DANISH OFFSHORE WIND
Key Environmental Issues – a Follow-up



DANISH ENERGY AGENCY
DANISH NATURE AGENCY
DONG ENERGY
VATTENFALL

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INDEPENDENCE OF FOSSIL FUELS BY 2050!

Denmark's energy target is unique, both in its ambition as well as its broad political backing. Over the coming decades this shared commitment will be translated into an historic transition of the Danish energy sector. One goal will be to achieve 50% wind penetration in the grid by 2020.

Like other countries, Denmark faces two major global energy challenges: addressing global warming and ensuring security of supply. One answer to these challenges lies in the way we produce and consume energy and in our ability to adapt our society to climate change.

The Danish wind energy sector is a core element in Danish energy policy. The historic agreement of 2012 contains a wide range of ambitious initiatives, bringing Denmark a big step closer to the target of 100 % renewable energy in the energy and transport sectors by 2050. Today, almost 30 % of the electricity produced is already being generated by wind. By 2020, almost 50 % of Danish electricity consumption will be covered by wind power.

At sea, wind resources are better and suitable sites are more readily available. So, an obvious choice is to have a significant proportion of the renewable energy expansion delivered by large, offshore wind farms.

For such a transition to succeed, it is vital to be clear about the environmental impacts of large-scale offshore wind farms. New research has been utilised to improve our screening of new sites and in authorisation of new projects. To provide continued protection to vulnerable marine habitats, it is important to build on the positive experience gained so far.

This follow-up to the Danish environmental monitoring programme on large-scale offshore wind power builds on the result of the former programme and focuses on updated knowledge on harbour porpoises, water birds and fish communities, and on the cumulative effects of wind farms. The scientific quality of the projects in this follow-up has been assessed by experts from the International Advisory Panel of Experts on Marine Ecology (IAPEME), who have commented on the results in an independent evaluation which is reproduced in this publication.

If we are to unlock the true potential of offshore wind power, it is crucial that we employ the best available research in the planning process to minimize the environmental impacts. This new environmental monitoring programme provides us with invaluable insights on the impacts of wind farms on marine flora and fauna. It is our hope that the results of this publication will serve as inspiration for future wind projects.

Ida Auken
MINISTER FOR THE ENVIRONMENT

Martin Lidegaard
MINISTER FOR CLIMATE, ENERGY AND BUILDING

READER'S GUIDE

The first two chapters contain an executive summary (chapter 1) and an introduction (chapter 2) detailing the background and scope of the environmental monitoring programme.

The following chapters deal with the latest research findings of the monitoring programme. While chapter 3 deals with effects on fish populations, chapter 4 looks at effects on marine mammals and chapter 5 examines the impact on birds like common scoters and red-throated divers. Each of these chapters contain an introduction to key issues, a description of the research methods, a description and a brief discussion of the results.

At the end of chapters 3-5 an expert from the International Advisory Panel of Experts on Marine Ecology (IAPEME) presents his viewpoints on the results of the environmental monitoring programme.

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1

EXECUTIVE SUMMARY
SUSTAINABLE WIND POWER EXPANSION

All over the world, governments are investing in renewable energy to reduce their dependency on fossil fuels and to curb carbon emissions. A crucial tool in this transformation is the exploitation of wind energy, and significant growth in offshore wind deployment is projected.

In light of this historic transition, it is of fundamental importance to continually improve the basis for planning decisions by incorporating new research on the environmental impacts of wind farms.

Denmark has more than 20 years of experience in developing offshore wind farms and a decade ago Denmark commissioned the groundbreaking environmental monitoring programme. After its conclusion in 2006, a follow-up programme was initiated focusing on long-term and cumulative effects on fish, harbour porpoises, common scoters and red-throated divers. The new studies provide planners and developers with tools to address the cumulative effects of wind farms, and to mitigate injury to harbour porpoises during construction.

The Danish environmental monitoring programme and its follow-up programme have led to the important conclusion that, with proper spatial planning, it is possible to construct offshore wind farms in an environmentally sustainable manner that does not lead to significant damage to nature.

SUMMARY 2006

This follow-up builds on the extensive knowledge gathered during the first phase of the environmental monitoring programme that was conducted from 2000 to 2006. The programme was commissioned by the government and run by the Environmental Group consisting of the Danish Nature Agency, and the Danish Energy Agency, with Vattenfall and DONG Energy representing the operators.

The 2000-2006 programme followed a "Before After Control Impact" (BACI) design that aims to estimate the state of the environment before and after any change and to compare these effects with changes in reference sites. This applied to all the studies except the socio-economic study.

Visualisation of wind farm. PHOTO: ELSAM ENGINEERING A/S

SUMMARY 2006, CONTINUED

Below is a brief summary of the 2006 conclusions from each topic examined:

- Benthic fauna and flora: Before construction of the wind farms, the seabed almost exclusively consisted of sandy sediments. The wind turbine foundations introduced hard bottom structures that changed benthic communities from typical infauna communities to hard bottom communities. Overall the wind farms increased habitat heterogeneity as well as the abundance and biomass of benthic communities.

- Fish: The researchers monitored fish abundance and diversity at both wind farm sites as well as at a reference area. The study showed few effects on the fish fauna. Investigations also included fish behaviour around electromagnetic fields from cables. These studies showed that some species were attracted, while other species demonstrated avoidance behaviour.

- Birds: Birds tend to avoid wind turbines and the study confirmed this. By using radar and infra-red video monitoring, researchers saw avoidance behaviour from the major species at both sites. Also post-construction studies showed almost complete absence of red-throated divers and common scoters within the wind farm area at Horns Rev. For Nysted it was long-tailed duck that was negatively affected.

- Marine mammals: Both seal and harbour porpoise behaviour and activity were studied during construction and operation of the two wind farms. For seals no change in behaviour at sea or on land could be linked to the wind farms, except for one incident during construction at the Nysted site. The harbour porpoises were equally unaffected at the Horns Rev site but at the Nysted site activity clearly decreased during construction and operation. The effect persisted after two years, with indications of a slow recovery.

- Socioeconomic effects: Attitudes towards offshore wind farms were measured both at national and at local levels. The socioeconomic study showed positive attitudes towards wind farms and a willingness to pay to place future farms away from the shore to minimize visual impacts. However attitudes varied between the two sites and there were also limits to willingness to move wind farms out of sight.

THE FOLLOW-UP:
EVALUATING LONG-TERM AND CUMULATIVE EFFECTS

The findings in the 2000-2006 environmental monitoring programme were assessed by an international panel of independent experts, IAPEME (International Advisory Panel of Experts on Marine Ecology). Based on the comments and recommendations of this panel of experts, a follow-up programme was commissioned. The aim was to address topics of particular relevance to the future development of offshore wind farms in Denmark.

Specifically the new round of studies aimed to establish whether fish populations increase at offshore wind farms over a longer time scale than covered by the previous studies. In addition, further studies were needed to illuminate whether, over time, common scoters can learn to forage within wind farms. In addition, the extent of piling noise disturbance on harbour porpoises, and the effectiveness of mitigation measures, was addressed. Finally the follow-up sought to develop models to estimate cumulative effects of multiple wind farms on marine mammals and birds.

Below is a brief summary of the follow-up studies that are presented in further detail in chapters 3 to 5.

FISH:
WIND FARMS AS A REFUGE FOR FISH

Extending seven years after the deployment of the wind farm in 2003, the study on Horns Rev is the first long-term study of the effects of offshore wind farms on fish communities.

A number of fish species showed attraction towards the wind turbine foundations, and this has now resulted in a higher number of species inside the wind-farm area compared to areas outside the wind farm.

Overall the studies showed that offshore wind farms did not have any negative impact on fish abundance. A number of species appears to use the foundation and asso-

THE CHALLENGE: EXPANDING POWER FROM WIND

- The EU target: The European Union has agreed on climate and energy targets that demand a 20% reduction in carbon emissions by 2020. Energy efficiency is also to be improved by 20% and 20% of energy consumption is to come from renewables.
- National targets: The Renewable Energy Directive also assigns an individually binding renewable energy target, which will contribute to achieving the overall EU goal. To reach these targets, offshore wind will have to play a large role.
- The Danish targets: In 2012 Denmark adopted a broadly agreed and very ambitious energy agreement stretching to 2020. The agreement means that new large-scale offshore wind farms will be built in the North Sea at Horns Rev and in the Baltic Sea at Kriegers Flak. Furthermore, several smaller wind farms near the coast are projected before 2020. By 2020 half of the electricity consumption in Denmark will come from wind power. This is more than a tripling of current offshore wind capacity.

Fishing by Nysted Offshore Wind Farm. PHOTO: CHRISTIAN B. HVIDT

Red-throated diver, a common sea bird wintering in Danish waters. PHOTO: MARK MALLORY

ciated scour protection as refuge areas for hide and forage.

The positive effect may be enhanced by exclusion of commercial fishing inside the wind farm area and thus function as a small marine protected area. However, the area occupied by an offshore wind farm is relatively small compared the spatial use of most migratory species with a broad distribution pattern. The cumulative effect of multiple wind farms located close together within the same region might therefore be beneficial to fish communities.

MARINE MAMMALS: INJURY AND POPULATION IMPACTS CAN BE MITIGATED

The first part of the follow-up programme focused on construction noise effects on the harbour porpoise, looking at long-distance disturbance effects as well as the effectiveness of devices to deter harbour porpoises from zones of potential injury. The second part of the study developed and tested a computer model to predict the cumulative effects on harbour porpoise populations of wind turbines, ships and by-catch.

The first study documented considerable noise effects on harbour porpoises during pile driving, with possible temporary hearing impairment as a consequence. However, the effect was also shown to be short-lived. Furthermore researchers investigated the effect of seal scarers on harbour porpoises and found that the sound-emitting device indeed has a deterrent effect on harbour porpoises, thus protecting against injury from piling noise.

In the third study researchers developed a computer model to predict effects of wind farms, ships and by-catch over time on harbour porpoise populations. In the model each animal moved around in a virtual landscape and reacted to noise and variations in food availability in a way that closely resembled that of real animals.

The model predicted that noise from ships and wind farms has a minor effect on harbour porpoise population size. By-catch in commercial fisheries may in contrast reduce the population size substantially. These results need to be treated with some caution however, as uncertainties exist about some of the input data and assumptions on which the model is based.

Harbour porpoise surfacing to breathe. PHOTO: ANDERS LIND-HANSEN

Harbour porpoise female with calf. PHOTO: ANDERS LIND-HANSEN

BIRDS:

MODELS AS TOOLS TO PREDICT IMPACTS ON BIRDS

The results from the 2000-2006 environmental monitoring programme suggested that the common scoter and the red-throated diver were adversely affected by the Horns Rev wind farm. To follow up on this for common scoters, two additional studies were conducted: one aiming to improve the understanding of the availability and changes in food supply for common scoters in the Horns Rev area, and another documenting the distribution of common scoters in the area in 2007. For red-throated divers, a study was conducted aiming at modelling the cumulative disturbance effects of large-scale windfarm development in Danish and Baltic waters.

