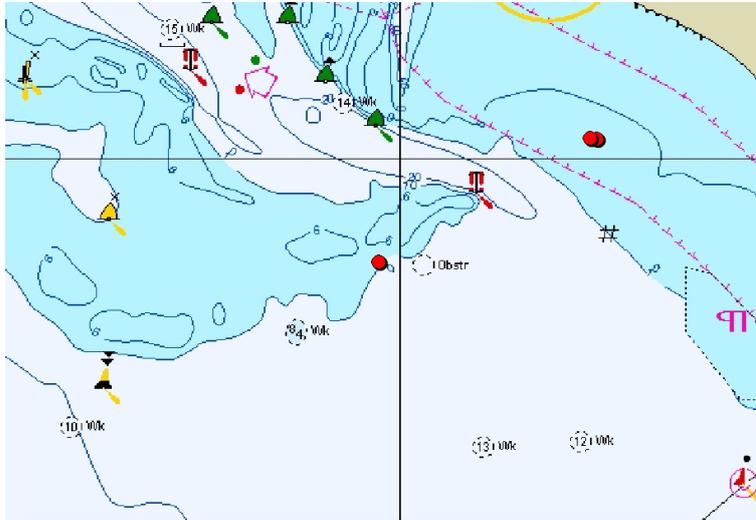
Only 6 whole *Spisula subtruncata* were found with a minimum size of 11.4 mm, max. 14.2 mm, mean 12.7 mm and stdev. 1.01 mm corresponding to an age of these mussels of about one year. The size of these trough shells were then a bit smaller than those reported from Common Scoters by Durinck et al. 1993. All *Spisula subtruncata* registered in the bottom samples and in the dredge samples were found in areas where the Common Scoters were foraging, Figure 6-4 and the size of the mussels with a mean length of 11.7mm, max 15.1mm and min. 6.7mm were in concordance with the mussels found in the stomachs of these birds Appendix A, Figure 6-6.
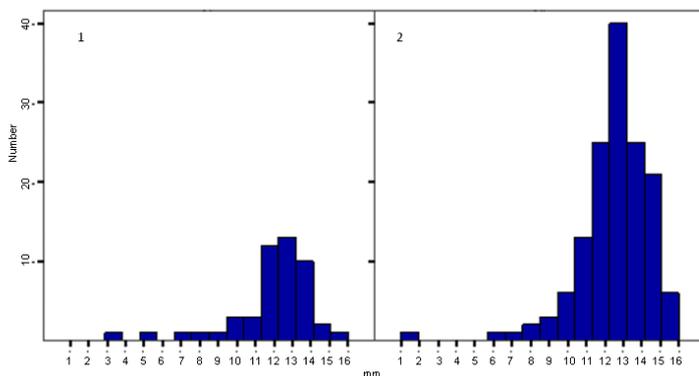
Four jaws of *Nereis diversicolor* were found and from Zwarts and Esselink (1989) the length of the animals count be calculated. These polychaetes were between 6 and 11 cm long with a mean length of 8.1 cm.

