Energinet.dk

Anholt Offshore Wind Farm

Benthic Habitats

September 2009

Energinet.dk

Anholt Offshore Wind Farm

Benthic habitats

September 2009

Ref 11803332-7
Draft - Version 3
0550_05_5_6_001_03
Dato 2009-06-30
Udarbejdet af FLM
Kontrolleret af
Godkendt af

Anholt offshore wind Farm

Benthic habitats.

Baseline Description and Impact Assessment.

Agern Allé 5
DK-2970 Hørsholm
Denmark

Tel: +45 4516 9200
Fax: +45 4516 9292
dhi@dhigroup.com
www.dhigroup.com

Client Energinet.dk	Client's representative

Project Anholt	Project No 11803332-7
Authors Flemming Møhlenberg	Date 28 September 2009
	Approved by FLM

3	Draft Rev. 2	FLM			28.09.09
2	Draft Rev. 2	FLM	HSK		12.08.09
1	Draft Rev. 1	FLM			30.06.09
Revision	Description	By	Checked	Approved	Date

Key words	Classification ☐ Open ☐ Internal ☒ Proprietary

Distribution Rambøll: Mikkel Benthien Kristensen DHI:	No of copies pdf

Table of contents

1. Summaries

1.1 Dansk resumé

I rapporten beskrives de nuværende forhold i relation til bentiske habitater samt funktionelle faunagrupper i projektområdet for den planlagte Anholt Havmøllepark samt en vurdering af de forventede påvirkninger af disse habitater og vigtige funktionelle benthiske grupper ved drift af en møllepark i projektområdet. Potentielle påvirkninger under etableringsfasen er behandlet i rapport om Bundfauna /1/. Ændringer i strømforhold vil potentielt ændre leveforholdene de forskellige fødebiologiske grupper hvor bundlevende filtratorer så som muslinger vil favoriseres af øget strømhastighed mens detritusædere vil favoriseres af en øget sedimentation af organisk stof, der især er karakteristisk for områder med lave strømhastigheder.

1.1.1 Metode

Med udgangspunkt i baggrundsundersøgelserne af hydrografi, vandkvalitet og bundfauna /16/ blev der etableret statistiske prædiktionsmodeller der kunne forklare udbredelse og biomasse af forskellige fødebiologiske grupper. På basis af disse modeller og beregnede ændringer i hydrografi, vandkvalitet og sedimentpålejring efter etablering af havmøllepark (to forskellige design) blev der beregnet en ny rumlig fordeling af de fødebiologiske grupper indenfor projektområdet.

Prædiktionsmodellerne blev udviklet ved multivariat PLS-regression med anvendelse af op til 10 uafhængige variable (målte sedimentforhold, modellerede hydrodynamiske og økologiske forhold) til at beskrive observationerne fra bundfaunaundersøgelsens 80 stationer /1/. På hver faunalokalitet blev der beregnet tæthed og biomasse af filtratorer, detritusædere og karnivore/omnivorer. Disse afhængige variable blev parret med rækken af målte (sediment) uafhængige variable og beregnede variable netop på positioner, hvor fauna blev indsamlet.

Indenfor projektområdet var bundfaunaen helt domineret af filtratorer (93%).

PLS regressionsmodeller

Der kunne kun udvikles regressionsmodeller for biomassen af filtratorer og overflade detritusædere og alligevel var modellernes prædiktionsgrad lave, mellem 15 og 23%. Årsagen hertil skal søges i forholdsvist ensartede forhold i projektområdet samt en betydelig små-skala variation i faunaprøverne. Den lave prædiktionsgrad betyder, at forudsigelser er behæftet med en betydelig usikkerhed. Modellerne viste at filtratorer var favoriseret af høje strømhastigher, stor median kornstørrelse af overfladesediment samt af et højt 'filter-feeder' indeks der primært drives af en høj transport af klorofyl over bunden, mens biomassen af detritusædere viste en komplementært billede hvor lav strømhastighed, lille median kornstørrelse, et usorteret sediment samt et lavt 'filter-feeder' indeks var sammenfaldende med forholdsvis høje biomasser af detritusædere.

1.1.2 Baseline forhold

De bentiske habitatforhold var forholdsvis ens indenfor projektområdet med stor dominans af filtratorer (især muslinger). På basis af målte og modellerede habitatforhold kunne der udvikles regressionsmodeller 2 fødebiologiske grupper, filtratorer og overflade detritusædere. Regressionsmodellerne havde forholdsvis lav prædiktionskraft og forudsigelser af habitatændringer og fordeling af fødebiologiske grupper efter etablering af møllepark vil være behæftet med stor usikkerhed.

1.1.3 Påvirkning af bentiske habitater og fødebiologiske grupper i projektområdet

Vurdering af den forventede påvirkning på bentiske habitatforhold i driftsfasen er baseret på modelberegninger af et worst case scenario, omfattende opstilling af 174 møller hver på 2,3 MW og anvendelse af beton (gravitations-) fundamenter.

Modelberegningerne viste at der kunne forventes ændringer af bentiske filtratorer og detritusædere indenfor mølleparken, således at biomassen af filtratorer blev reduceret med ca. 5%, mens biomassen af detritusædere blev øget med ca. 10%. Disse ændringer blev drevet af reduceret strømhastighed og reduceret tilførsel af føde (algeplankton) gennem mølleparken. Effekten af fødetransport skyldes både ændringer i strømforhold samt konkurrence om føden fra filtrerende blåmuslinger der forventeres at kolonisere møllefundamenterne.

På grund af lave spildrater ved gravearbejder var de beregnede ændringer i sedimentets kornstørrelse for små til at have betydning for den fødebiologiske grupper.

Beregningerne viste også at de små ændringer i biomasser indenfor mølleparken stort set blev modsvaret af en øgning i biomassen af filtratorer og reduktion i detritusædere udenfor mølleparken drevet af en svagt højere strømhastighed her.

1.2 Summary

This report describes the present condition of benthic habitats and of important feeding guilds among benthic invertebrates in the project area from the planned Anholt Wind Farm in addition to an evaluation of impacts on habitats and feeding guilds related to operation of the wind farm. Basically, changes in current speed and sediment conditions are expected to affect the various functional groups such as filter-feeding bivalves being stimulated by high current speeds and high rates of plankton advection, while deposit-feeders being favored by low current conditions and high sedimentation rates.

1.2.1 Method

Based on modelled baseline condition in hydrography, water quality and, *in situ* monitoring of benthos and sediments /16/ statistical models were developed to explain the present distribution and biomass of different functional benthic groups. Models subsequently were used to predict changes in these benthic groups after establishment of the wind farm using predicted changes in the explanatory variables that included current speed, advection of plankton and sediment conditions.

Because of a limited spatial variability in external conditions, i.e. current speed, food advection and sediment characteristics within the project area the statistical models explaining variation in benthic groups had low predictive powers, between 15 and 23%. Accordingly, predictions of change in functional groups invariable are associated with a high uncertainty.

1.2.2 Predicted impacts on benthic habitats

Using the modelled changes in bottom current speeds, advection of food for filter-feeders and sedimentation a reduction of 5-6% in biomass of filter-feeders and, an increase of 10% in biomass of deposit-feeders were predicted within the wind farm area. The changes were caused by small reductions in current speeds due to flow obstruction by foundations, and by reductions in plankton advection partly caused by fouling blue mussels on foundations competing with the benthic filter-feeders for planktonic food. The predicted changes within the wind farm were mirrored by changes occurring outside the wind farm (but partly within the project area). Due to slightly higher current speeds outside the wind farm benthic filter-feeders are likely to increase and deposit-feeders likely to decrease in biomass.

Overall, the predicted changes in benthic habitats and important benthic groups during the operational phase were very small and considering the relative large uncertainty associated with the predictions the impacts are likely to be insignificant.

2. Introduction

2.1 Background

In 1998 the Ministry of Environment and Energy empowered the Danish energy companies to build offshore wind farms of a total capacity of 750 MW, as part of fulfilling the national action plan for energy, Energy 21. One aim of the action plan, which was elaborated in the wake of Denmark's commitment to the Kyoto agreement, is to increase the production of energy from wind power to 5.500 MW in the year 2030. Hereof 4.000 MW has to be produced in offshore wind farms.

In the years 2002-2003 the two first wind farms was established at Horns Rev west of Esbjerg and Rødsand south of Lolland, consisting of 80 and 72 wind turbines, respectively, producing a total of 325,6 MW. In 2004 it was furthermore decided to construct two new wind farms in proximity of the two existing parks at Horns rev and Rødsand. The two new parks, Horns rev 2 and Rødsand 2, are going to produce 215 MW each and are expected to be fully operational by the end 2010.