In the first study, a habitat suitability model was developed for cut trough shells and razor clams – the two main prey species for the common scoters. This model has provided a means for extrapolating the results of the biological sampling carried out to the whole area around Horns Rev. The model also makes it possible to make estimates for the whole period of the baseline and post-construction investigations (2000-2010). The habitat-suitability model has proved useful in describing the relationship between distribution patterns of common scoters and their prey. The model may serve as a predictive tool in the planning process for development of future offshore wind farms.

Aerial surveys conducted in 2007 found high common scoter densities within the Horns Rev 1 offshore wind farm, but this is only likely to happen a number of years after construction. It could not be excluded, however, that this reflects changes in food supply rather than a change in the behaviour of the birds.

The computer model developed to assess cumulative effects of multiple wind farms on the red-throated diver population suggested there would be very small impacts from the three wind-farm development scenarios considered for Danish waters and the Baltic Sea. Even in the scenario where 15,000 km² were classified as wind farms, a less than 2% change in the population level was predicted. Further development of the model, and better knowledge on the biology of red-throated divers, are needed to be able to draw conclusions with more certainty.

2

INTRODUCTION
IMPROVING KNOWLEDGE ABOUT ENVIRONMENTAL IMPACTS

BY METTE CRAMER BUCH *(Danish Energy Agency)*

There are significant benefits to be gained from offshore wind farms. These include mitigating climate change and diversifying energy supply, as well as creating independence from fossil fuels and creating jobs. Wind farms, however, have an impact on the natural environment that has to be taken into account in the planning stages.

This book presents unique knowledge on environmental impacts that is the outcome of the follow-up to the environmental monitoring programme for Danish large-scale offshore wind farms. The follow-up was conducted during 2007-2012. The programme has been carried out for the Danish Energy Agency by the Environmental group consisting of the Danish Nature Agency, the operators of the Nysted and Horns Rev 1 offshore wind farms and the Danish Energy Agency. An International Advisory Panel of Experts on Marine Ecology (IAPEME) has followed the programme from the start.

A FUTURE DEPENDING ON OFFSHORE WIND

In 2007, the European Union and its Member States agreed to new climate and energy targets: a 20% reduction in greenhouse gas emissions by 2020; 20% energy efficiency by 2020 and 20% of the EU's energy consumption to be from renewable sources by 2020. The Renewable Energy Directive establishes the framework for achieving the 20% renewable energy target by 2020.

Under the terms of the Renewable Energy Directive, each Member State is assigned an individually binding renewable energy target, which will contribute to achieving the overall EU goal. A significant part of the expansion of renewables is expected to be covered by offshore wind.

In Denmark these targets have led to a broadly agreed and very ambitious energy agreement stretching to 2020. More specifically, this means that new large-scale offshore wind farms will be built in the North Sea at Horns Rev and in the Baltic Sea at Kriegers Flak. Furthermore, several smaller wind farms near the coast are projected before 2020.

Service vessel leaving Horns Rev 1. PHOTO: VATTENFALL

By 2020 half of the electricity consumption in Denmark will come from wind power. This is more than a tripling of current offshore wind capacity.

SHALLOW AND WINDY – IDEAL CONDITIONS FOR WIND POWER

Denmark has an abundance of relatively shallow waters suitable for offshore wind farms. Of Denmark's total area at sea of about 105,000 km², 43,000 km² have a depth of less than 30 m. The Danish waters lie in the zone between the Baltic Sea, which comprises one of the world's largest bodies of brackish water, and the saltwater of the North Sea. The living conditions of plants and animals are quite differentiated, e.g. by the fact that the salinity of the water can vary considerably over short distances. Often, each species can only live within a narrow salinity scale.

The sea around Denmark consists of highly variable ecosystems. The seabed, for instance, is the habitat for a number of ecologically valuable plant and animal communities that range from requiring brackish water with almost freshwater properties to communities requiring water with high salinity. This variation is further augmented by the great variation in the structure and dynamics of the seabed as well as the currents and the physical and chemical aspects of the sea.

The favourable conditions for offshore wind farms/energy in Danish waters created by strong winds and relatively shallow waters, have allowed Denmark to be a pioneer in the development of offshore wind farms. The valuable lessons learned from this early development are beneficial to both Danish as well as international actors.

A PLANNING SYSTEM RESPECTFUL OF ALL SEA USES

While offshore wind is an attractive energy alternative, development of offshore wind farms should be based

TABLE 2.1 EXISTING DANISH OFFSHORE WIND FARMS 2012

NAME OF WIND FARM	YEAR OF COMMISSIONING	NUMBER OF TURBINES	TOTAL CAPACITY
Vindeby	1991	11	5 MW
Tunø Knob	1995	10	5 MW
Middelgrunden	2001	20	40 MW
Horns Rev 1	2002	80	160 MW
Samsø	2003	10	23 MW
Rønland	2003	8	17 MW
Frederikshavn	2003	3	8 MW
Nysted	2003	72	165.5 MW
Horns Rev 2	2009	91	209 MW
Avedøre Holme	2009/10	3	11 MW
Sprogø	2009	7	21 MW
Rødsand 2	2010	90	207 MW
Anholt	2012	111	400 MW

on thorough and well considered planning. This should involve a planning approach, which respects the vulnerability of the marine environment, and takes all sea uses into account.

Wind farms cannot be seen in isolation from the natural and anthropogenic landscape in which they are constructed. Therefore planning systems are necessary to reveal the multitude of anthropogenic pressures on the environment and their cumulative effects. It is important in planning to observe the multitude of effects and to attempt to mitigate the effects with the largest impact on vulnerable species or habitats. For example by-catches or noisy explosions may prove to be a larger problem for the population of cetaceans than wind farms.

In Denmark a spatial planning committee for offshore wind has been established. The committee is led by the Danish Energy Agency and consists of the authorities responsible for the natural environment, safety at sea and navigation, offshore resources extraction, visual interests and grid transmission conditions. Furthermore, the committee comprises expertise within the technical fields of wind power as well as turbine, foundation and grid technologies.

The committee assesses on a regular basis the placement of offshore wind farms with respect of other interests at sea and appropriate sea uses. The committee is tasked with finding appropriate sites for offshore wind farms, i.e. sites where the impact on nature and other sea uses is expected to be low, whilst suitable for harvesting offshore wind. Subsequently, the suggested sites are discussed with the other marine authorities. When all authorities agree to appropriate placements of offshore wind farms, these are sent into public hearing. A hearing of relevant neighbouring countries is also carried out when appropriate. This may lead to further adjustments of the plans. This process was carried out in 2007, 2011 and 2012.

The report "Future Offshore Wind Turbine Locations – 2025" was first published in April 2007. This report was subsequently updated in April 2011. The updated report charts a number of possible offshore areas where offshore turbines could be built to deliver an overall capacity of app. 4,200 MW. This corresponds to app. 50% of Danish electricity consumption. Several of the sites identified are being developed for large-scale wind farms, e.g. Anholt (400 MW), Horns Rev 3 (400 MW) and Kriegers Flak (600 MW).

In 2012 the spatial planning committee for offshore wind published the results of a planning exercise aiming at identifying the most suitable sites for near-coast offshore wind farms. 15 areas were selected, each with a possible capacity of up to 200 MW.

Knowledge from the present environmental monitoring programme for large-scale offshore wind farms, and the knowledge collected in environmental impact assessments is continually being fed into the spatial planning process. Furthermore the strategic marine planning process is subject to a strategic environmental review in accordance with the EU Directive on Strategic Environmental Assessment.

NATURA 2000 AREAS

Pursuant to the Bird Protection and Habitat Directives, Natura 2000 areas have been designated in Danish waters. These areas are meant to secure a coherent ecological network of the Natura 2000 sites in Europe. The aim of the designation is to promote maintenance or restoration of the natural habitat types and encourage relevant species so that they can attain favourable conservation status in their natural environment.

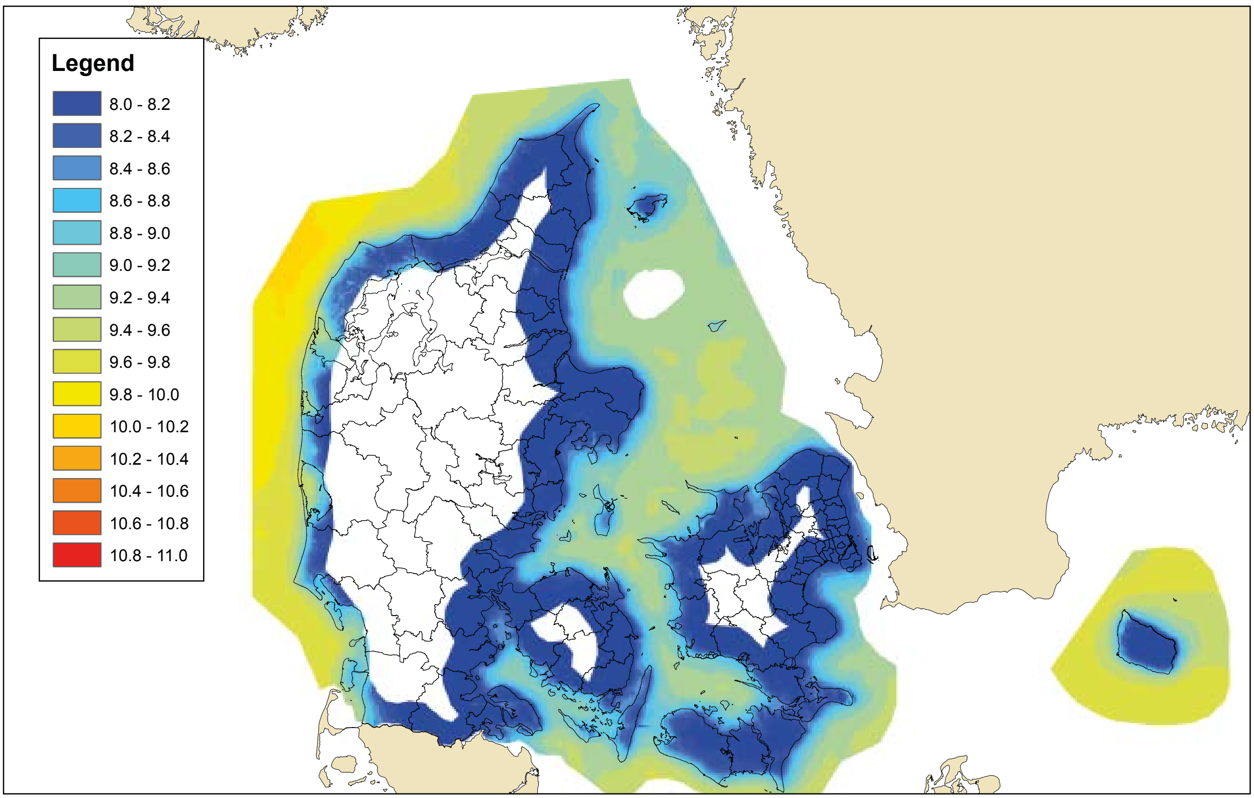


FIGURE 2.1 *Average coastal and offshore wind speeds (m/s) in Denmark, 100 m above sea level.*