Figure 6-6. Size class distribution of Spisula subtruncata *registered in dredge samples from two locations in Esperence Bugt.*
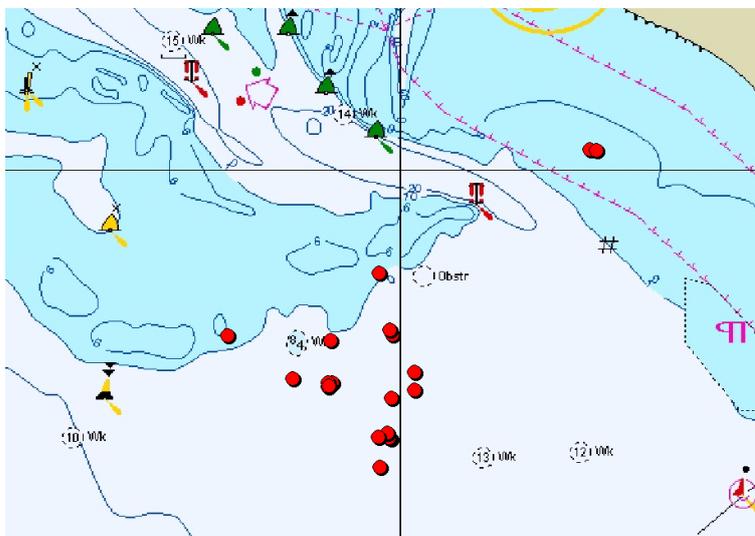
Figure 6-7. Positions of 29 birds sampled with Ensis americanus *in the stomachs.*
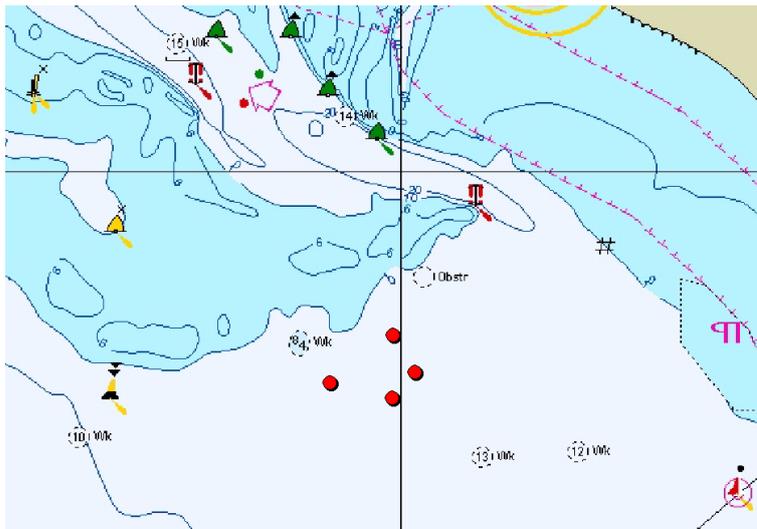
Figure 6-8. Positions of four birds sampled with Nereis diversicolor *in the stomachs.*

7 DISCUSSION AND CONCLUSIONS

7.1 Evaluation of model results

7.1.1 Hydrodynamic and water quality model data
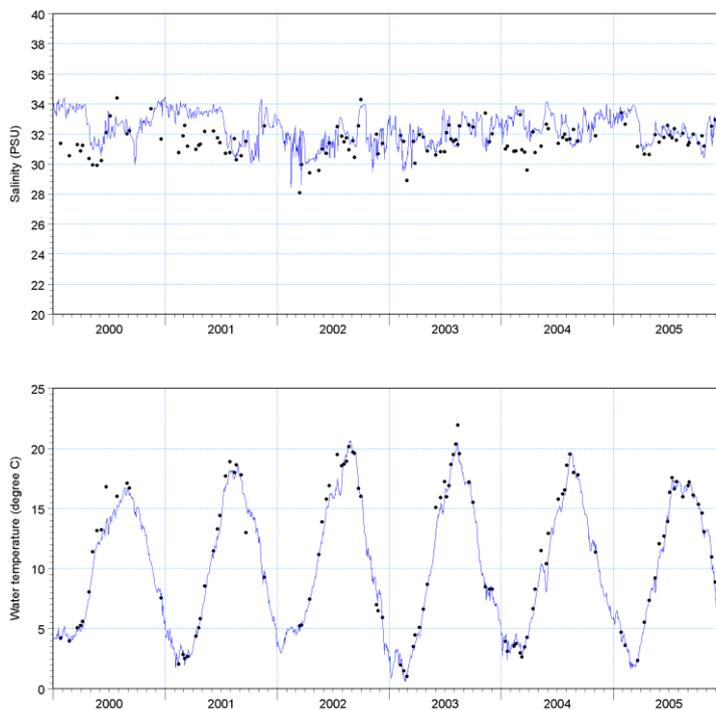
Figure 7-1. Surface salinity (top) and water temperature (below) measured at station 1510003 (dots) and modelled (line).