The 400 MW Anholt Offshore Wind Farm constitutes the next step of the fulfilment of aim of the action plan. The wind farm will be constructed in 2012, and the expected production of electricity will cover the yearly consumption of approximately 400.000 households. Energinet.dk on behalf of the Ministry of Climate and Energy is responsible for the construction of the electrical connection to the shore and for development of the wind farm site, including the organization of the impact assessment which will result in the identification of the best suitable site for constructing the wind farm. Rambøll with DHI and other sub consultants are undertaking the site development including a full-scale Environmental Impact Assessment for the wind farm.

The present report is a part of a number of technical reports forming the base for the Environmental Impact Assessment for Anholt Offshore Wind Farm.

The Environmental Impact Assessment of the Anholt Offshore Wind Farm is based on the following technical reports:

- Technical Description
- Geotechnical Investigations
- Geophysical Investigations
- Metocean data for design and operational conditions
- Hydrography including sediment spill, water quality, geomorphology and coastal morphology]
- Benthic Fauna
- Birds
- Marine mammals

- Fish
- Substrates and benthic communities
- Benthic habitats
- Maritime archaeology
- Visualization
- Commercial fishery
- Tourism and Recreational Activities
- Risk to ship traffic
- Noise calculations
- Air emmissions

2.2 Content of specific report

This report describes the baseline status of benthic habitats and provides an evaluation of consequences related to operation of a wind farm in the project area. The present status is based on characteristics of surface sediments, near bed currents, horizontal flux of chlorophyll, sedimentation rate of algae and detritus, oxygen conditions and the "resulting" composition of functional invertebrate groups. Spatial variation in the dominating functional groups is sought described by spatial variations in external forcings such as current speed and sediment organic content using multivariate statistics. The resulting statistical models are subsequently used to predict changes in the relative distribution of functional groups using a new set of modelled data for currents, Chlorophyll flux, oxygen concentration etc. that are characteristic for the operational phase of the wind farms.

3. Offshore wind farm

3.1 Project description

This chapter describes the technical aspects of the Anholt Offshore Wind Farm. The following description is based on expected conditions for the technical project; however, the detailed design will not be done until a developer of the Anholt Offshore Wind Farm has been awarded.

3.1.1 Site location

The designated investigation area for the Anholt Offshore Wind Farm is located in Kattegat between the headland Djursland of Jutland and the island Anholt - see Figure 3.1. The investigation area is 144 km^2, but the planned wind turbines must not cover an area of more than 88 km^2. The distance from Djursland and Anholt to the project area is 15 and 20 km, respectively. The area is characterised by fairly uniform seabed conditions and water depths between 15 and 20 m.

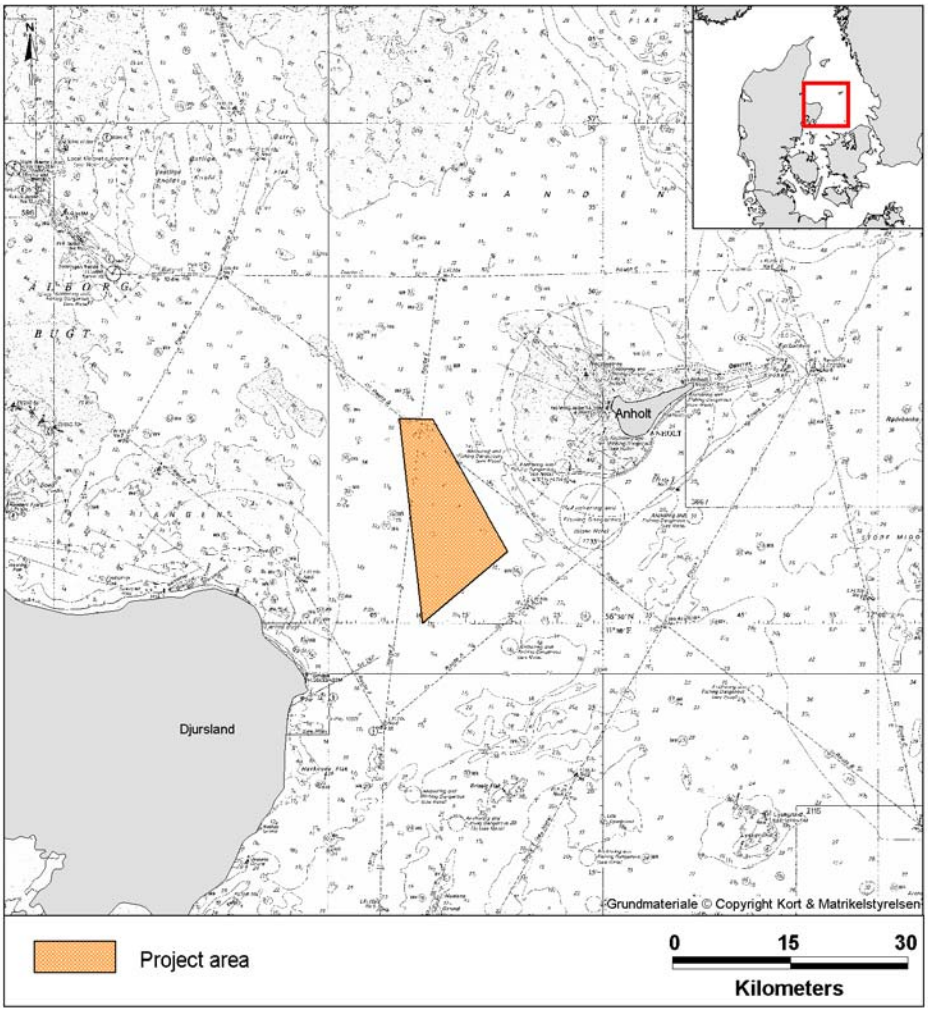

Figure 3.1 Location of the Anholt Offshore Wind Farm project area.

3.1.2 Offshore components

3.1.2.1 Foundations

The wind turbines will be supported on foundations fixed to the seabed. The foundations will be one of two types; either driven steel monopiles or concrete gravity based structures. Both concepts have successfully been used for operating offshore wind farms in Denmark /2, 3/.

The monopile solution comprises driving a hollow steel pile into the seabed. A steel transition piece is attached to the pile head using grout to make the connection with the wind turbine tower.

The gravity based solution comprises a concrete base that stands on the seabed and thus relies on its mass including ballast to withstand the loads generated by the offshore environment and the wind turbine.

3.1.2.2 Wind turbines

The maximum rated capacity of the wind farm is by the authorities limited to 400 MW /4/. The farm will feature from 80 to 174 turbines depending on the rated energy of the selected turbines corresponding to the range of 2.3 to 5.0 MW.

Preliminary dimensions of the turbines are not expected to exceed a maximum tip height of 160 m above mean sea level for the largest turbine size (5.0 MW) and a minimum air gap of approximately 23 m above mean sea level. An operational sound power level is expected in the order of 110 dB(A), but will depend on the selected type of turbine.

The wind turbines will exhibit distinguishing markings visible for vessels and aircrafts in accordance with recommendations by the Danish Maritime Safety Administration and the Danish Civil Aviation Administration. Safety zones will be applied for the wind farm area or parts hereof.

3.1.3 Installation

The foundations and the wind turbine components will either be stored at an adjacent port and transported to site by support barge or the installation vessel itself, or transported directly from the manufacturer to the wind farm site by barge or by the installation vessel.

The installation will be performed by jack-up barges or floating crane barges depending on the foundation design. A number of support barges, tugs, safety vessels and personnel transfer vessels will also be required.

Construction activity is expected for 24 hours per day until construction is complete. Following installation and grid connection, the wind turbines are commissioned and are available to generate electricity.

A safety zone of 500 m will be established to protect the project plant and personnel, and the safety of third parties during the construction and commissioning phases of the wind farm. The extent of the safety zone at any one time will be dependent on the locations of construction activity. However the safety zone may include the entire construction area or a rolling safety zone may be selected.

3.1.3.1 Wind turbines

The installation of the wind turbines will typically require one or more jack-up barges. These vessels stand on the seabed and create a stable lifting platform by lifting themselves out of the water. The area of seabed taken by a vessels feet is approximately 350 m^2 (in total), with leg penetrations of up to 2 to 15 m (depending on seabed properties). These holes will be left to in-fill naturally.

3.1.3.2 Foundations

The monopile concept is not expected to require any seabed preparation.

The installation of the driven monopiles will take place from either a jack-up platform or an anchored vessel. In addition, a small drilling spread may be adopted if driving difficulties are experienced. After transportation to the site the pile is transferred from the barge to the jack-up and then lifted into a vertical position. The pile is then driven until target penetration is achieved, the hammer is removed and the transition piece is installed.