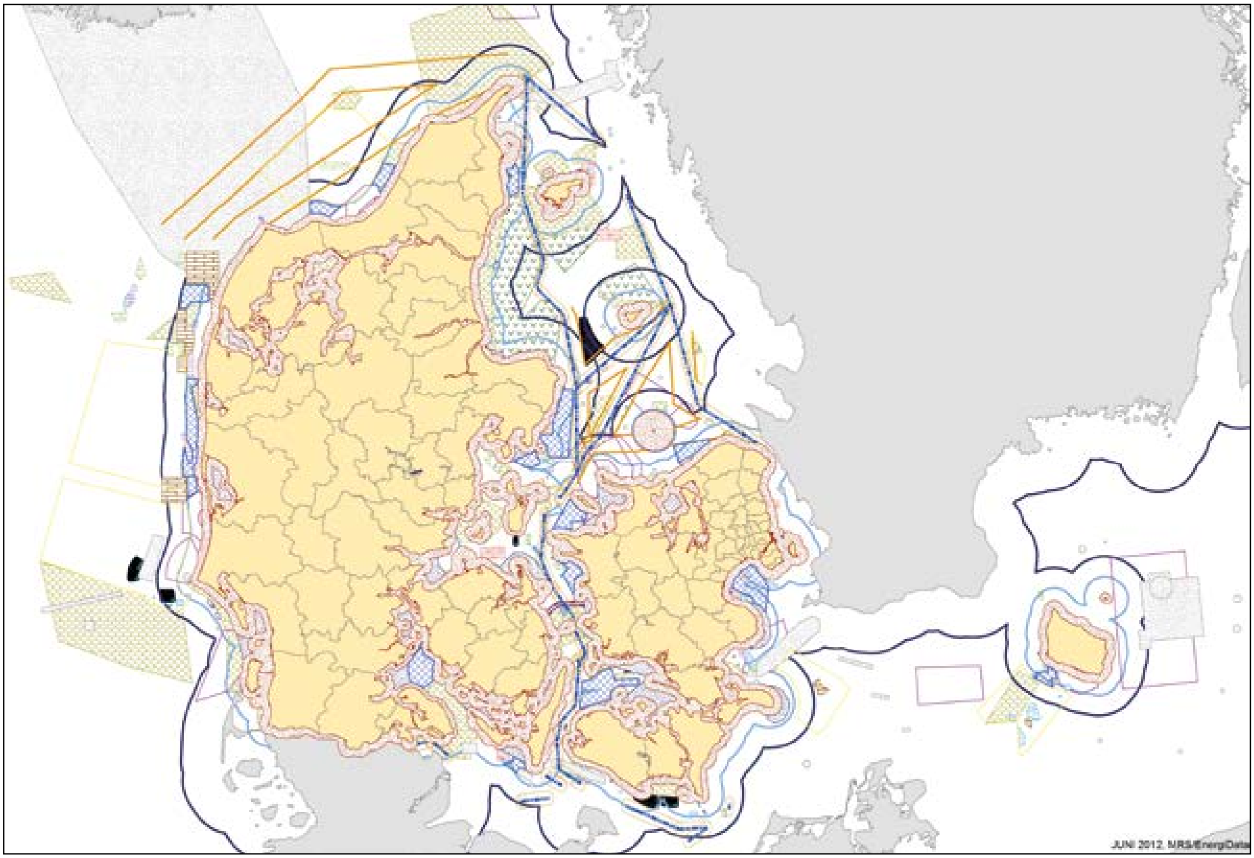


FIGURE 2.2 *Example of the result of a spatial planning exercise to find suitable sites for offshore wind. This example shows the 15 suitable near-coast sites identified. The near-coast sites are the blue hatched areas on the map.*

HISTORY OF THE ENVIRONMENTAL MONITORING PROGRAMME FOR LARGE-SCALE OFFSHORE WIND

In 1997, the Danish Energy Agency published the first action plan outlining the conditions for large-scale expansion and commercialization of offshore wind power. Several smaller-scale test farms had been performing well at sea for some years. The economic parameters for commercial use of offshore wind were favourable, as costs were declining and the wind potential was larger than expected.

At that time, the Danish government had a vision of expanding wind power at sea by means of large-scale wind farms. The reasoning was that concentrating wind production in larger farms was the most economically efficient and also a good way to protect the integrity of the coastal environments. In this action plan the environmental demonstration programme for large-scale offshore wind farms was born.

As a result of the action plan, in 1998 the government asked two Danish utilities to carry out an environmental demonstration programme for large-scale offshore wind farms. Horns Rev and Nysted offshore wind farms were selected for the programmes. The lessons learned resulted in a framework for the formal part of the approval procedure and a solid basis for spatial planning for offshore wind farms in Denmark.

EU GUIDANCE ON WIND AND NATURA 2000

An ad hoc group was established by the European Commission in cooperation between the environmental and energy directorates to assist the Commission in developing a guidance document for wind-energy planning. The purpose of the document is to clarify what it takes for a wind-energy project to comply with the nature conservation requirements of the EU and other relevant international nature legislation applicable in Europe. The guidance document describes which steps must be undertaken in order to examine and document the effects of new wind farms.

FOCUS OF THE ENVIRONMENTAL STUDIES IN THE FIRST PART OF THE MONITORING PROGRAMME IN 2000-2006

The studies and analyses in the demonstration programme have dealt with:

- Benthic fauna and flora, with particular focus on the consequences of the introduction of a hard-bottom habitat, i.e. the turbine foundations and the scour protection. This also included a survey of the infauna community at the wind farms.
- The distribution of fish around the wind turbines and the scour protection.
- Coastal morphology.
- Studies of the numbers and the distribution of feeding and resting birds, performed by aerial surveys, and studies on the food choice of common scoters.
- Migrating birds, including study of the risks of collision between birds and wind turbines.
- Marine mammals – harbour porpoise and seal – behaviour and reaction to wind farms.
- The impact of electromagnetic fields on fish.
- Sociological and environmental economic studies.

The objective of the programme was to investigate environmental issues of relevance to offshore-wind development. The challenge was to clarify the environmental impacts of a relatively unknown technology and explore possibilities to overcome these. The results would prove vital to finding relevant areas for future wind farms.

In order to ensure that the development of large-scale offshore wind farms could take place with due consideration to natural and environmental interests, a comprehensive environmental monitoring programme was carried out during the period 1999–2006 for the Nysted and Horns Rev 1 offshore wind farms. The monitoring programme was groundbreaking as these were the first large-scale offshore wind farms in the world and the specific environmental impacts were largely unknown. The results of the programme were reported in a number of reports and summarized in the publication Key Environmental Issues and in the booklet Offshore Wind Farms and the Environment. These publications can be found on the web site of the Danish Energy Agency, www.ens.dk. Environmental Impact Assessments (EIAs) from other existing wind farms may also be found here.

The results of the studies have been regularly assessed by an international panel of independent experts, the IAPEME (International Advisory Panel of Experts on Marine Ecology), consisting of experts with unique competence within the different topics covered by the monitoring programme. The experts evaluated the progress of the environmental monitoring programme approximately once a year, validated the results, and made recommendations for future monitoring. The programme was also followed and commented on by a group of green NGOs.

Subsequently a follow-up programme on selected issues was conducted during the period 2007-12. The priorities of this programme were based on the recommendations produced by the IAPEME following the original programme, in order to concentrate on topics of specific relevance to the planned future Danish offshore wind

HORNS REV AND NYSTED WIND FARMS

Nysted and Horns Rev were the first large-scale offshore wind farms in the world to be commissioned. However, a decade of rapid development in large-scale offshore wind deployment has made these wind farms seem relatively small in comparison to what is being commissioned at present. Nevertheless, the production from each of the wind farms is equivalent to the electricity consumption of app. 160,000 Danish households.

In 1999, the Danish Energy Agency authorised the undertaking of preliminary surveys at the two sites. In the summer of 2000 Environmental Impact Assessments (EIAs), including baseline studies for subsequent monitoring of the environment for both sites, were submitted to the authorities and issued for public hearing. In 2002, both wind farms were approved for development by the authorities, subject to certain conditions, among these a comprehensive environmental monitoring programme.

HORNS REV

In 2002, Elsam constructed the Horns Rev Offshore Wind Farm at 7-14 m depth at Horns Rev, 14–20 km off the coast in the North Sea near the city of Esbjerg. The Horns Rev Offshore Wind Farm consists of a total of 80 turbines totalling 160 MW. The wind farm is constructed in a grid array of 8 x 10 turbines. In July 2006, Vattenfall took over responsibility for operation and maintenance.

NYSTED

The Nysted Offshore Wind Farm was commissioned in 2003 by Energi E2, and consists of a total of 72 wind turbines in a grid pattern of eights rows of nine turbines each. The wind farm is located at 6-10 m depth approx. 10 km off the coast of the island of Lolland in the Baltic Sea. The 72 turbines have a total installed capacity of 165.5 MW. The farm has been operated by DONG Energy since 2006.

development. This meant that several of the studies were broader in scope than addressing the specific effects of the two original wind farms Nysted and Horns Rev 1.

The summary of the results of these follow-up studies is presented in this book. For a more in-depth review of the studies and results, the technical reports can be found at the Danish Energy Agency's website, www.ens.dk.

CONCLUSION FROM THE ORIGINAL PROGRAMME – LIMITED EFFECTS WITH CAREFUL PLANNING

The general conclusion from the original environmental programme at Horns Rev and Nysted was that offshore wind power is indeed possible to construct and operate in an environmentally sustainable manner that does not lead to significant damage to the marine environment and

Horns Rev 1 Wind Farm. PHOTO: HEIDI LUNDSGAARD vulnerable species. The studies have consistently shown that the Nysted and Horns Rev offshore wind farms have had very little impact on the environment, neither during their construction nor during their operational phases.

There have been local effects on the benthic communities, particularly increases in faunal biomass and diversity associated with the introduction of hard substrates (towers, foundations and scour protection) onto a naturally sandy seabed. Over time, these structures and increases in food may well attract higher numbers, and a wider range of species, of fish. One conclusion from the work was that measuring changes in fish populations at these relatively small local scales is difficult as fluctuations in fish stocks occur at larger spatial scales.

Hydrophones recording harbour porpoise echo-location sounds underwater were deployed to measure harbour porpoise activity within the wind farm and in control areas. During the construction phase, the number of harbour porpoises at the farm sites decreased immediately when noisy activities commenced. This observation alleviated fears that marine mammals would remain in the area and as a consequence might be hurt by the intense sound pressures generated by pile driving. At Horns Rev the harbour porpoise numbers returned to normal once construction was completed. This was not the case at Nysted. However, later studies have found indications of slow recovery of harbour porpoise acticity at Nysted 10 years after construction. Seals also showed little response to the wind farms, except during a single sheet piling during construction of the Nysted Offshore Wind farm, when they left the nearby haul-out site during the activity.