For the two coastal calibration stations the hydrodynamic simulations, represented by salinity and temperature, Figure 7-1 and Figure 7-2, indicates that the model does reproduce the physical variability in the area as well as the inter-annual variability (see temperature). However, during summer the salinity is somehow overestimated in the model which probably is a result of the strong gradients in the area combined with the resolution of the model.
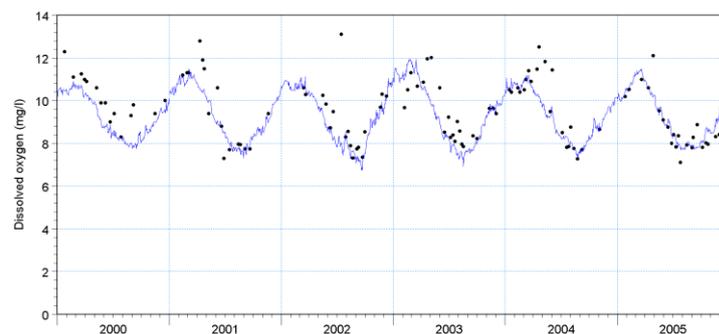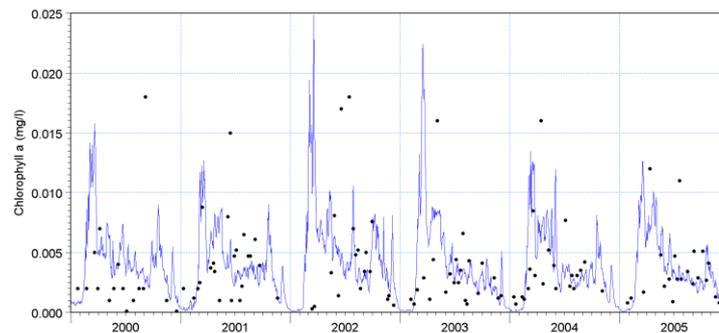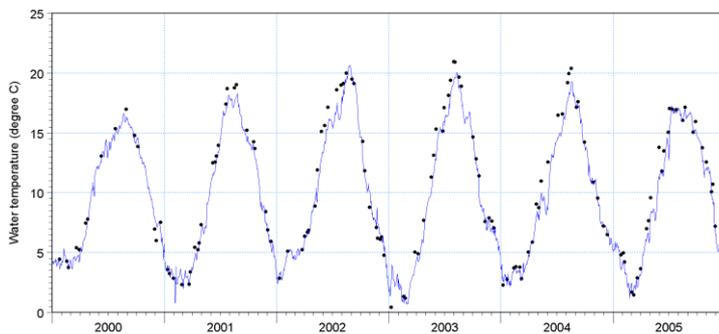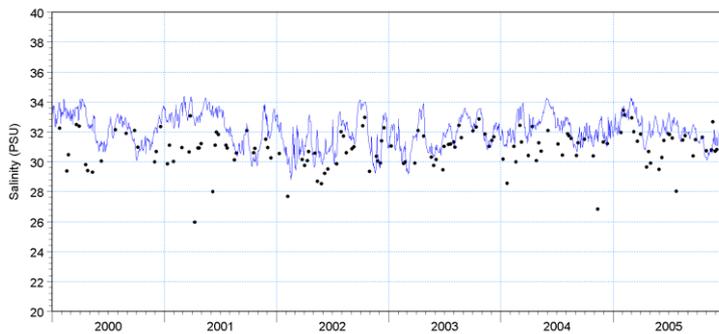
Figure 7-2. Surface salinity (top) and water temperature (below) measured at station 43 (dots) and modelled (line).

With respect to chlorophyll-a and oxygen, Figure 7-3 and Figure 7-4, the model does reproduce the overall pattern of the biological system. The different measured algae blooms are not timed exactly correct in the model, but the blooms are represented and the overall averaged levels do meet the measurements, and the patterns between the years. Also, the modelled oxygen concentrations are rather well reproduced compared to the measurements, and follows the saturation levels prescribed by the temperature variations.

Figure 7-3. Surface concentration of chlorophyll a (top) and dissolved oxygen (below) measured at station 1510003 (dots) and modelled (line).