For the gravity based foundations the seabed needs most often to be prepared prior to installation, i.e. the top layer of material is removed and replaced by a stone bed. The material excavated during the seabed preparation works will be loaded onto split-hopper barges for disposal. There is likely to be some discharge to water from the material excavation process. A conservative estimate is 5% material spill, i.e. up to 200 m^3 for each base, over a period of 3 days per excavation.

The installation of the concrete gravity base will likely take place using a floating crane barge, with attendant tugs and support craft. The bases will either be floated and towed to site or transported to site on a flat-top barge. The bases will then be lowered from the barge onto the prepared stone bed and filled with ballast.

After the structure is placed on the seabed, the base is filled with a suitable ballast material, usually sand. A steel 'skirt' may be installed around the base to penetrate into the seabed and to constrain the seabed underneath the base.

3.1.4 Protection systems

3.1.4.1 Corrosion

Corrosion protection on the steel structure will be achieved by a combination of a protective paint coating and installation of sacrificial anodes on the subsea structure. The anodes are standard products for offshore structures and are welded onto the steel structures.

3.1.4.2 Scour

If the seabed is erodible and the water flow is sufficient high a scour hole will form around the structure. The protection system normally adopted for scour consists of rock placement in a ring around the in-situ structure. The rock will be deployed from the host vessel either directly onto the seabed from the barge, via a bucket grab or via a telescopic tube.

For the monopile solution the total diameter of the scour protection is assumed to be 5 times the pile diameter. The total volume of cover stones will be around 850-1,000 m^3 per foundation. For the gravity based solution the quantities are assessed to be 800–1100 m^3 per foundation.

4. Transformer platform and cable project description

4.1 Project description

An offshore transformer platform will be established to bundle the electricity produced at the wind farm and to convert the voltage from 33 kilovolts to a transmission voltage of 220 kilovolts, so that the electric power generated at the wind farm can be supplied to the Danish national grid.

4.1.1 Transformer platform

Energinet.dk will build and own the transformer platform and the high voltage cable which runs from the transformer platform to the shore and further on to the existing substation Trige, where it is connected to the existing transmission network via 220/440 kV transformer.

The transformer platform will be placed on a location with a sea depth of 12-14 metres. The length of the export cable from the transformer station to the shore of Djursland will be approximately 25 km. On the platform the equipment is placed inside a building. In the building there will be a cable deck, two decks for technical equipment and facilities for emergency residence.

The platform will have a design basis of up to 60 by 60 meters. The top of the platform will be up to 25 meters above sea level. The foundation for the platform will be a floating caisson, concrete gravitation base or a steel jacket.

4.1.2 Subsea Cabling

The wind turbines will be connected by 33 kV submarine cables, so-called inter-array cables. The inter-array cables will connect the wind turbines in groups to the transformer platform. There will be up to 20 cable connections from the platform to the wind turbines. From the transformer platform a 220 kV export cable is laid to the shore at Saltbæk north of Grenå. The cables will be PEX insulated or similar with armoring.

The installation of the cables will be carried out by a specialist cable lay vessel that will maneuver either by use of a four or eight point moving system or an either fully or assisted DP (Dynamically Positioned) operation.

All the subsea cables will be buried in order to provide protection from fishing activity, dragging of anchors etc. A burial depth of minimum one meter is expected. The final depth of burial will be determined at a later date and will vary depending on more detailed soil condition surveys and the equipment selected.

The cables will be buried either using an underwater cable plough that executes a simultaneous lay and burial technique that mobilises very little sediment; or a Remotely Operated Vehicle (ROV) that utilises high-pressure water jets to fluidise a narrow trench into which the cable is located. The jetted sediments will settle back into the trench.

4.1.3 **Onshore components**

At sea the submarine cable is laid from a vessel with a large turn table. Close to the coast, where the depth is inadequate for the vessel, floaters are mounted onto the cable and the cable end is pulled onto the shore. The submarine cable is connected to the land cable close to the coast line via a cable joint. Afterwards the cables and the cable joint are buried into the soil and the surface is re-established.

On shore the land cable connection runs from the coast to compensation substation 2-3 km from the coast and further on to the substation Trige near Århus. At the substation Trige a new 220/400 kV transformer, compensation coils and associated switchgear will be installed. The onshore works are not part of the scope of the Environmental Statement for the Anholt Offshore Wind Farm. The onshore works will be assessed in a separate study and are therefore not further discussed in this document.

5. Baseline study

It was the aim of the baseline study to build statistical models relating the functional aspects of the benthic community to important physical, chemical and biological variables and subsequently use these models to predict changes in benthic habitats following the establishment of wind farms.

5.1 Methods

Statistical models describing benthic habitats and the associated feeding guilds characteristics for those habitats were build on field data (sediment characteristics and benthic invertebrate data) collected in the project area in spring 2009, outputs from hydrodynamic modelling (current speed in particular), outputs from water quality modelling (chlorophyll, dissolved oxygen, sedimentation of organic matter) and derived model outputs including "carrying capacity" for benthic filter-feeders (see below). Partial Least Square statistics was used to build these models.

5.1.1 PLS multivariate regression

PLS regression was used to describe the relationship between two sets of variables, X representing external forcings/ pressures and Y representing corresponding feeding guild metrics (biomass, abundance etc.). PLS is a bilinear modelling method where information in the matrix X is projected onto a small number of underlying ("latent") variables called PLS components, referred to as PCs. The matrix Y is simultaneously used in estimating the "latent" variables in X that is the most relevant for predicting the Y variables. In PLS the PCs are calculated in order of declining importance. Usually by adding components beyond 2 to 3 the increase in variance explained primarily is attributed to noise. Hence, it is important to determine the correct (and simplest possible) complexity of a PLS model. The optimal number of components and the identity of significant predictors, e.g. mean current speed in the near-bed layer was assessed by a cross-validation procedure using 60–70% of the full data as a training set and comparing the PLS model with the remaining data by linear correlation. $R^2(Y)$ represents the fraction of variance explained by the PLS model, and Q^2 is a measure of the predictive power of the model. The prediction error sum of squares (PRESS) obtained in the cross-validation is calculated each time that a new PC is added to the model. The optimum number of PCs coincides with the first local minimum in the PRESS versus PC plot.

Predictor (X-) and response (Y-) variables

A large suite of predictor and response variables was included in the initial modelling work. The list of predictor and response variables and their sources are shown in Table 5-1. In order to match the sampling positions of the 80 fauna and sediment stations to modelled variables these were extracted in the grid cell and the near-bed layer were fauna samples were taken.

Table 5-1: Overview of predictor and response variables used in PLS modelling of benthic habitats

Predictor variables	Source	Response variables (Survey)
Depth	Bathymetry	Filter-feeder abundance
Salinity (avr)	HD-model	Filter-feeder biomass
Current speed (avr)	HD-model	Surf deposit-feeder abundance
Sediment LOI	Survey	Surf deposit-feeder biomass
Sediment Grain+sort	Survey	Deep deposit-feeder abundance
Oxygen *	Eco model	Deep deposit-feeder biomass
Chlorophyll	Eco model	Carn/omnivor abundance
Mytilus FF-index	Eco model	Carn/omnivor biomass
Spisula FF-index	Eco model	
Org C sedimentation	Eco model	

*duration of uninterrupted DO conc below 4 and 2 mg/l

5.1.2 Feeding guilds for benthic invertebrates

Each taxon was assigned to a feeding guild according to its food type. The feeding guilds used were carnivores/omnivores (C/O), surface deposit-feeder (SDF), filter-feeder (FF), and deep-deposit feeder (DDF) according to the literature /5, 6, 7/. Seventeen species out of a total of 171 could not be confidently assigned to any of these groups.

Filter-feeders (primarily bivalves but also sponges, polychaetes, gastropods, Cephalochordata) dominated the biomass in the project area followed by deep-deposit feeders (echinodersms, polychaetes), carnivores /omnivores (polychaetes, gastropods, surface deposit-feeders (polychaetes, crustaceans, bivalves) and herbivors (snails feeding on encrustered red algae). Common to all guilds are that the range in biomass between samples is very large primarily due to dominance of few large individuals with patchy distributions (Table 5-2). Among the different functional groups several taxons, e.g. bivalves (filter-feeders), carnivores (gastropods) and deep-deposit feeders (echinodersms) have outer shell(s) or skeletons that constitute with 40-70% of the dry weight. If this ‘non-active’ weight is subtracted from the total dry weight the importance of filter-feeders, carnivores /omnivores and deep-deposit feeders would be halved. Still, the overall pattern that filter-feeders by far dominate biomass in the project area is maintained.