The thermal animal detection system (TADS) provided empirical evidence that water-bird collisions were rare events. Collision-risk modelling and bird tracking by radar as well as visual observations show that many water-bird species tend to avoid the wind farm, changing flight direction some kilometres away to deflect their path around the site. Birds flying through the wind farm tend to alter course or altitude to avoid the risk of collision. Under adverse weather conditions, which were thought to be likely to increase collision risk, results show that waterbirds tend to avoid flying. The strong avoidance behaviour results in very low estimates of collision risk. The bird studies demonstrate strong differences between bird species in response to the offshore wind farms, with some species of conservation concern such as red-throated divers and common scoters showing particularly high aversion to these structures. This was further explored in the follow-up programme.

BASIC METHOD FOR THE ENVIRONMENTAL MONITORING PROGRAMME

Between 1999 and 2001, as part of the Environmental Impact Assessments (EIAs) and as the basis for the Horns Rev and Nysted environmental monitoring programmes, baseline studies were carried out. The aim was to establish points of reference for later analyses, so as to be able to compare the existing environmental conditions prior to the introduction of a wind farm.

The environmental monitoring programme was launched following completion of the EIAs. In other words, the environmental studies carried out in the period 2000–2006 were obligatory as part of the planning permission for the utilities to construct a wind farm at the two sites.

Where possible, the projects in the demonstration programme apply the BACI approach (BACI: "Before After Control Impact"). The aim of the method is to estimate the state of the environment before and after any changes and in particular to compare changes against reference sites (or control sites). The monitoring programme is divided into three stages consisting of three years of baseline monitoring, monitoring during construction and three years of monitoring during operation.

Wind power, as a renewable source of energy, produces no emissions and is an excellent alternative in environmental terms to conventional electricity production based on fuels such as oil, coal or natural gas. PHOTO: DONG ENERGY

FOLLOW-UP PROGRAMME – EXPLORING LONG-TERM AND CUMULATIVE EFFECTS

As a follow-up to the Environmental Monitoring Programme for Large-scale Offshore Wind Farms (2000-2006) a new programme was initiated. The focus of the follow-up programme was to explore and conclude on the longer-term effects on fish, harbour porpoises and birds. The selection of projects was carried out in accordance with the dual objective of further supporting conclusions in the first programme and addressing key issues for the planning efforts of future offshore wind farms in Danish waters. The remaining questions identified by the IAPEME were heavily drawn upon in the selection process. These were:

- Does the opportunity that hard structures introduced on the seabed present for species such as crabs and cod result in these predators increasing and impacting the communities of the surrounding sandy substrate?
- Do fish increase at marine wind farms over a longer time scale than the studies reported here, or do their communities and numbers respond more to large-scale processes than to local changes at the scale of individual wind farms?
- Can experiments be designed to test more critically the question of whether fish movements are affected by the electromagnetic field generated by cables carrying the electricity ashore?
- What characterizes important habitats for marine mammals and how tolerant are they of disturbance in such areas?
- Do some waterbird species accommodate to marine wind farms and learn not to show such strong avoidance behaviour?
- Do marine mammals and waterbirds learn to forage within offshore wind farms if food abundances in these sites increase above normal levels?
- Even if the impact of a single wind farm on birds is apparently negligible at population level, can a paradigm be developed to assess cumulative impacts on bird populations of numerous offshore wind farms along their flight routes?

The follow-up programme is building upon the result of the former programme and is focusing on:

- Fish communities: See chapter 3 "Benefits from offshore wind farm development".
- Harbour porpoises: See chapter 4 "Harbour porpoises affected by construction".
- Waterbirds. See chapter 5 "Wind farms affect common scoter and red-throated diver behaviour".

Furthermore, several projects which do not build on the results of the original programme, were carried out. Also, a Danish guidance document on how to carry out environmental impact assessments (EIAs) for offshore wind farms has been developed under the follow-up programme. These projects have not been reported in this book, as they do not directly address effects of offshore wind farms.

These projects have, however, played an important role in the form of input to the spatial planning exercises carried out in 2010-2012. One project provided an updated overview of numbers and distribution of key seabird species in Danish offshore waters with the aim of improving the basis for spatial planning decisions and environmental impact assessment for future offshore wind farms. A separate part of the project focused on the occurrence of moulting common scoters in the northern Kattegat area. Another project gathered new and updated data on the numbers and distribution of key seabird species in the Jammerbugt area.

The reports from these projects can be found on the Danish Energy Agency's website, www.ens.dk, along with the rest of the documentation for the follow-up programme.

INTERNATIONAL RESEARCH PROJECTS

A joint German, Swedish, Norwegian and Danish cooperation on Research for Offshore Wind Energy Deployment has been established. The aim is to intensify cooperation in research on offshore wind power, to strengthen the transfer of know-how and exchange of information and data between the parties, and to carry out joint research projects in relation to the associated monitoring of offshore wind farms.

The cooperation has among other things accomplished information exchange on national developments and various studies undertaken within the countries, including the Horns Rev and Nysted wind farm areas, e.g. temperature measurements in sediments near cables, bird studies with focus on collision risks, and studies of offshore wind-farm effects on harbour porpoise. All data obtained from the research projects are shared among the parties, including raw data.

In relation to the follow-up programme, the Danish-German cooperation has been further developed. One study addressed the long-distance disturbance effects of pile driving noise on harbour porpoises during the construction of Horns Rev 2 offshore wind farm in the Danish North Sea and the FINO 3 platform in the German North Sea. Another study, looking into the effectiveness of seal scarers to mitigate injury to harbour porpoises during piling, was conducted as a jointly funded Danish-German project in German and Danish waters. The results of these studies are reported in chapter 4.

Playing harbour porpoises. PHOTO: ANDERS LIND-HANSEN

ADMINISTRATION OF THE PROGRAMME

The programme was managed by the Environmental Group, with individual members of the group being responsible for managing the specific projects. This group consists of representatives from the Danish Energy Agency, Danish Nature Agency, and the operators of the offshore wind farms at Horns Rev: Vattenfall (before 2006: Elsam) and Nysted: DONG Energy (before 2006: Energi E2).

The panel of internationally recognised environmental experts (IAPEME) was reappointed for the follow-up programme for the specific topics in focus here.

The environmental studies under the original and follow-up programmes have been financed with a budget of DKK 84 million under the Public Service Obligation (PSO) scheme. This funding has now been exhausted and currently no further publicly funded monitoring programmes are being considered. The PSO funds are financed by electricity consumers as part of their electricity bill, and the funds are earmarked for research and development projects. The Transmission System Operator, Energinet.dk, administers the financial part of the PSO and submits projects for approval by the Danish Energy Agency.

IAPEME

The Environmental Group reappointed members of the International Advisory Panel of Experts on Marine Ecology (IAPEME) in order for them to review and comment on the results of the studies in the follow-up programme. The panel members are:

- Professor Bob Furness,
  MacArthur Green Ltd. and University of Glasgow
- Dr. Klaus Lucke,
  IMARES, Wageningen UR, The Netherlands
- Associate Professor Peter Grønkjær,
  University of Aarhus, Denmark

Nysted Offshore Wind Farm. PHOTO: NYSTED OFFSHORE WIND FARM

3

FISH
BENEFITS FROM OFFSHORE WIND FARM DEVELOPMENT

BY SIMON B. LEONHARD *(Orbicon)*, CLAUS STENBERG *(DTU Aqua)*, JOSIANNE STØTTRUP *(DTU Aqua)*, MIKAEL VAN DEURS *(DTU Aqua)*, ASBJØRN CHRISTENSEN *(DTU Aqua)* AND JOHN PEDERSEN *(Orbicon)*

The study on Horns Rev is the first long-term study on the effects of offshore wind farms on fish assemblages. It incorporates a study on the effects up to seven years after the deployment of the wind farm in 2003.

A number of fish species were attracted to the wind turbine foundations, resulting in a higher number of species inside the wind farm area compared to a reference area outside the wind farm.

Overall the results suggested that offshore wind farms may have a positive impact on fish populations, foundations acting as refuge areas where fish can hide or forage.

The positive effect of an offshore wind farm may be enhanced by the exclusion of commercial fishing inside the wind farm area. In this respect it may function like a marine protected area. A cumulative effect of multiple wind farms located close together within the same region might therefore be beneficial to fish communities in general, including some sandeel communities.

SUMMARY 2006

The studies up until 2006 showed few effects on the fish fauna that could be attributed to the establishment and operation of the wind farms.

Fish abundance and diversity were not higher inside the wind farms than in the areas outside the wind farms. One obvious reason for this could be that the studies and investigations were made during the early stages of colonisation of the turbine foundations at Horns Rev that constitute artificial reefs. At Nysted, the effect was weak, presumably because the benthic community consisted of a monoculture of large common mussels *(Mytilus edulis)* that are only moderately attractive to fish.

Also investigations into the effects on fish and fish behaviour from electromagnetic fields were made at Nysted. Data documented some effects from the cable route on fish behaviour, with some species avoiding the cable, while other species were attracted. However, only flounder *(Platichthys flesus)* showed correlation between the phenomena observed and the strength of the magnetic fields.

Scour protection with common mussels and foraging goldsinny wrasse at Nysted. PHOTO: MAKS KLAUSTRUP

INTRODUCTION:
POSSIBILITIES OF ARTIFICIAL REEFS

The construction of offshore wind farms may change local ecosystems. Offshore wind farms are often placed in relatively shallow waters and on sandy seafloors. As the base of each turbine is surrounded by beds of boulders to prevent erosion, deployments of wind farms introduce reef-like structures to the seabed. This may change local environmental conditions and provide new habitat opportunities for reef-fish and fouling organisms. At the same time it can cause changes in the original sand habitats and affect their associated fauna. Present and planned Danish wind farms in the North Sea are located on sandy bottoms that are inhabited by communities of species very different from those of boulder reefs. Sandeels *(Ammodytidae spp.)* for example inhabit specific sandy habitats and may be affected if construction and operation of offshore wind farms change the seabed conditions. Sandeels play a key role in the local ecosystems and are of high importance to the fishing industry.

At the same time the underwater structures of offshore wind farms may provide new refuge and foraging opportunities for a number of other fish species. Existing boulder reefs in the North Sea are known to hold a high diversity of fish species, and in deeper waters they attract larger migratory fish species such as cod *(Gadus morhua)*, saithe *(Pollachius virens)* and whiting *(Merlangius merlangus)*.

The aim of the study at Horns Rev was to document the long-term development in fish communities. The studies on Horns Rev in 2009/2010 are the first long-term studies of the effects of marine offshore wind farms on fish assemblages. They include a study on the effects of the wind farm seven years after deployment in 2002/2003.

Sandeels display distinct diurnal activity, buried in the sediment during the night and foraging in the free waters during the day.

METHODS:
FISH DISTRIBUTION BEFORE AND AFTER

The effects of the Horns Rev 1 Offshore Wind Farm on fish communities were studied using a before-after-impact-control survey design and species distribution modelling. Gillnets were used to sample semipelagic and bottom-living fish species while sandeels were sampled by a bottom dredge. Gillnet sampling was performed in autumn and spring at three different turbine sites and dredge sampling was performed during spring in a grid inside the wind farm area. Identical sampling methods and sampling strategies were used to sample fish communities in a control site outside the impacted wind farm site. Sandeel sampling was supplemented by a survey in spring 2004, shortly after the end of construction of the wind farm, and in autumn 2009. Changes in seabed conditions for sandeel were monitored during each sandeel survey by analysing the grain size of the sediment.