7.2   Evaluation of calibration data

7.2.1   Sediment and benthos samples

Data on surface sediments and benthos are lacking in the areas to the west of Fanø and the whole area northeast of Horns Rev, - areas which are important to describe in terms of potential food supply to Common Scoter. Equally important, the available data on the *Spisula* and *Ensis* do only allow for a breakdown of habitat suitability based on presence/absence. Quantitative data are needed to base suitability estimations on biomass levels rather than presence/absence patterns; as such estimations most likely will result in better spatial information on gradients and patchiness in the distribution of the two species on Horns Rev.
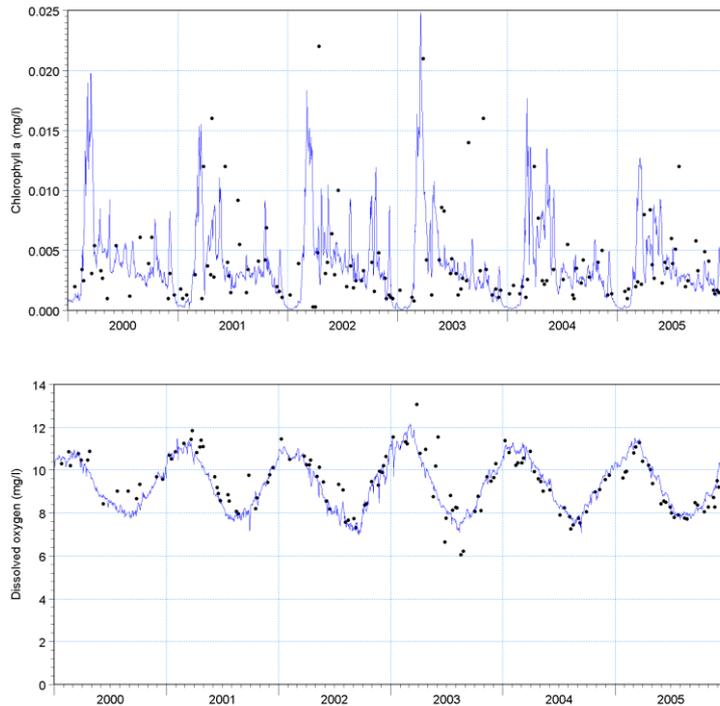
Figur 7-4. Surface concentration of chlorophyll a (top) and dissolved oxygen (below) measured at station 43 (dots) and modelled (line).

7.2.2 Dietary data

Clearly, both *Spisula subtruncata* and *Ensis americanus* were important food sources for the Common Scoters. Considering that most Common Scoters are found near the coast and in the Esperance Bugt in areas of prime habitat to *Spisula subtruncata*, this may caution not to overestimate the importance on *Ensis americanus* for scoters in the area.'

7.3 Conclusions

Existing knowledge of food selection and prey dynamics by Common Scoter in the Horns Rev area could not be corroborated by the study. As opposed to the suggestions by Freudendahl & Jensen (2006) both the dietary investigations, linked benthos sampling programme and the model results unambiguously point at the existence of two rather well-defined prey communities of *Ensis americanus* and *Spisula subtruncata*, which are both utilised by the scoters. The community of cut through shells is related to the area of fine sediments and very high food supply in terms of near-seabed chlorophyll concentrations found in the Esperance Bugt and at Cancer. Most of the areas over the reef are unsuitable to the species, due to the sediment structure and the frequent rebedding of sediments as a result of periodic strong currents over the reef. The community of razor clams, on the other hand, prefer the medium-sized sediments over the reef and to the northwest of the reef, including the planned wind farm site, as well as the gentle slopes of the reef, and the clams are due to their deep penetration into the sediment able to survive the frequent sediment rebedding in these areas. On Cancer, the communities of trough shells and razor clams are overlapping. Although razor clams are also found in the eastern-most coastal part of the area the fine sediments here seem to be unsuitable to the species, and prevent the razor clams to utilise the higher concentrations of food found just off the Danish coast.'

Rather than an ecosystem dominated by one prey species, American razor clams, our results indicate that both prey species are important at Horns Rev, and that most birds during 2007-08 were feeding on trough shells. The main proof of the importance of trough shells comes from the location of the main concentrations of scoters, which was in the main habitat for trough shells south of Cancer and in the Esperance Bugt. The dietary

investigations, albeit limited in their quantitative results due to the lack of whole remains in the birds, indicated that the birds also fed on razor clams within the preferred habitat to trough shells. The eastern part of the area marking the preferred habitat to trough shells has historically been the area, where the largest concentrations of Common Scoter have been observed. Common Scoter distribution in the region has been surveyed during nation-wide waterbird survey campaigns (Joensen et al. 1974, Laursen et al. 1997) and during international waterbird projects (Skov et al. 1995). During all these surveys ranging from 1969 to 1994 the largest flocks of scoters were always located in the Esperance Bugt, at Fanø or at Cancer.