Table 5-2: Biomass (average and range) of benthic invertebrates distributed among feeding guilds.

	avr Biomass	range
	------ g dw/m2 ----	
FF	441.4	0.5-2886
C/O	8.67	0.001-373
DDF	20.65	0.03-298
SDF	1.14	0.05-13.3
Herb	0.01	0-0.58
not assigned	1.52	0-32.7

5.1.3 Carrying capacity for benthic filter-feeders

Two different carrying capacity models for filter-feeders (FF) were established for epibenthic filter-feeding bivalves exemplified by *Mytilus edulis* and *Modiolus modiolus* and infauna filter-feeding bivalves exemplified by *Arctica islandica* and *Spisula subtruncata* using the output from the hydrodynamic and water quality models. Both FF models build on the same concept by combining a physiology-based growth and survival model for a standard individual with an advection term that replenish the food ingested by filter-feeders. On large scale benthic FF for filter-feeders depends on the local primary production and on smaller scale current speed plays an increasing role for FF.

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 /8/

Energetic growth models are available for many filter-feeders, including *Spisula subtruncata* /9/ and *Mytilus edulis* /10,11/.

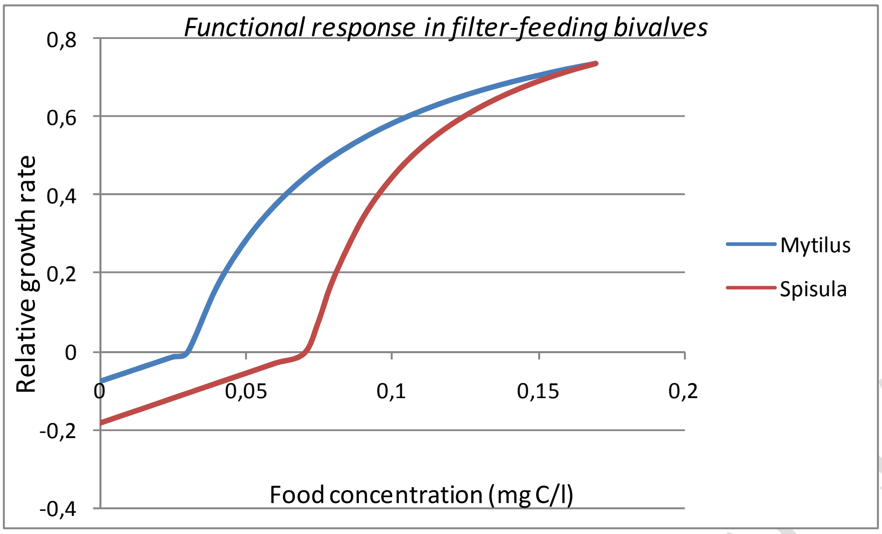

Figure 5-1: Comparison of functional response in *Spisula subtruncata* and *Mytilus edulis*.

Important documented evidence for food requirements for *Spisula subtruncata* Figure 5-1 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 /9/. 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:

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

The growth functions 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 such as in 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. The resulting average Gf index for *Mytilus* and *Spisula* from March to October are presented in Figure 5-2. The highest values are reached on shallow waters where the primary food in form of phytoplankton is more plentiful than in deeper areas.

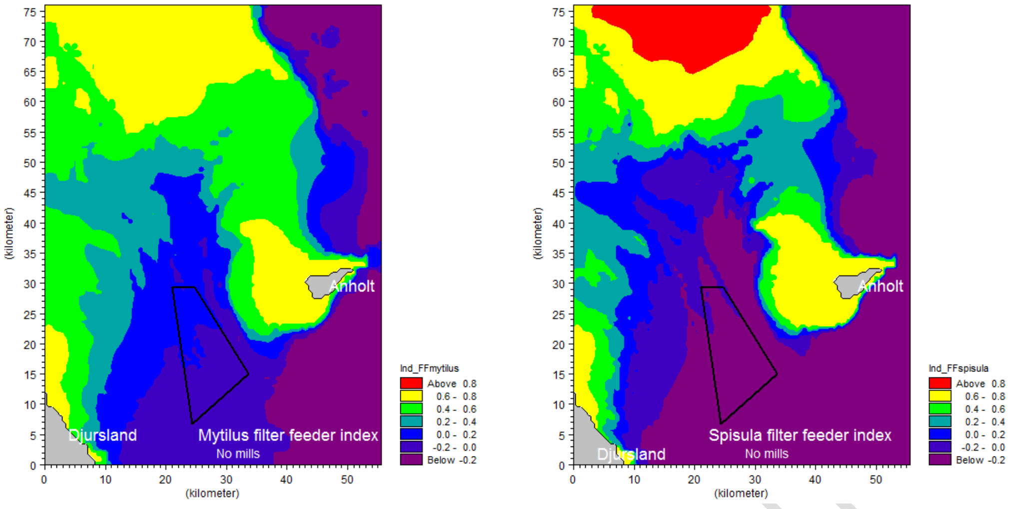

Figure 5-2: Growth or feeding function (Gf) for blue mussels (left panel) and *Spisula* (right panel) in the small model area.

Effect of current speed on growth in individual filter-feeding bivalves has rarely been studied. One example relates to giant scallop (*Pectindae*), 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 /13/. In *Mytilus* the *in situ* growth rate increased with current speed (Riisgård et al. 1994) and wind-induced turbulence /14/. 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 a bell-shaped current function with an optimum speed at 0.3 m s^{-1} was constructed (Figure 5-3).

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.

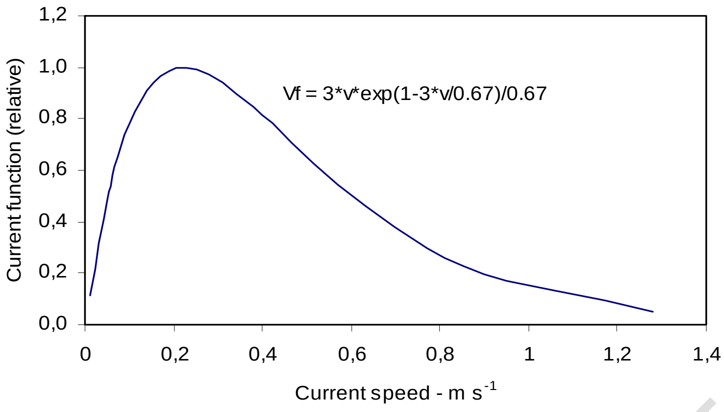

Figure 5-3. Current function to describe food replenishment and physical stress in filter-feeding bivalves.

The average current index from March to October 2005 for the small model area is presented in figure 5-4. It is clear that the highest current indexes are found on shallow waters over 10-12 m.

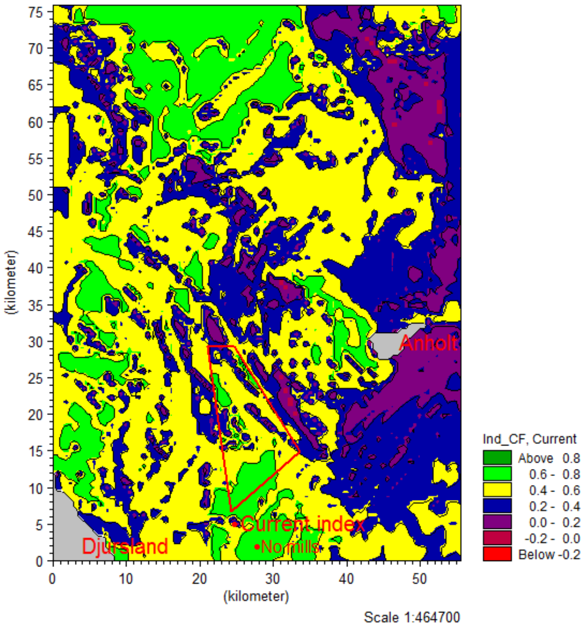

Figure 5-4: Average of current index Vf from March to October 2005 in the small model area.

Extended periods with low oxygen concentration can reduce growth and increase mortality in benthic invertebrates including filter-feeders. Such information is included numerically by multiplying the CC-index with a factor (0.8-0.9) for each day oxygen concentration is below 2 mg O_2/l but starting the reduction at day 7 with low oxygen. Also a salinity-dependent function (species-specific) is included in the combined index:

FF-Index=CC index* SF*OF

SF denotes a species dependent salinity index and OF denotes a species independent oxygen index. SF attains values below 1 at salinities less than 20 psu and accordingly SF do not contribute to the FF-indices in the Anholt wind park.

The final index for *Mytilus edulis* type and *Spisula* type in the smaller model area is shown in Fig 5-5. Both indices are rather high in the shallow areas at depth less than 12-13 m. At depth larger than 15 m, i.e. where the seabed is located below pycnocline indices are low due to lower chlorophyll concentrations and lower current speeds.