Information on how migrant species like whiting, cod and pelagic species are distributed around wind farms was obtained by using vertical and horizontal hydro-acoustics in the autumn/winter 2004/2005 surveys and in the 2009 surveys. The horizontal recordings provided information about the spatial distribution of fish assemblages around the turbines, whereas the vertical recordings provided information about the distribution of fish in the area between the individual turbines.

Simulations of larval drift were made for sandeels in order to determine whether the sandeel aggregations on Horns Rev are potentially self-sustainable or merely the result of "spillovers" from other sandeel areas in the North Sea.

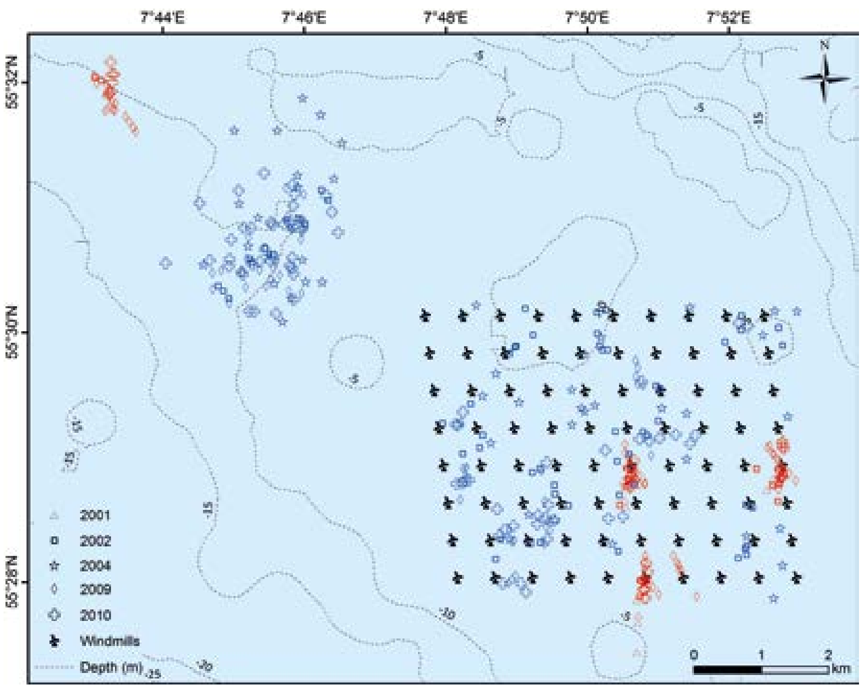
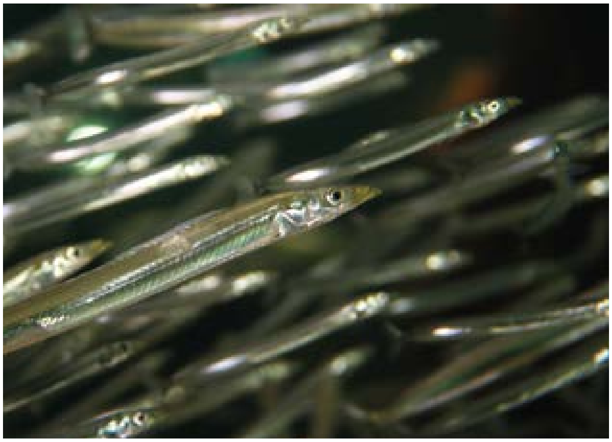
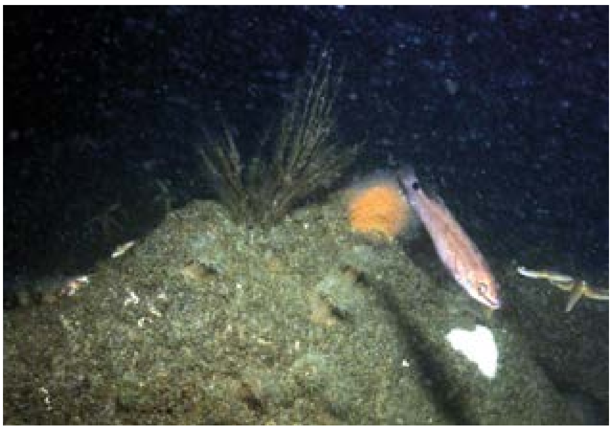


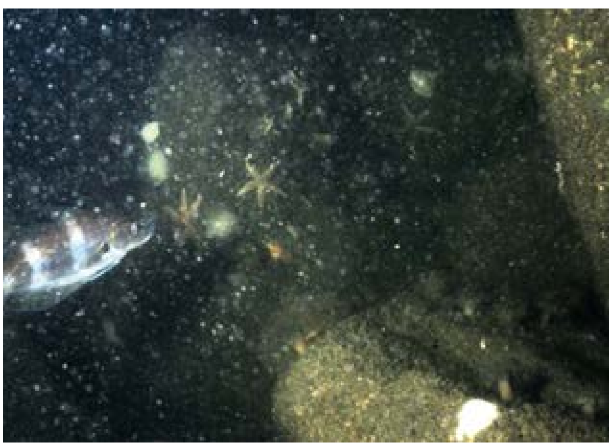
FIGURE 3.1 *Sampling locations for sandeels in the Horns Rev 1 area. Control areas used in both the sandeel and fish community studies are located northwest of the impact area – the wind farm. Blue symbols represent sandeel sampling stations and red symbols gillnet sampling stations.* GIS: KERSTIN GEITNER



Sandeels. PHOTO: THOMAS WARNAR



Goldsinny wrasse at boulders at Horns Rev.
PHOTO: THOMAS WARNAR



Pouting and goldsinny wrasse at the turbine foundation at Horns Rev.
PHOTO: THOMAS WARNAR

RESULTS:

REEF FISH ARE ATTRACTED TO THE FOUNDATION OF WIND TURBINES

The construction of the wind farm at Horns Rev in 2003 has resulted in changes and differences in the fish community and abundances inside the wind farm.

A number of fish species showed attraction towards the wind turbine foundations, and this has now resulted in higher number of species inside the wind farm area compared to areas outside the wind farm. Fish species commonly associated with hard-bottom habitats were first observed after the deployment of the wind farm. In total 30 different species were found outside the wind farm, while 41 different species were registered inside the wind farm area during the investigations at Horns Rev. Only a few uncommon species registered as single individuals were not recorded after the construction, either inside or outside the wind farm.

Many of the most common fish in the North Sea were registered in the Horns Rev area, but some of these, including the goldsinny wrasse *(Ctenolabrus rupestris)*, the lumpsucker *(Cycloplerus lumpus)* and the eelpout *(Zoarces viviparous)*, only appeared inside the wind farm area and within the investigated area after the construction of the wind farm. These are typical "reef fish", which were primarily found very close to the turbine foundations.

In general the number of species and the abundance of fish increased close to the turbines.

At the larger scale, a change in the distribution of fish was found after the construction of the wind farm compared to seven years earlier. Before the farm was built fish were generally more abundant in the deeper reference area compared to the wind farm area. However, seven years after the establishment of the wind farm, the distribution of fish was much more similar, as the abundance in the wind farm area had increased. Generally, fish communities tend to be more abundant in deeper areas. The establishment of the wind farm in slightly shallower waters compared to the reference area might have compensated for this effect by creating a more heterogeneous habitat.

GOOD FEEDING OPPORTUNITIES ON THE WIND TURBINE FOUNDATIONS

The wind farm area, with its numerous cracks and crevices for shelter, hiding and feeding opportunities has attracted and increased the number of foraging fish on the reef.

The fouling communities have colonised the introduced solid surfaces of boulders and steel monopiles and these newly established prey organisms are now found in huge numbers and are being exploited by foraging fish. For example pouting *(Trisopterus luscus)*, which is commonly found around the wind turbines, are feeding on a small crustacean, *Jassa marmorata*, and the goldsinny wrasse is known to feed on common mussels. Both these prey organisms are found in billions on the turbine foundations in the wind farm area at Horns Rev.

Fish often migrate between foraging areas and areas where they hide during rest. This alternating use of habitats between day and night was also displayed by differences in fish distribution patterns for different migrating species at Horns Rev. Fish were mainly present inside the wind farm area during the day, while they tended to migrate to deeper waters outside the wind farm site during the night, This suggests that even though the wind farm area offers a more diverse habitat, fish are still dependent on areas outside the wind farm. This may be because the

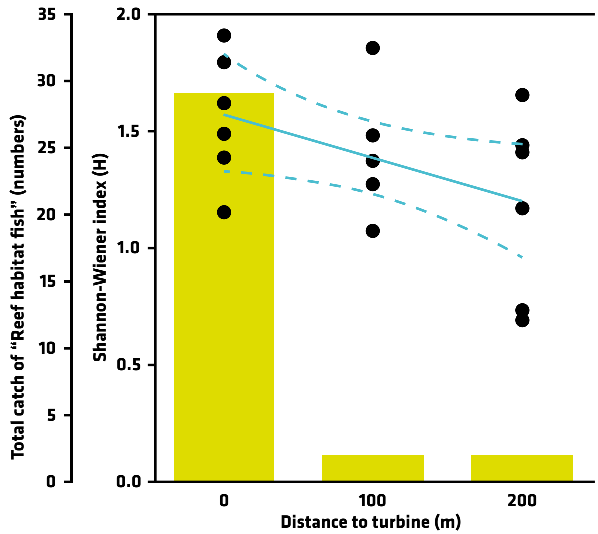


FIGURE 3.2 *Increase in number of species or diversity expressed as an increase in the diversity index (H') (scatter plot) with decreasing distance to the wind turbine foundation and increased average cumulative catch (bar plot) in September 2009 after the construction of Horns Rev 1 Offshore Wind Farm.*

FOULING COMMUNITIES

Fouling communities are assemblages of organisms living on solid substrates and fouling species can easily colonise newly deployed substrate. Typically there is a succession in species composition and abundance as the age of the deployed substrate increases. This succession is a result of species competing for space and equilibrium in fouling communities is generally not established within less than five years.