The change in the historic distribution of Common Scoter recorded after 1999 showed a replacement of a proportion of 10-25 % of the birds along the reef into the offshore areas shallower than 15 m on the reef as well as on the plains northwest of the reef. These areas can now be identified as suitable habitat for razor clams and as mainly unsuitable for trough shells. Thus, it is highly likely that Common Scoters mainly feed on razor clams in the 'new' area of their distribution (Freudendahl & Jensen 2006). As the birds collected by Freudendahl & Jensen (2006) and this study all were in excellent condition the most probable function of this dual prey system is that razor clams provide a supplementary source of food for scoters which are generally experiencing a rich supply of food in terms of trough shells. This is supported by the fact that scoters seem to use the razor clam habitats more during the later part of the season (Petersen & Fox 2007, Skov et al. 2008), when food availability in their primary feeding area may become scarce as a result of their own predation.

There are no indications that the dual prey system is a result of a general reduction in availability or biomass of trough shells, or a result of an adaptation to a system in which an invasive species, razor clams, take over the ecological role of trough shells in the coastal ecosystem, as has been suggested for the Dutch coastal waters (Leopold et al. 2007). However, it is recommended to monitor the scoter-prey system at Horns Rev closely in the years to come to enable the detection of any possible major changes in the supply and predation of trough shells and razor clams by scoters. Monitoring should preferably be carried out based on a combination of counts of scoters, benthos sampling and habitat modelling. Habitat modelling should preferably include estimations on the harvest of the two prey species by scoters.

The distribution model for razor clam for the period 2000 to 2008 clearly shows that most of the footprint area of the HR2 OWF is prime habitat for this species, and hence that concentrations of Common Scoters may occur regularly in the wind farm site, as found during the surveys from 2005 to present (Petersen & Fox 2007, Skov et al. 2008). Based on the model results it is questionable whether scoters will use the HR1 OWF frequently, as the area does not seem to be highly suitable to razor clams.

Data on surface sediments and benthos are lacking in the areas to the west of Fanø and the whole area northeast of Horns Rev, - areas which are important to describe in terms of potential food supply to Common Scoter. Equally important, the available data on the *Spisula* and *Ensis* do only allow for a break-down of habitat suitability based on presence/absence. Quantitative data are needed to base suitability estimations on biomass levels rather than presence/absence patterns, as such estimations most likely will result in better spatial information on gradients and patchiness in the distribution of the two species on Horns Rev.

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APPENDICES

A P P E N D I X   A

Benthos samples

Table Size classes of mussels recorded from Van Veen grab samples in the Horns Rev area

Horns Rev 2, bundfauna april 2008
Muslinger
Længde i mm

		Gennemsnit	St. dv.	N	Min	Max
Nucula sulcata	1,00	7,91	2,06	N=2	6,45	9,37
	2,00	6,03	,85	N=2	5,43	6,63
	3,00	6,30	.	N=1	6,30	6,30
	ART total	6,84	1,49	N=5	5,43	9,37
Mysella bidentata	11,00	2,50	,62	N=3	2,12	3,22
	12,00	2,51	,45	N=17	2,20	3,48
	ART total	2,51	,46	N=20	2,12	3,48
Mactra stultorum	11,00	46,00	,00	N=2	46,00	46,00
	12,00	55,00	.	N=1	55,00	55,00
	ART total	49,00	5,20	N=3	46,00	55,00
Spisula subtruncata	1,00	10,49	.	N=1	10,49	10,49
	3,00	13,12	,96	N=6	11,75	14,16
	4,00	7,70	1,40	N=2	6,71	8,69
	5,00	8,55	.	N=1	8,55	8,55
	6,00	7,78	.	N=1	7,78	7,78
	7,00	14,41	.	N=1	14,41	14,41
	10,00	7,57	.	N=1	7,57	7,57
	12,00	12,89	2,43	N=9	8,63	15,17
	ART total	11,77	2,78	N=22	6,71	15,17
Angulus tenuis	3,00	8,72	.	N=1	8,72	8,72
	4,00	9,79	.	N=1	9,79	9,79
	6,00	7,50	.	N=1	7,50	7,50
	11,00	9,13	,03	N=2	9,11	9,15
	ART total	8,85	,85	N=5	7,50	9,79
Fabulina fabula	1,00	9,45	2,80	N=9	6,62	14,39
	2,00	12,75	3,78	N=3	9,78	17,01
	3,00	6,64	1,66	N=6	4,45	8,83
	4,00	12,97	2,91	N=4	8,83	15,55
	5,00	8,25	1,60	N=5	6,43	10,15
	6,00	8,24	1,71	N=7	5,31	10,32
	7,00	12,13	,11	N=2	12,05	12,21
	9,00	6,98	2,04	N=7	4,66	10,01
	11,00	17,54	.	N=1	17,54	17,54
	12,00	10,70	4,60	N=6	3,73	17,38
	ART total	9,38	3,40	N=50	3,73	17,54
Chamelea gallina	2,00	9,94	.	N=1	9,94	9,94
	ART total	9,94	.	N=1	9,94	9,94
Ensis americanus	1,00	124,71	.	N=1	124,71	124,71
	2,00	150,00	.	N=1	150,00	150,00
	4,00	80,00	.	N=1	80,00	80,00
	9,00	130,00	.	N=1	130,00	130,00
	ART total	121,18	29,53	N=4	80,00	150,00
Phaxas pellucidus	3,00	24,22	.	N=1	24,22	24,22
	ART total	24,22	.	N=1	24,22	24,22