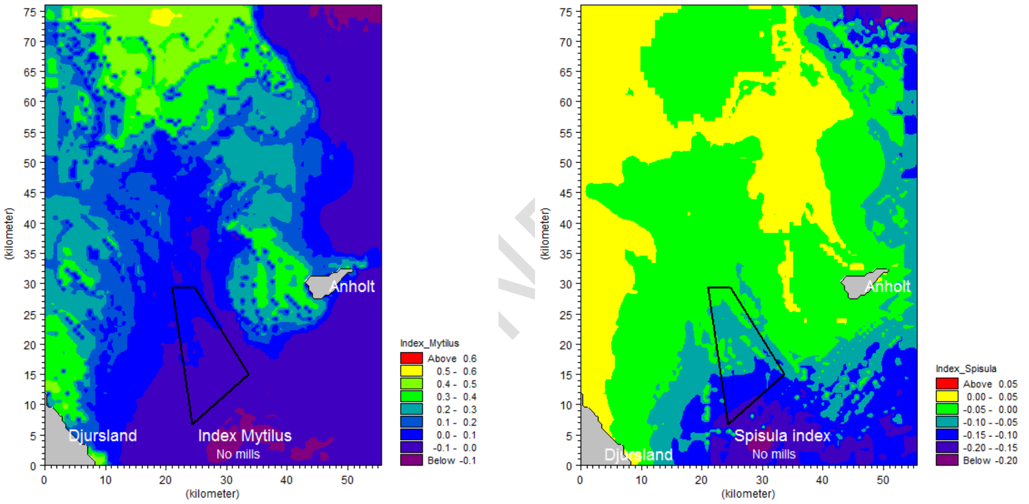

Figure 5-5: Index for blue mussels (left panel) and *Spisula* (right panel) in the small model area. Notice the different scale in legends.

5.2 Habitat modelling

Initially six outliers (i.e. six benthos and sediment samples) were identified and subsequently removed using the Hotelling procedure of the software /15/.

The optimal PLS models varied between response variables, but a consistent pattern was that depth at station, average salinity, oxygen conditions (i.e. number of days with uninterrupted conc. below 2 mg/l) and calculated sedimentation rate of carbon were insignificant in all models. Higher average current speeds affected both abundance and biomass of filter-feeders positively while surface deposit-feeders were negatively affected by higher currents. Large median grain size correlated positively to filter-feeder biomass but to low biomass of surface and deep deposit-feeders. Unsorted sediments (low slope of grain size curve) with a low medium grain size were favorable for surface deposit-feeders, and high organic content (LOI) favored surface and deep deposit-feeders. High concentration of chlorophyll and high values of filter-feeder index correlated positively to abundance and biomass of filter-feeders, while a low filter-feeder index tended to favor surface deposit-feeders (Table 5-3). Overall the coefficient of variation and the predictability of PLS models were low, and with one exception less than 20%. Such low predictability is likely caused by the homogeneous conditions within the project area and, accordingly a limited range in each of the predictor values (Table 5-3).

The low predictability of the statistical models imply that prediction of change in habitats as reflected in the functional benthos groups after establishment of a wind farm will be rather uncertain.

Table 5-3: Overview of coefficient of determination (R^2) and predictability (Q^2) of PLS models of habitat response variables and significance of potential predictor variables included in PLS models. Signs (positive or negative influence) denote predictor variables contributing with more than 4% to model R^2. Signs in brackets denote variables contributing with more that 3% but less than 4%. PLS models are built using predictors contributing with 4% or more to the model.

Response variable	R^2	Q^2	Depth	Salt	Cur	Grain	un-Sort	LOI	DO	Chla	C-sed	FF-index
Filter-feeder abundance	0.13	0.11			+			-		(+)		+
Filter-feeder biomass	0.19	0.15			+	+				(+)		+
Surf deposit-feeder abundance	0.17	0.15			-		-					(-)
Surf deposit-feeder biomass	0.29	0.23			-	-	-	(+)				-
Deep deposit-feeder abundance	0.10	0.07						+				
Deep deposit-feeder biomass	0.06	0.04				-						
Car/omnivor abundance	0.04	0.04										
Car/omnivor biomass	0.05	0.04										

6. Impact assessment

6.1 Methodology

The multivariate statistical models developed for baseline conditions were used for impact assessment by imposing the predicted changes in those variables, such as current speed that were significant for the benthic habitat groups. Because of low predictability of PLS models for carnivores/omnivores, deep deposit-feeders and for abundances within all feeding-groups impacts were only estimated for biomass within filter-feeders and surface deposit-feeders. Basically, only permanent effects are considered and inclusion of sediment grain size changes resulting from dredging activities as a long-lasting effect can be questioned, as we do not know the persistence of accumulation at a site.

6.2 Impacts during operation

6.2.1 Impacts on benthic habitats and functional groups during operational phase

Habitat modeling based on hydrodynamic and water quality modeling of baseline conditions in combination with *in situ* data collected during survey in spring 2009 examined a large range of variables that potentially could affect important functional groups in the benthic communities. For the two benthos variables, biomass of benthic filter-feeders and surface suspension-feeders four governing variables were identified:

- Changes in sediment grain size resulting from sediment accumulation
- Degree of sediment sorting resulting from sediment accumulation
- Changes in mean current speed above seabed
- Changes in combined filter-feeder index (FF)

In addition to potential impacts identified during benthic Habitat modeling

- Occupation of seabed by foundations and scour protection will destroy habitats for infauna which include surface deposit-feeders and a major part of the filter-feeder community
- Introduction of hard substrate, i.e. wind mill foundation potentially will favor epibenthic filter-feeders
- Small-scale changes in current patterns around foundations and scour protections surely will change habitats for all functional groups

The small-scale changes are not dealt with because changes in governing factors cannot be resolved at appropriate scale using a model grid size of 600m.

The potential impacts on the two important functional groups during the operation phase are summarized in Table 6-1.

Table 6-1: Sources of impact and potential impacts on benthic fauna in the operation phase. Notice that sediment grain size changes related to construction phase potentially

Project Activity	Sources of Potential impact	Potential environmental impact
Operation Phase		Environmental impact parameter affected /target of impact
Presence of physical structures (foundations and turbines)	Changes in currents, food fluxes	Changes in biomass of major the benthic functional groups
Introduction of solid substrates (foundations and scour protection stones)	Development of hard bottom community of invertebrates	Reduction in food for benthic filter-feeders due to competition. Changes sedimentation pattern (affecting deposit-feeders)
Dredging for foundations and cables	Long-lasting change in sediment grain-size distribution	Changes in composition of benthic communities

6.2.2 Changes in governing variables and functions

6.2.2.1 Change in benthic habitats caused by current speed changes

Permanent changes in current speeds above seabed will affect benthic filter-feeders and surface deposit-feeders according to the statistical models developed on basis of baseline data (see Table 5-3). The magnitude of change in currents is dependent on the size and shape of the wind mill foundations and the distance between the wind mills compared to the radius of the wind mills. The change in mean current speeds was modelled for the two different wind park layouts in /16/ and is briefly summarised.

The wind park acts as an extra roughness or a partial blockage of the overall current field. The blocked water volume is forced around the park which leads to a decrease in the flow inside the park and an increase in flow velocities outside of the park.

The largest impact is expected at the surface where the flow velocities are significantly higher than at the bottom. The flow resistance at the bottom is smaller even though the geometry of the concrete foundations is larger at the bed.

The main flow direction is north-south. The results in Figure 6-1 show very small effects with average velocity changes less than 1 – 2 mm/s and in most areas even lower. The mean surface velocity changes are very small and insignificant compared to the mean flow velocity, which for the surface flow is in the order of 0.2 m/s. At bottom mean currents are lower at 0.071 m/s and mean reduction within the wind park is 0.0003 m/s.

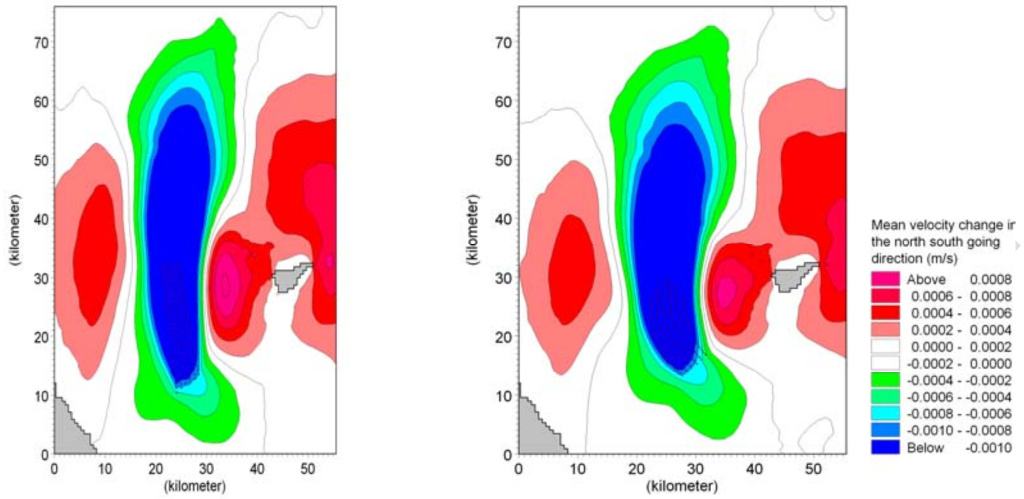

Figure 6-1: Annual mean surface velocity changes in the north-south velocity component in 2005 for the two wind farm layouts. Model results from the local 3D model (grid spacing approximately 600 m). Green-blue colours indicate a velocity reduction and red colours indicate an increase in current velocity.