Horns Rev Sampling.
PHOTO: CLAUS STENBERG

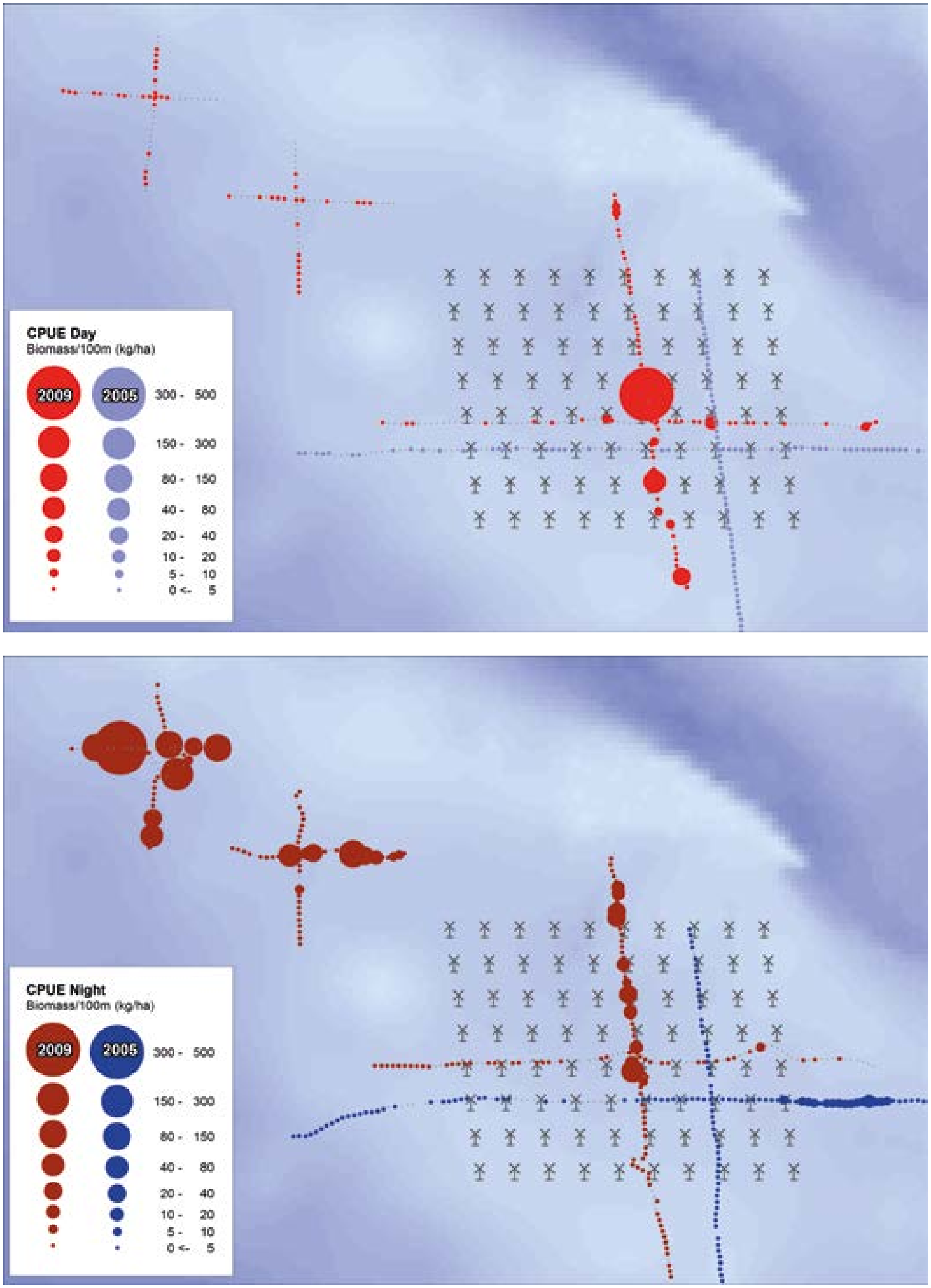


FIGURE 3.3 *Biomass distribution pattern of pelagic and migrating fish (eg. cod and whiting) in the impact and control areas in September 2005 and 2009 measured in the horizontal hydro-acoustic survey.*

wind farm area is not big enough or because adjacent areas provide opportunities for prey or refuge areas that exceed those in the wind farm area.

After the deployment of the wind farm, fish abundance has shown to decline in the wind farm area as well as in the reference area. This trend is presumed to be a result of larger-scale processes having affected fish occurrence in this part of the North Sea. Migrating or pelagic fish populations fluctuate highly from year to year and whiting, which was the most abundant species before the deploy-

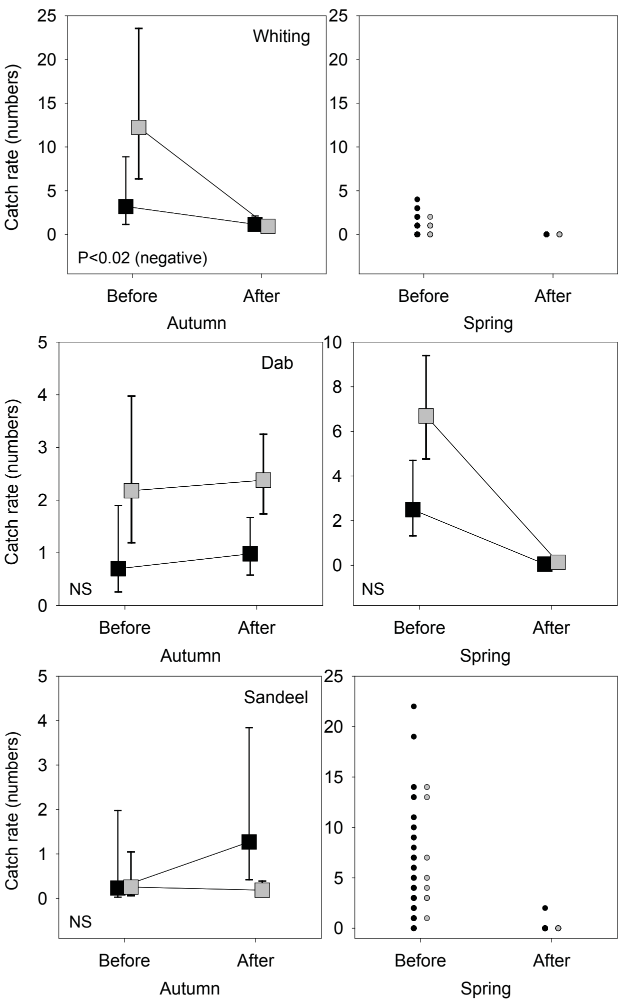


FIGURE 3.4 *Catch rate per gillnet for whiting, dab and sandeel for autumn and spring surveys in Control (grey) and Impact (black). Graphs for whiting autumn, dab autumn and spring and sandeel autumn are shown as model estimates (squares) with +/- SE while in the remaining graphs show raw values as model not converge. Probability for the interactions effect Before-After x Control-Impact are shown where they are significant (p<0.05).*

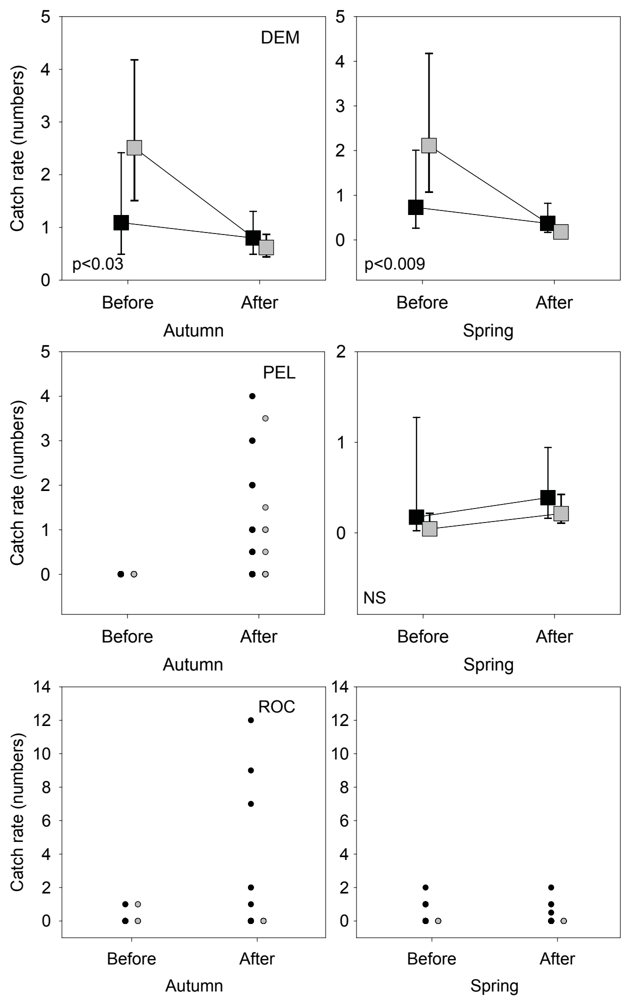


FIGURE 3.5 *Catch rate per gillnet for the groups DEM (bottom living fish), PEL (bottom living fish) and ROC (rock associated fish) for autumn and spring surveys in Control (grey) and Impact (black). Graphs for DEM autumn and spring and PEL spring are shown as model estimates (squares) with +/- SE while in the remaining graphs show raw values as model not converge. Probability for the interactions effect Before-After x Control-Impact are shown where they are significant (p<0.05).*

ment, showed a general stock decline in the North Sea during the period from 2001 to 2010. This is consistent with the observed decline in the study from Horns Rev.

HIGHLY DYNAMIC FISH COMMUNITIES IN SHALLOW-WATER ENVIRONMENTS

The distribution patterns of fish communities in the Horns Rev area are affected by variations in environmental variables such as current, depth regimes, temperature and wave exposure, as well as differences in behavioural activity in the fish communities between day and night. During the investigation, fish communities displayed high spatial and temporal variability in distribution and occurrence. This applies for both the pelagic and bottom living species.

In temperate waters most juvenile fish migrate away from the shallow coastal areas before winter in response

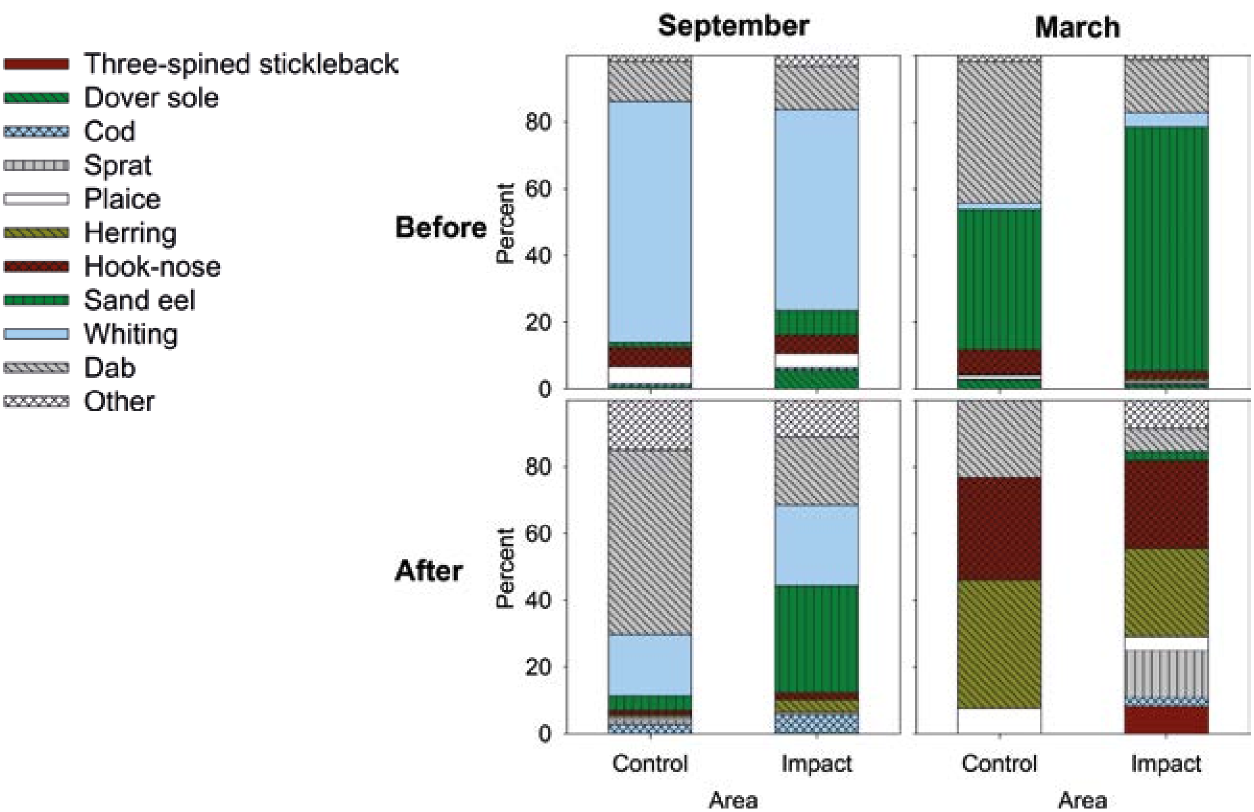


FIGURE 3.6 *Relative distribution of the most common species in the wind farm area (impact) and reference area (control) before and after construction of the wind farm.*

Barnacles growing on common mussels filtering the water for plankton with their cirri. PHOTO: MAKS KLAUSTRUP

to declining temperatures. In spring they return to feed in the warmer shallow waters, where food is abundant. Sandeels are buried in the sand refuge areas during winter and emerge from the seabed to the water column in the spring to feed.