Table Benthos abundance and biomass sampled by Van Veen grab

Horns Rev 2

April 2008
Abundans, total prøve

		1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00
KORALDYR	Actiniaria indet.	.	.	+	.	.	+	.	.	.	.	.	+
HAVBØRSTEORME	Polychaeta indet.	+	+	+	+	+	+	+	+	+	.	+	+
KREBSDYR	Crustacea indet.	.	+	+	+	.	+	.	.	.	.	.	+
MUSLINGER	Nucula sulcata	2	2	1	.	.	.	.	.	.	.	.	.
	Mysella bidentata	.	.	.	.	.	.	.	.	.	.	3	17
	Mactra stultorum	.	.	.	.	.	.	.	.	.	.	2	1
	Spisula subtruncata	1	.	6	2	1	1	1	.	.	1	.	9
	Angulus tenuis	.	.	1	1	.	1	.	.	.	.	2	.
	Fabulina fabula	9	3	6	4	5	7	2	.	7	.	1	6
	Chamelea gallina	.	1	.	.	.	.	.	.	.	.	.	.
	Ensis americanus	1	1	.	1	.	.	.	.	1	.	.	.
	Phaxas pellucidus	.	.	1	.	.	.	.	.	.	.	.	.
PIGHUDER	Ophiura sp.	+	+	+	+	.	+	.	.	+	.	+	+
	Echinocardium sp.	.	+	+	+	.	.	+	.	.	.	.	+

Horns Rev 2

April 2008
Biomasse
Tørvægt indicated

		1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00
KORALDYR	Actiniaria indet.	.	.	+	.	.	+	.	.	.	.	.	+
HAVBØRSTEORME	Polychaeta indet.	+	+	+	+	+	+	+	+	+	.	+	+
KREBSDYR	Crustacea indet.	.	.	+	+	.	+	.	.	.	.	.	+
MUSLINGER	Nucula sulcata	261,8	78,7	60,5	.	.	.	.	.	.	.	.	.
	Mysella bidentata	.	.	.	.	.	.	.	.	.	.	5,6	23,3
	Mactra stultorum	.	.	.	.	.	.	.	.	.	.	12879,2	6488,9
	Spisula subtruncata	150,8	.	1831,5	158,3	106,3	73,0	283,5	.	.	35,8	.	3254,1
	Angulus tenuis	.	.	21,6	30,5	.	16,2	.	.	.	.	38,6	.
	Fabulina fabula	304,8	245,0	52,9	307,5	91,6	128,8	135,4	.	94,1	.	189,5	335,4
	Chamelea gallina	.	204,6	.	.	.	.	.	.	.	.	.	.
	Ensis americanus	10451,3	12146,5	.	10581,5	.	.	.	.	860,2	.	.	.
	Phaxas pellucidus	.	.	96,5	.	.	.	.	.	.	.	.	.
PIGHUDER	Ophiura sp.	+	+	+	+	.	+	.	.	+	.	+	+
	Echinocardium sp.	.	+	+	+	.	.	+	.	.	.	.	+

Table Sampling transects and number of key species of mussels and benthic species in the triangular dredge samples.