6.2.2.2 Change in benthic habitats caused by sediment accumulation and changes in grain size

Permanent changes in grain size of surface sediments will affect biomass of filter-feeders and surface deposit-feeders and, change in degree of sorting (i.e. indexed by the slope at median grain size) will affect biomass of surface deposit-feeders (Table 5-3). Changes in sediment grain size may result from permanent change in current speeds and from accumulation of spilled sediment on the sediment surface. Reduction in current speeds above sea bed is very modest averaging 0.0003 m/s within the wind farm areas, and a comparable increase outside the wind farm area. Such small changes are not likely to affect surface sediment significantly, especially considering that mean current speed (modeled) and median sediment grain size (measured) are only weakly correlated within the wind farm area (r = 0.17; p = 0.12, n=74).

Accumulation of fine sediment (20µm) on the sea bed resulting from dredging is very modest at either wind farm layouts (Figure 6-2) with only a limited area where accumulation exceeds 100 g/m2 (eqv. to 0.10mm thickness) within the wind farm area, while accumulation rarely exceeds 25 g/m2 outside the farm area. Theoretically, an accumulation of 0.10mm consisting of 20µm particles on the seabed will reduce the calculated median grain size from a typical 0.320mm to 0.3195mm (using data from 'Sample D-4' from benthic and sediment survey). Correspondingly, a worst case scenario with 0.45mm accumulation will reduce the median grain size of a typical sediment from 0.320 to 0.317mm. The reduction in median diameter can be entered into prediction models to for estimating impacts.

The persistence of changes in grain size is unknown and given the relative minor changes it is doubtful if such changes can be measured. Monitoring after the construction of Nysted Offshore Wind farm generally showed no changes in sediment composition after the dredging operations. However, at few stations close to the construction area the content of silt/clay was increased after the earthworks /18/.

'Unsorted' sediments collected in the wind park area typically contain a large proportion of gravel (>10%) and on average a median grain size 0.42mm compared the an average median size of 0.34mm for the entire pool of samples. In addition to a low median grain size biomass of surface deposit-feeders also correlated significantly to proportion of gravel in a sample. The degree of 'sorting' was described by the slope (%/mm) in the cumulative grain size curve.

Accumulation of fine sediments had very little influence on the slope even in the worst case (0.45mm accumulation) and, in combination with a low regression coefficient the predicted increase in deposit-feeder biomass due to reductions in slope of the grain size curve was less than 0.02%. Therefore, this effect was not considered.

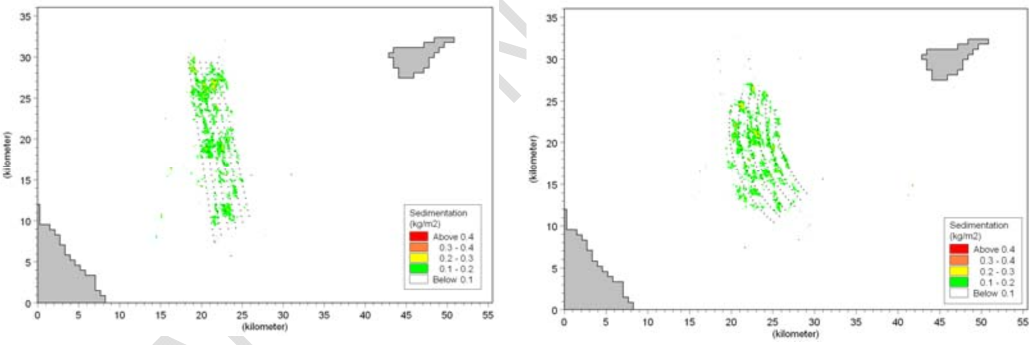

Figure 6-2: Deposition pattern after dredging operation for wind farm layout 1 (left) and layout 2 (right). Model results from the sediment spreading calculations. Information from /3/.

6.2.2.3 Change in Filter-Feeder index

The combined filter-feeder indices ('Mytilus-FF', 'Spisula-FF') were significant for biomass of benthic filter-feeders and for surface deposit-feeders (Table 5-3). The two indices were closely inter-correlated ($r = 0.86$, $p<10^{-5}$), but as the Mytilus-FF index had the largest contribution to model R^2 and also was the most robust in PLS models this index was chosen for impact predictions. Spatial distribution and changes in the Spisula-FF index for the two wind farm layouts is shown in Annex A.

The Mytilus-FF index encompasses a current speed function in addition elements of food concentration and oxygen impacts. The fact that the PLS models for filter-feeder biomass and surface deposit-feeder biomass also include current speed as an independent variable (Table 5-3) underline that near bed currents are very important and that a power function rather that linear function probably would be more appropriate.

The spatial distribution of change in Mytilus-FF is shown in Figures 6-3 and 6-4 for the two wind farm layouts. Changes are small but consistent with reduction in values within the wind farms and downstream (i.e. north of farms) while FF-values are slightly increased outside the farms, overall reflecting the small changes in average current speed.

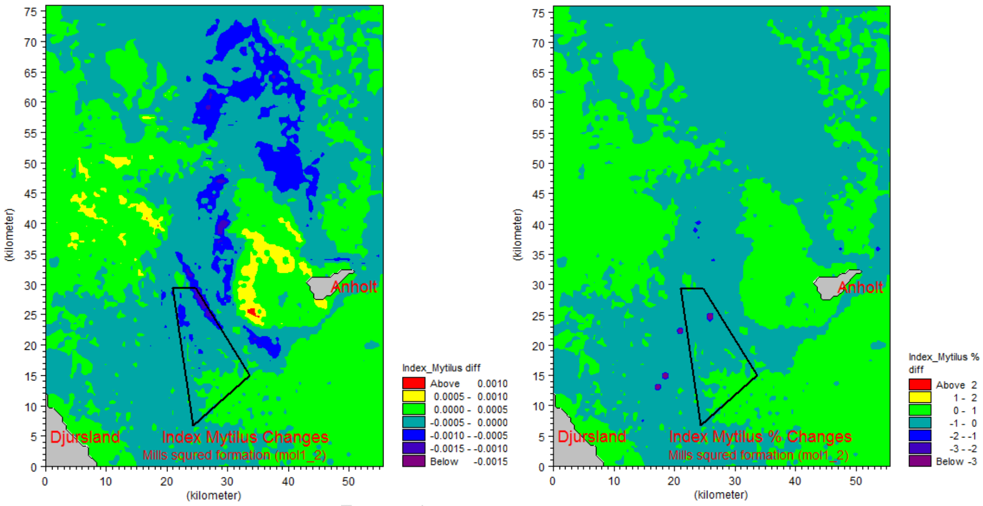

Figure 6-3: Difference in Mytilus-FF index between baseline condition and wind mill park layout 1 (squared formation). Right: absolute values, left: % change.

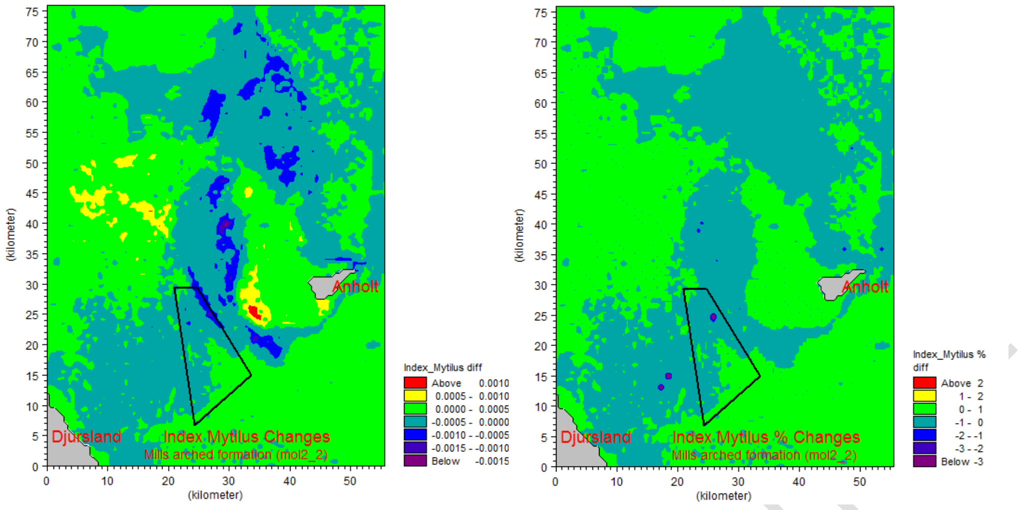

Figure 6-4: Difference in Mytilus-FF index between baseline condition and wind mill park layout 2 (arched formation). Right: absolute values, left: % change.