Seasonal effects were reflected in the fish communities, including the sandeel community. The number of species was low in spring compared to autumn. This effect seems to be further strengthened by an unusually cold winter and subsequent cold water temperature in spring 2010. At this time the water temperature at the bottom near the seabed was 2.7°C lower than the average of the years from 2002 to 2009.

Differences in fish abundance and in diversity between autumn and spring surveys were also observed in a study from a Dutch wind farm. Seasonal and temporal variability in distribution seems therefore to be a general pattern for shallow-water fish communities in the North Sea. The effect of temperature variations was also clearly demonstrated in the sandeel study in 2010, where increased water temperature resulted in a greater number of sandeels in the samples during the month of March. By late March the occurrence of sandeels had reached a level comparable to previous samplings.

SANDEELS ON HORNS REV

All four species of sandeel living in the North Sea were encountered on Horns Rev:

- Lesser sandeel *(Ammodytes marinus)*,
- Small sandeel *(Ammodytes tobianus)*,
- Greater sandeel *(Hyperoplus lanceolatus)*,
- Smooth sandeel *(Gymnammodytes semisquamatus)*

Greater sandeel was by far the most frequent species, whereas the smooth sandeel was only sporadically encountered.

SHORT-TERM BENEFITS FOR SANDEELS

The presence of the wind farm did not result in any significant long-term habitat degradation for sandeel communities within the time frame of the study. However

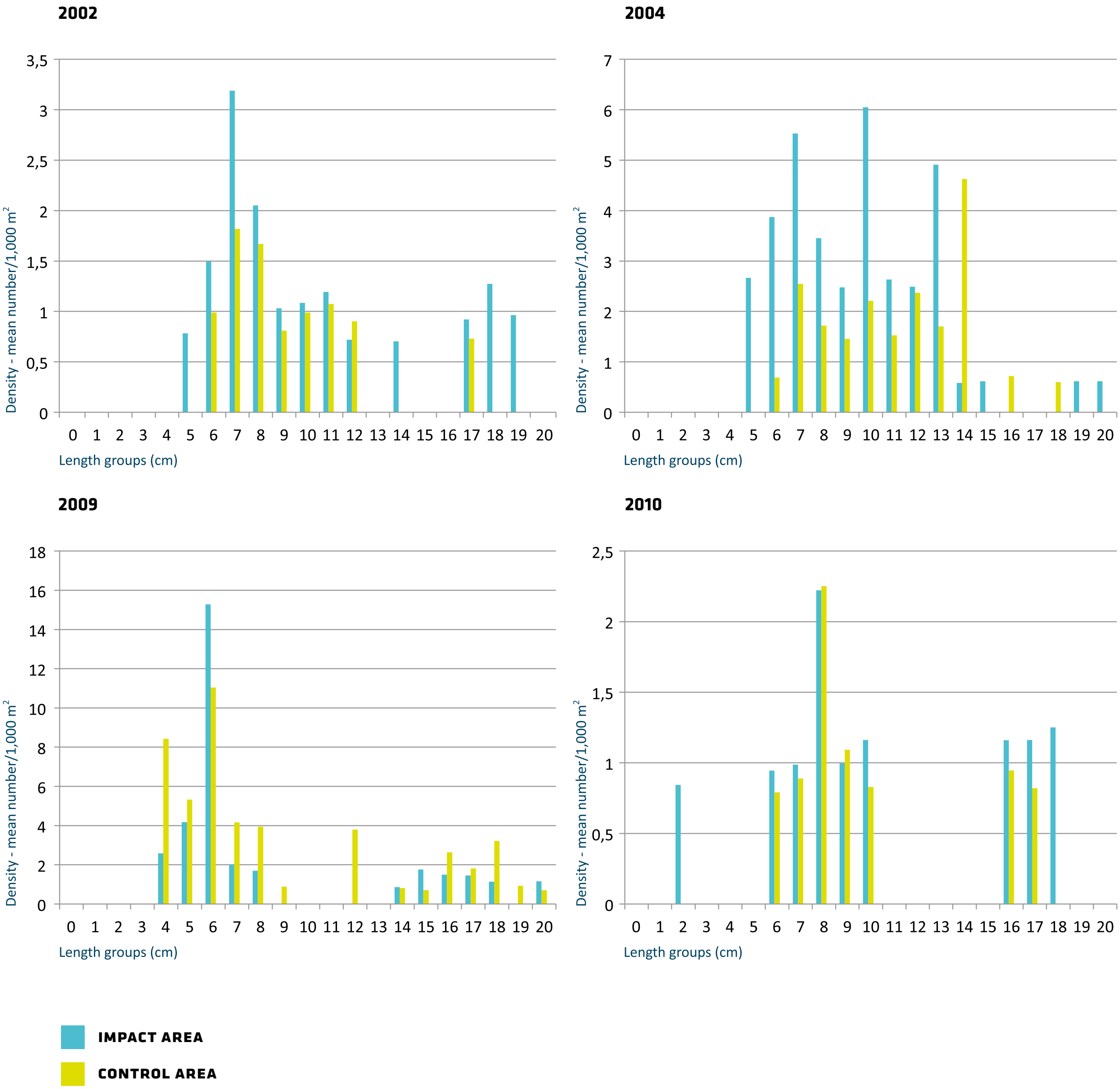


FIGURE 3.7 *Length distribution for greater sandeel (Hyperoplus lanceolatus) before (2002) and after deployment of the wind farm.*

the results of the study indicated a positive short-term effect on sandeels from the construction of the wind farm.

Inside the wind farm area an increase in the abundance of juvenile sandeels was observed one year after construction. Sandeels have preference for sediments with a fraction of fine particles of less than two percent. It is possible that the short-term increase in sandeels was a consequence of a slight increase in the frequency of sediment particles between 0.1 and 0.2 mm due to the construction. However, no general change was recorded in the sediment structure throughout the study period and the fraction of the smallest sediment particles remained below the critical limit for sandeel preferences at all times. A similar short-term increase in the abundance of sandeel was found in a study from an offshore wind farm in the Dutch coastal zone roughly 500 km southwest of Horns Rev.

A shift in the sandeel community was recorded during the study. In 2002, lesser sandeel was relatively more prevalent than small sandeel, but it became exceedingly rare both inside and outside the wind farm area after 2002.

The sandeel community was dominated by juveniles of greater sandeel during all years. After 2002, juveniles of lesser sandeels and small sandeels were less frequently found than adults of the same species inside as well as outside of the impact area. This was interpreted as a result of a natural change in the sandeel community in a local area of the North Sea rather than as an effect of the wind farm.

Apart from this change, only small variations in abundances and occurrences were found. The overall catches of the most abundant species of sandeels varied only slightly from year to year, except for March 2010 where catch rates were notably lower than in the preceding years due to the cold winter.

Changes in dominance in sandeel communities are often determined by differences in the recruitment success of the different species. Spawning time is of specific importance and different species of sandeels spawn at

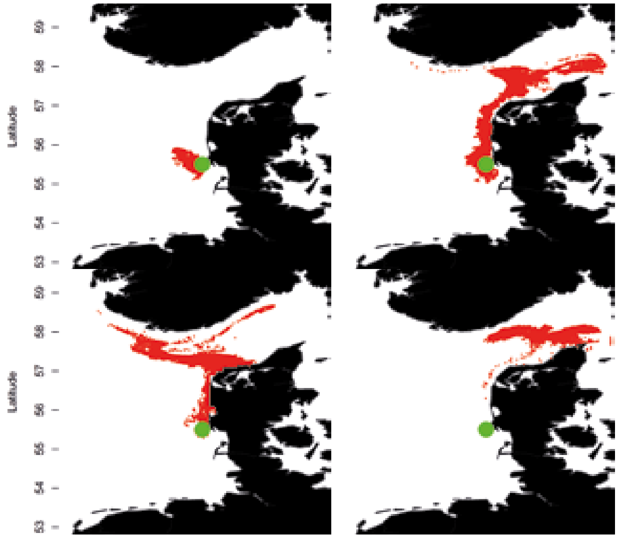


FIGURE 3.8 *Results from a hydrodynamic simulation exercise of distribution patterns of sandeel larvae spawned in the Horns Rev area. The figures depict the end location for two species of sandeel larvae drifting from Horns Rev at different spawning times. Upper left: Greater sandeel 2005; Upper right: Greater sandeel 2006; Lower left: Lesser sandeel 2005; Lower right: Lesser sandeel 2006. In the model larvae were released at the time of hatching and allowed to drift passively until the day of transition from larvae to juvenile (metamorphosis). Hatching time and time of metamorphosis were established from otolith analyses. Results suggest that larval exchange between Horns Rev and surrounding habitats is highly variable between years and species. However, in general the spatial scale of Horns Rev is too small to sustain a self-recruiting sub population of sandeels, even though some degree of larval retention may be possible for greater sandeel.*

Catch from Nysted. PHOTO: CHRISTIAN B. HVIDT

Greater sandeel larvae originate from the Horns Rev area and metamorphose into juveniles in the same area.

Lesser sandeel, small sandeel and juvenile greater sandeel are planktivorous, feeding on small crustacean plankton, whereas adult greater sandeel are predators, feeding on other fish, including sandeel.