Triangular dredge sampler

	Start		End		Species			
Location	"WGS84 MIN Y"	WGS84 MI N X"	"WGS84 MIN Y"	WGS84 MI N X"	Spisula subtruncata	Spisula solida	Ensis americanus	Ophiura texturata
Esperance Bugt 1	8°10,646	55°50,564	8°11,236	55°50,539	50	0	0	273
Esperance Bugt 2	8°11,236	55°50,539	8°12,036	55°50,496	148	0	0	513
VovVov 1 *	7°58,719	55°54,636	7°57,911	55°54,592	0	0	0	0
VovVov 2	7°57,911	55°54,592	7°57,130	55°54,471	0	1	0	0
VovVov3 *	7°57,130	55°54,471	7°56,350	55°54,444	0	0	0	0
VovVov 4 *	7°56,071	55°54,871	7°56,876	55°54,973	0	0	0	0
VovVov 5	7°56,876	55°54,973	7°57,716	55°55,000	0	0	0	0
VovVov 6	7°56,071	55°54,871	7°56,876	55°54,973	0	0	0	0
VovVov 7	7°58,569	55°55,243	7°56,948	55°55,216	0	1	0	0
VovVov 8	7°56,867	55°55,506	7°58,141	55°55,533	0	0	0	0

*   Empty samples

A P P E N D I X   B

Sediment characteristics

Horns Rev April 08

Glødetab
DS 204

Station.	Dybde meter	Possition		Glødetab i %	Gløderest i %
1	13,5	55.26,318	007.59,301	0,34	99,66
2	15,0	55.25,730	007.59,771	0,72	99,28
3	14,5	55.25,905	007.59,032	0,66	99,34
4	14,0	55.26,560	007.58,990	0,41	99,59
5	13,0	55.26,606	007.57,542	0,62	99,38
6	12,5	55.26,857	007.56,179	0,64	99,36
7	12,0	55.27,109	007.58,035	0,73	99,27
8	11,0 - 8,5	55.27,526	007.58,468	0,39	99,61
9	12,5	55.27,257	007.59,078	1,01	98,99
10	7,5-6	55.28,331	007.59,119	0,48	99,52
11	6,5	55.30,307	008.06,410	1,27	98,73
12	6,5	55.30,286	008.06,778	1,34	98,66

April 08

Horns Rev April 08

Vandindhold   DS 405.11

Station.	Dybde meter	Possition		Vandinfdh. %	Tørstof %
1	13,5	55.26,318	007.59,301	17,7	82,3
2	15,0	55.25,730	007.59,771	16,8	83,2
3	14,5	55.25,905	007.59,032	14,1	85,9
4	14,0	55.26,560	007.58,990	13,9	86,1
5	13,0	55.26,606	007.57,542	14,6	85,4
6	12,5	55.26,857	007.56,179	17,4	82,6
7	12,0	55.27,109	007.58,035	18,4	81,6
8	11,0 - 8,5	55.27,526	007.58,468	15,7	84,3
9	12,5	55.27,257	007.59,078	9,4	90,6
10	7,5-6	55.28,331	007.59,119	17,9	82,1
11	6,5	55.30,307	008.06,410	18,2	81,8
12	6,5	55.30,286	008.06,778	17,4	82,6