6.2.2.4 Impact on filter-feeders and deposit-feeders within wind farm area

Based on the predicted changes in governing variables the impact on filter-feeders and deposit-feeders can be estimated using the PLS regression models developed for the baseline conditions. Calculations are carried out for the average changes within the wind park and for the worst case referring to model grid cells with the maximum accumulation of fine sediment, i.e. 0.45 mm.

6.2.2.5 Filter-feeders

Prediction of future biomass of filter-feeders within wind farm area is calculated as:

$$\text{Filt-Feed}_{wf} = \text{Filt-Feed}_{Bas} - \%\text{cur-red} * \text{reg}_{cur} - \text{grain-red} * \text{reg}_{grain} - \%\text{FF-red}*\text{reg}_{FF}$$

where

Filt-Feed_{Bas} are the average biomass of filter-feeders under baseline conditions (from survey),

%cur-red is the reduction in near-current speed in % of baseline,

reg_{cur} is the PLS regression coefficient for current influence on filter-feeders,

grain-red is the reduction in median grain size (mm)

reg_{grain} is the PLS regression coefficient for grain size influence on filter-feeders,

%FF-red is the reduction in FF-index in % of baseline, and

reg_{FF} is the PLS regression coefficient for FF-index influence on filter-feeders

Inserting values in equation gives for average condition within the wind park:

Filt-Feed_{wf} = 441–0.0003/0.071*3089 – 0.000073*1163 – 0.003*2844 = <u>419 gdw/m^2</u>

and for worst conditions (highest sediment accumulation):

Filt-Feed_{wf} = 441–0.0003/0.071*3089 – 0.001*1163 – 0.003*2844 = <u>418 gdw/m^2</u>

The reductions in biomass amounts to 5 and 6% of the baseline value for average condition and worst case, respectively. However, these predictions must be taken with some precaution because of the low predictability of the PLS-model (Q_2 = 0.15).

The physical loss of seabed habitats by occupation of wind mill foundations including scour protection was estimated to a max of 0.5% of the entire project area /1/ and compared to this figure the indirect effects mediated through current reductions, sediment accumulation and reduction in FF-index were notable higher.

Blue mussels are expected to colonize and populate the concrete foundations from the pycnocline (≈13 m) to 2 m below water surface with an average biomass of 23.5 kg wet weight/m^2 /16/. The available surface area of concrete for mussel settlement is 384 m^2 for a single wind mill and 66.814 m^2 for the entire wind park and assuming a steady-state biomass of 23.5 kg /m^2 the total mussel biomass amounts to 1.570 tons. This figure can be compared to the loss of benthic filter-feeder biomass due to physical loss and indirect loss predicted using statistical models (Table 6-2).

Table 6-2: Estimated change in filter-feeder biomass due to direct effects (physical habitat loss and gains) and indirect effects. Dry weight is converted to wet weight (both including shells) by multiplying by 2.

Impact	Causes	Calculation (kg wet weight)	Tons Wet Weight
Physical loss	Wind mill footprints	$0.005*88*10^6*0.441*2$	-388
Indirect loss	Current reduction Sediment change	$(0.441-0.414)*2*88*10^6$	-4752
Additional hard substrate	Wind mill foundations	66814*23.5	+1570

Despite a predicted much higher biomass per area of filter-feeders on concrete foundation (i.e. 23.5 kg/m2) than the baseline biomass on seabed (i.e. 0.44 kg/m2) the calculated loss of filter-feeder biomass in the wind park area as a whole exceeds the gain in biomass due to introduction of additional hard substrate with a factor of about 3, . because of a much higher area of seabed compared to concrete foundations. However, as mussels on foundations are exposed to higher current speeds and higher algal concentrations than filter-feeders on and in seabed the ecological activity in terms of biomass of phytoplankton filtered and yearly net production probable are more comparable than differences in biomass suggest.

6.2.2.6 Surface deposit-feeders

Prediction of future biomass of surface deposit-feeders within wind farm area is calculated as:

$$\text{Dep-Feed}_{wf} = \text{Dep-Feed}_{Bas} + \%\text{cur-red} * \text{reg}_{cur} + \text{grain-red} * \text{reg}_{grain} + \%\text{FF-red}*\text{reg}_{FF}$$

where

Dep-Feed$_{Bas}$ are the average biomass of deposit-feeders under baseline conditions (from survey),

%cur-red is the reduction in near-current speed in % of baseline,

reg$_{cur}$ is the PLS regression coefficient for current influence on deposit-feeders,

grain-red is the reduction in median grain size (mm)

reg$_{grain}$ is the PLS regression coefficient for grain size influence on deposit-feeders,

%FF-red is the reduction in FF-index in % of baseline, and

reg$_{FF}$ is the PLS regression coefficient for FF-index influence on deposit-feeders

Inserting values in equation gives for average condition within the wind park:

$\text{Dep-Feed}_{wf} = 1.14 + 0.0003/0.071*19.6 + 0.000073*11.5 + 0.003*6.5 = \underline{1.24\ \text{gdw/m}^2}$

and for worst conditions (highest sediment accumulation):

$\text{Dep-Feed}_{wf} = 1.14 + 0.0003/0.071*19.6 + 0.0010*11.5 + 0.003*6.5 = \underline{1.25\ \text{gdw/m}^2}$

The increases in biomass amounts to 9 and 10% of the baseline value for average condition and worst case, respectively. Overall, the influence of sediment accumulation was insignificant, due to low accumulation rates and relative coarse sediment. Hence, to change median grain size significantly accumulation rates should exceed say 5 mm. Compared to the model for filter-feeders the predictability of the deposit-feeder model is higher at $Q^2 = 0.23$, but in absolute terms the predictability must be considered to be low and the predictions should be taken with some precaution.

6.2.2.7 Impact on filter-feeders and deposit-feeders outside the wind farm area

Average current speed and Mytilus FF-index will increase west and east of the wind farm with numerical values comparable to decreases within the farm (Figures 6-1, 6-3, 6-4), while sediment accumulation resulting from spill will not extend outside the wind farm (Figure 6-2). Assuming that the PLS-model developed for the wind farm area also applies to the area outside the wind farm, it follows that biomass of benthic filter-feeders will increase and biomass of surface deposit-feeders will decrease, probably in same proportions as the changes predicted within the wind farm.

In popular terms we could say that biomass loss and gains within the farm area are mirrored by gains and losses outside the farm area.

6.2.3 Summary of impacts during the operation phase

The expected impacts on benthic filter-feeders and surface deposit-feeders due to sediment changes, introduction of hard substrate, and changes in current pattern and food fluxed are summarized in Table 6-3. The duration of sediment changes in terms of grain size change cannot be predicted with certainty as sediment spread modeling was not carried out beyond the dredging period.

Table 6-3: Summary of impacts on the benthic filter-feeder and deposit-feeder habitats and biomasses

Impact	**Intensity of effect**	**Scale/geographical extent of effect**	**Duration of Effect**	**Overall significance of impact**
Sediment change	Minor	Local	Long-term?	No impact
Solid substrate	Minor	Local	Long-term	Minor impact
Change in currents and food-fluxes	Minor	Regional	Long-term	Minor impact

7. Mitigation measures

The overall impacts of wind farm operation on the major benthic functional groups are limited and mitigation measures during construction and in the operation phase are not needed.

8. Cumulative effects

The impacts on the benthic habitats and associated functional groups are minor and with a local to regional extension. Hence, important cumulative effects are not expected. Over time, the reversal of eutrophication is expected to continue in internal Danish waters /17/, which ultimately implies that biomass of benthic filter-feeders will be reduced and deposit-feeders will increase due to reduction in pelagic primary production and increased sedimentation of poor-quality food. On a local scale such development is expected within the wind farm area and in a popular language the presence of the wind farm will tend to accelerate the eutrophication reversal, but at very local scales and with little intensity.

9. Decommissioning

There is no experience with decommission of a large offshore wind farms yet and predictions invariable must be very uncertain. If a full rehabilitation is required the removal of foundations, stones, cables and backfilling with sand of appropriate characteristics will constitute a pressure on benthic habitats and important functional benthic groups. A more detailed evaluation and a predicted recovery time during af following decommission are discussed in the report on benthic fauna /1/.

10. Technical deficiencies or lack of knowledge

The analysis and evaluations in this report is based on numerical modelling of hydrography, water quality and sediment spill, in addition to benthos and sediment data collected in the in spring 2009. The modelling was to a large extent based on well calibrated models, which are regarded as trust-worthy for the analyses carried out for this study, as are the data collected *in situ*.

A formal deficiency of the data analysis is related to combining of modelled hydrographic and water quality data representing the model year of 2005 with *in situ* data collected in spring 2009. We know that year 2008 in terms of wind speed and direction and, temperature was somewhat different from 2005 while precipitation and nutrient loads were comparable. To what extent this affects conclusions is not really known. But given that the most important functional group, filter-feeders was dominated by very large specimens of *Arctica islandica* and *Modiolus modiolus* that probably was 20-100 years old /1/ and thus rather stable over time the year-to-year variation in external forcings probably is less important than spatial variation in forcings.

11. Conclusions concerning Anholt Offshore Wind Farm

The overall conclusions concerning the expected impacts on the benthic habitats and important functional groups during the operation phases of Anholt Offshore Wind Farm are summarized in Table 11-1.
The principles for rating the quality of available data are given in Table 11-2.

Table 11-1: Summary of expected impacts on the benthic habitats and dominating functional groups during operation of Anholt Offshore Wind Farm.

Impacts on the benthic habitats in the wind farm area	**Overall significance of impact**	**Quality of available data**
Impacts during operation		
Habitat loss	Minor impact	3
Sediment change	No impact	3
Solid substrates (foundations and scour)	Minor impact	3
Current changes	Minor impact	2

12. References

/1/ DHI (2009) Anholt Offshore Wind Farm. Benthic Fauna – Baseline Surveys and Impact Assessment.

/2/ E.On, Rødsand 2 Havvindmøllepark, Vurdering af Virkninger på Miljøet, VVM-redegørelse, juni 2007

/3/ Dong Energy, Horns Rev 2, Vurdering af Virkninger på Miljøet, VVM-redegørelse, oktober 200

/4/ Energistyrelsen, Belingelser for offentligt udbud om Anholt Havvindmøllepark 30. april 2009

/5/ Fauchald K & PA Jumars (1979) The diet of worms: A study of polychaete feeding guilds. Oceanogr Mar Biol Ann Rev 17: 193-284

/6/ Gaston GR & JC Nasci (1988) Trophic structure of macrobenthic communities in the Calcasieu estuary, Louisiana. Estuaries 11: 201–211.

/7/ Mancinelli G, Fazi S & L Rossi (1998) Sediment structural properties mediating dominant feeding type patterns in soft-bottom macrobenthos of the Northern Adriatic Sea. Hydrobiologia 367: 211–222.

/8/ Kiørboe T & F Møhlenberg (1981) Particle selection in suspension feeding bivalves. Mar. Ecol. Prog. Ser. 5: 291-196.

/9/ Kiørboe T, Møhlenberg F & O Nøhr (1980) Feeding, particle selection and carbon adsorption in Mytilus edulis in different mixtures of algae and resuspended bottom material. Ophelia 19: 193-205

/10/ Møhlenberg F & T Kiørboe (1981) Growth and energetics in Spisula subtruncata (da Costa) and the effect of suspended bottom material. Ophelia 20: 79-90

/11/ Kiørboe T, F Møhlenberg & O Nøhr (1981a) Effect of suspended bottom material on growth and energetics in Mytilus edulis. Mar. Biol. 61: 283-288

/12/ Wildish DJ, Kristmanson DD, Hoar RL, DeCoste AM, McCormick SD & AW White (1987) Giant scallop feeding and growth responses to flow. J. Exp. Mar. Biol. Ecol. 113: 207-220.

/13/ Raiisgård HU (red.), Clausen I, Møhlenberg F, Petersen JK, Olesen NJ, Christensen, PB, Møller, MM & P Andersen. (1994) Filtratorer, planktondynamik og biologisk struktur i Kertinge Nor. Miljøstyrelsen, 75 sider. – Havforskning fra Miljøstyrelsen, nr. 45.

/14/ Sand-Jensen K (red.), Borum J, Geertz-Hansen O, Jensen JN, Josefson AB, Møhlenberg F & B Riemann (1994) Resuspension og stofomsætning i Roskilde Fjord. Miljøstyrelsen 69 sider. – Havforskning fra Miljøstyrelsen nr. 51.

/15/ Chatfield C (1980) Introduction to Multivariate Analysis. London: Chapman and Hall.

/16/ DHI (2009). Anholt Offshore Wind Farm. Hydrography, sediment spill, water quality, gepmorphology, and coastal morphology. Baseline description and Impact Assessment., September 2009.

/17/ Carstensen J, Conley DJ, Andersen JH & G Ærtebjerg (2006) Coastal eutrophication and trend reversal: A Danish case study. Limnology and Oceanography 51: 398–408.

/18/ DHI Water & Environment. 2004. Nysted Offshore Windfarm ar Rødsand - Morphology Study. Final Report. November 2004

Annex A Spisula FF-index

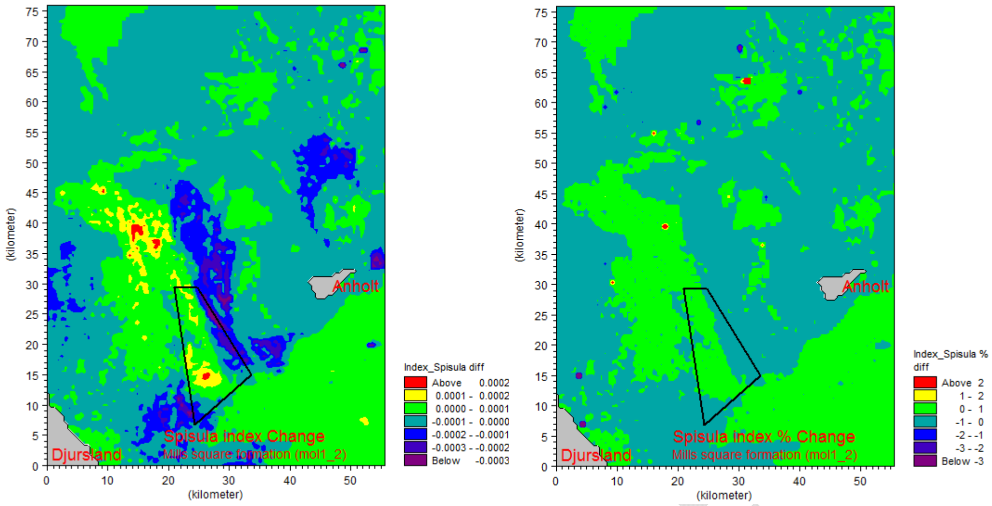

Figure A-1. Difference in Spisula-FF index between reference condition and mill farm layout 1 (squared formation). Right absolute values, left in % change.

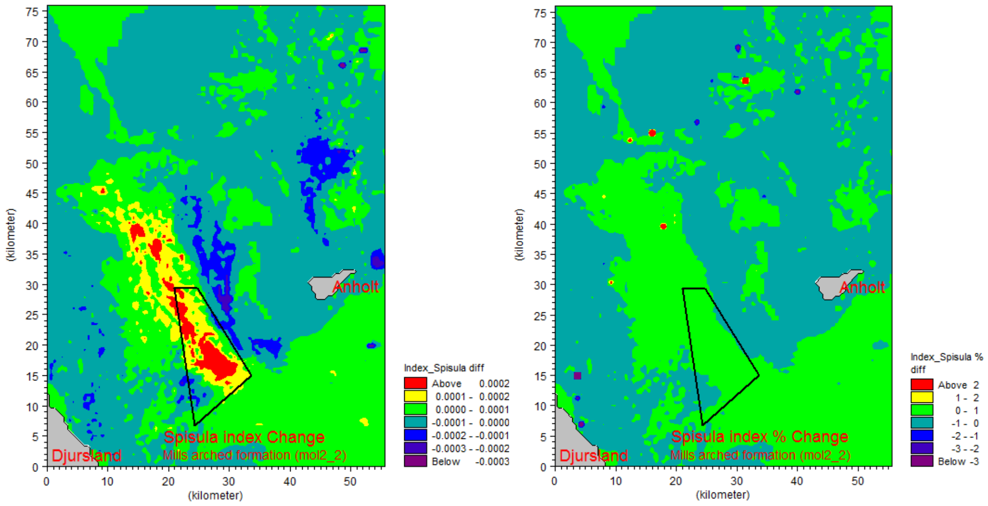

Figure A-1. Difference in Spisula-FF index between reference condition and mill farm layout 2 (arched formation). Right absolute values, left in % change.