April 08

a	b		ORBICON	ORBICON	ORBICON	ORBICON	ORBICON	ORBICON
		Rekvirent						
		Lokalitet	Horns Rev April.08	Horns Rev April.08	Horns Rev April.08	Horns Rev April.08	Horns Rev April.08	Horns Rev April.08
		Prøve nr.	26,318 007.59,301	55.25,730 007.59,771	55.25,905 007.59,032	55.26,560 007.58,990 m)	55.26,606 007.57,542	55.26,857 007.56,179
		Lab. nr.	80105	80106	80107	80108	80109	80110
		Bemærkninger	For mat < 2mm	For mat < 2mm	For mat < 2mm	For mat < 2mm	For mat < 2mm	For mat < 2mm
		Dato	01-05-2008	01-05-2008	01-05-2008	01-05-2008	01-05-2008	01-05-2008
		Laborant	L. Nørgaard	L. Nørgaard	L. Nørgaard	L. Nørgaard	L. Nørgaard	L. Nørgaard
		Prøvens totalvægt	107,26	106,08	107,01	106,48	107,24	106,68
		16,0						
		8,0						
		4,0	0,06	0,19		0,34	0,11	
		2,8	0,02	0,09	0,24	0,13	0,06	
		2,0	0,03	0,09	0,14	0,09	0,04	0,03
		1,4	0,02	0,02	0,03	0,01	0,02	0,02
		1,0	0,05	0,06	0,08	0,04	0,18	0,12
		0,710	0,05	0,12	0,10	0,33	0,41	0,36
		0,500	0,14	0,87	0,50	11,35	0,65	1,05
		0,355	0,36	2,51	1,47	46,54	1,05	1,82
		0,250	1,22	7,55	3,87	29,30	8,34	8,37
		0,180	8,55	20,76	19,92	7,29	37,33	28,83
		0,125	46,36	34,53	41,07	6,32	46,35	50,86
		0,090	40,04	32,64	34,23	2,51	10,22	12,52
		0,075	2,84	3,56	2,47	0,37	0,72	0,84
		0,063	1,14	1,02	1,02	0,18	0,28	0,28
		< 0,063	6,38	2,07	1,87	1,68	1,48	1,58
Size Classes	Silt and clay	(< 0,063 mm):	5,95	1,95	1,75	1,58	1,38	1,48
	Sand, fine	(0,063 mm - 0,200 mm):	86,54	73,23	78,95	10,77	63,63	68,18
	Sand, medium	(0,2 mm - 0,6 mm):	7,23	23,85	18,51	81,19	33,91	29,32
	Sand, coarse	(0,6 mm - 2 mm):	0,18	0,62	0,44	5,94	0,89	0,98
	Gravel	(> 2 mm):	0,10	0,35	0,36	0,53	0,20	0,03
		Sum:	100,00	100,00	100,00	100,00	100,00	100,00
Moments Measures		5% Percentile	0,22	0,34	0,28	0,63	0,32	0,33
		10% Percentile	0,17	0,23	0,21	0,49	0,24	0,24
		16% Percentile	0,16	0,20	0,18	0,46	0,22	0,21
		25% Percentile	0,14	0,16	0,16	0,41	0,19	0,18
		Median (50% Percentile)	0,13	0,15	0,14	0,37	0,17	0,17
		60% Percentile	0,10	0,11	0,11	0,28	0,14	0,14
		75% Percentile	0,10	0,10	0,10	0,24	0,13	0,13
		84% Percentile	0,09	0,09	0,10	0,18	0,12	0,11
		95% Percentile	------	0,08	0,09	0,13	0,10	0,10
Moments Statistics		Mean	2,96	2,73	2,78	1,51	2,51	2,55
		Sorting	------	0,60	0,51	0,60	0,47	0,49
		Skewness	------	-0,15	-0,12	0,30	-0,05	-0,13
		Kurtosis	------	0,97	0,98	1,32	1,05	1,13
		Uniformity Coefficient	1,57	1,74	1,65	2,30	1,61	1,58
Cumulated	mm	16,00	100,00	100,00	100,00	100,00	100,00	100,00
amount passing		8,00	100,00	100,00	100,00	100,00	100,00	100,00
Weight %		4,00	99,94	99,82	100,00	99,68	99,90	100,00
		2,80	99,93	99,74	99,78	99,56	99,84	100,00
		2,00	99,90	99,65	99,64	99,47	99,80	99,97
		1,40	99,88	99,63	99,62	99,46	99,79	99,95
		1,00	99,83	99,58	99,54	99,43	99,62	99,84
		0,710	99,79	99,46	99,45	99,12	99,24	99,50
		0,500	99,66	98,64	98,98	88,46	98,63	98,52
		0,355	99,32	96,28	97,61	44,75	97,65	96,81
		0,250	98,18	89,16	93,99	17,23	89,87	88,97
		0,180	90,21	69,59	75,38	10,39	55,06	61,94
		0,125	46,99	37,04	37,00	4,45	11,84	14,27
		0,090	9,66	6,27	5,01	2,09	2,31	2,53
		0,075	7,01	2,91	2,70	1,75	1,64	1,74
		0,0630	5,95	1,95	1,75	1,58	1,38	1,48

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