Catch at Nysted PHOTO: CHRISTIAN B. HVIDT

Sandeels sampled by the bottom dredge.

different times. Lesser sandeel spawn exclusively during winter, whereas greater sandeel spawn in late summer and small sandeel in both the spring and autumn seasons. As a result, the time when the larvae are exposed to currents that can transport them differs from species to species. As a winter spawner, lesser sandeel have a longer larvae phase, and during this they are transported by strong currents far north along the coast of Jutland to Skagerrak and the Norwegian trench. Hence, the local aggregation of lesser sandeel is not likely to sustain a population in the Horns Rev area, and may instead rely on recruitment from other spawning areas in the North Sea. The opposite was simulated for larvae of the greater sandeel and it was indicated that the Horns Rev area is of high importance as a spawning and nursery ground for this species of sandeel, as the dispersal of the pelagic larval stage is often limited. Thus, the population of greater sandeel at the Horns Rev could be independent of recruitment from other spawning areas and act as an important source for recruitment of larvae into other areas of the North Sea.

Although, only insignificant changes have been registered in the sandeel communities at Horns Rev, despite significant disturbance of sediments and introduction of new habitats, the response time may actually be more than seven years before the entire community of sandeels is stabilised. This could be due to an effect of the time needed to obtain a balance between populations of sandeels (prey) and populations of regulators such as predatory birds and fish. Populations of predators stabilise on the new substrates after a considerably longer timeframe than the five years expected for populations of fouling communities.

MORE WIND FARMS GENERATE WIDER SANCTUARY AREAS FOR FISH

Post-construction studies concerning effects on fish communities from offshore wind farm development are rare or almost non-existent. The results from the Horns Rev 1

HOME RANGE
Home range is the area in which an animal normally confines its activity.

studies may then serve as an important contribution to informed decision-making regarding the short-term and long-term impacts from the increasing rate of offshore wind farm development in the North Sea.

From the studies it seems that offshore wind farms may have a potentially positive impact on the local ecosystem. Foundations can act as refuge areas where fish can hide and forage. Furthermore, this effect is enhanced due to exclusion of commercial fishing inside the wind farm area. In this respect they can be similar to a marine protected area. A cumulative effect of multiple wind farms located close together within the same region might therefore be beneficial to fish communities, including sandeel communities.

However, no positive or negative effects on sandeel abundance in the wind farm area were detected, although a notable increase in sandeel fishing density in areas with high predicted suitability for sandeels around the wind farm occurred between 2003 and 2009. In our study this is likely to be a result of the relatively small size of the wind farm compared to the actual home range of sandeels in the Horns Rev area, which also includes more intensively fished areas.

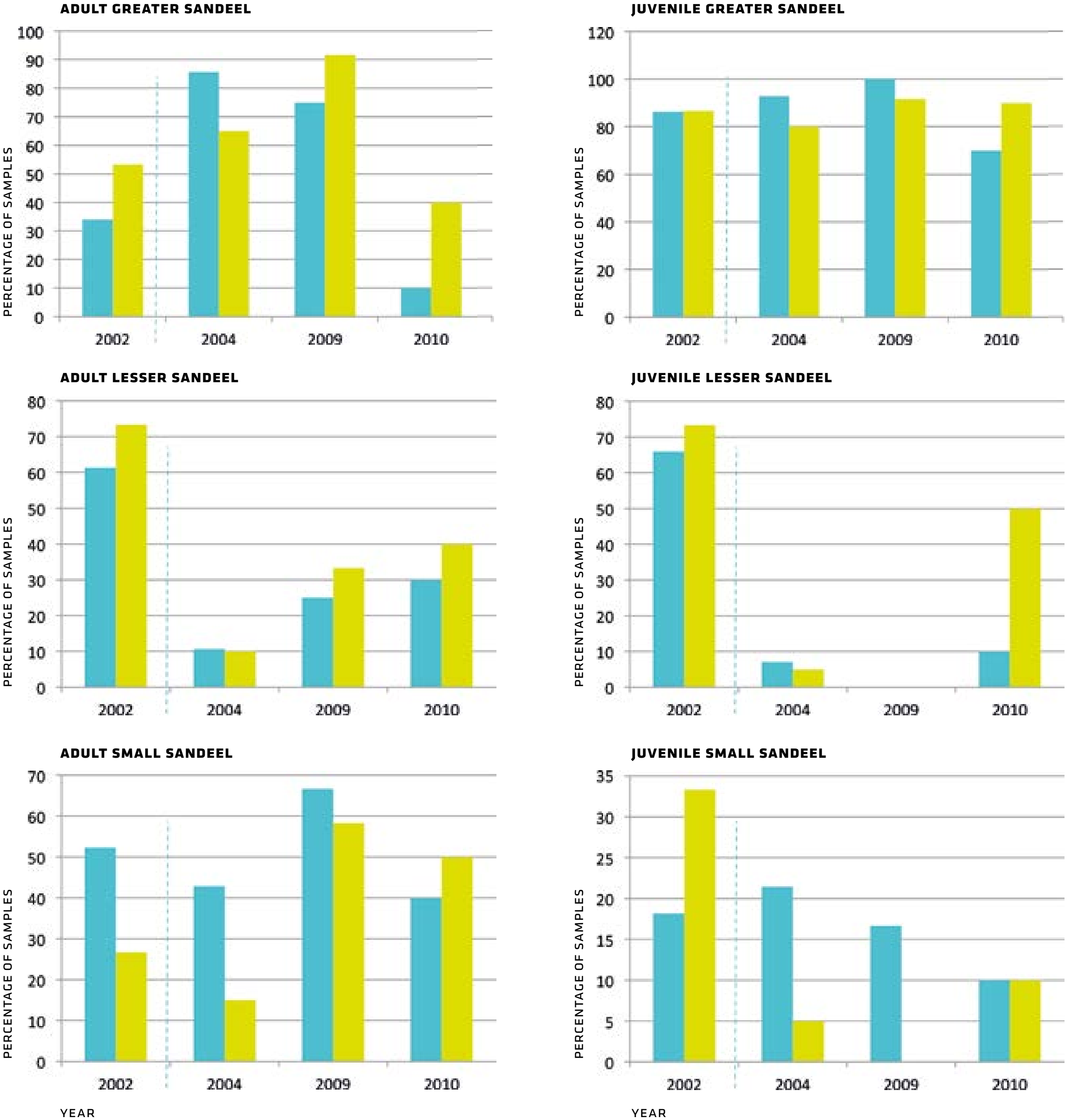
Multiple wind farms covering the whole home range area of sandeels could provide undisturbed spawning areas and provide benefits for sandeel populations beyond the local scale through long-distance drifting of larvae. The greater sandeel in particular may profit from the presence of offshore wind farms and the effects of exclusion of fisheries.

The home ranges for highly migratory gadoid species like cod, whiting and saithe, which often aggregate around reefs and wrecks, probably exceed the total size of areas with future multiple offshore wind farms along the North Sea coast of Jutland. As a result, these wind farm areas may not be sufficiently large to be beneficial for an increase in the stock of the gadoid migratory communities in general. Yet they may be large enough to serve as sanctuary, nursery and feeding areas for these species.

Development of multiple wind farms may also be beneficial for the recruitment of reef fish species in the area. The foundations provide habitat and also function as sites for settlement of drifting juveniles from existing wind farms. No effects on the abundances of flatfish have been shown, either in this study or other studies on the deployment of offshore wind farms. Thus a cumulative effect from multiple wind farms on flatfish will be more speculative and probably vary between species.

DISCUSSION:
WIND FARMS AS A TOOL TO PROMOTE GOOD MARITIME ENVIRONMENTS

The EU Marine Strategy Framework Directive aims to achieve a good environmental status for European seas by 2020 and several of the qualitative descriptors in this Directive have direct or indirect relevance for reef fish and sandeels or their habitats. The EU Maritime Policy calls for an ecosystem approach to integrated planning of maritime activities which aims for sustainable growth of maritime activities while ensuring that these activities develop in a way that does not threaten marine ecosystem health. Consequently, in this respect the planning and development of offshore wind farms may contribute to improving the likelihood of achieving the objectives in the Framework Directive. However the planning of future offshore wind farms should be carried out in respect to other interests and should minimise negative impacts on environments but improve tools for optimising the possible benefits for e.g. fish communities.



CONTROL
IMPACT

FIGURE 3.9 *Percentage of samples including one or more adult or juvenile fish (occurrence), presented as impact area versus control area for each survey year (2002, 2004, 2009 and 2010). Broken vertical line represents the time of wind farm construction. Only data from late March 2010 is included. Greater sandeel (Hyperolus lanceolatus), lesser sandeel (Ammodytes marinus) and small sandeel (Ammodytes tobianus).*

IAPEME VIEWPOINTS

ASSOCIATE PROFESSOR PETER GRØNKJÆR,
UNIVERSITY OF AARHUS, DENMARK

The establishment of wind farms in the marine environment has the potential to change living conditions for marine organisms, including fish. The immediate effects of wind farm construction and operation have been documented on several occasions, but not until now have the more crucial long-term effects been thoroughly investigated. The studies at Horns Rev seven years after deployment of the wind farm are unique in this respect and offer an important contribution to the understanding and projection of the effects of future offshore wind farm development.

NEW HABITATS – NEW SPECIES

The introduction of a new habitat in any environment will create opportunities for new species to establish. As the study shows, this is certainly the case for Horns Rev wind farm, where fish biodiversity has increased considerably within the wind farm area. However, the establishment of "reef fishes" in a desert of sand also demonstrates that these fishes are migrating across large sandy areas to find suitable hard substrate. This is an indication that the amount of natural reef habitat may limit the abundance of these fish, but also suggests that similar colonisation is likely to happen at other wind farms, irrespective of their distance to natural hard substrate habitats.

The studies have also shown that fish around wind turbines display behaviour similar to the fish in natural reef habitats. Some use the wind farm for shelter during the day and then use the surrounding sandy areas as a foraging area at night, while others are more stationary, living off the fouling community that has developed on the wind farm foundations and scour protection. In this respect wind farms function as natural habitats.

SANDEEL AND WIND FARMS

While the hard substrate has increased biodiversity and abundance of reef-associated fishes, there have been just concerns regarding other species. For instance the ecologically important sandeel species that rely on soft bottom substrate, and can potentially be disturbed by the noise and vibrations from the turbines. However, the Horns Rev study does not show any adverse effects of the wind farms on the sandeel community. The modelling of the dispersal of lesser and greater sandeel larvae illustrates an important point with regard to the susceptibility of fish populations to constructions such as wind farms. In the case of lesser sandeel, recruitment to the area is dependent on the supply of larvae from outside and it is therefore less dependent on the conditions in the wind farm area. In contrast, greater sandeel use the area for spawning and as nursery grounds and, consequently, deterioration of the area is likely to affect this species more. This small ecological difference may determine how a fish population reacts to the establishment of a wind farm.

WIND FARMS – FISH HABITATS OR FISH TRAPS?

Wind farms attract fish and increase biodiversity, but whether fish benefit in the long run from the new habitat and whether wind farms can be used to help sustain fish populations is a question that is just as much related to the management of wind farms areas as to the biology of the fish and the quality of habitats. In many areas, FADs – Fish Attracting Devices – are used to lure the open water fish and concentrate them in a smaller area where they are easier to catch. In some respects wind farms are similar to FADs. Fish aggregate there to find shelter and food. Therefore it is important to consider what management actions are necessary in a given wind farm area to ensure that it becomes an important fish habitat and not just a fish trap.

4

MARINE MAMMALS
HARBOUR PORPOISES AFFECTED BY CONSTRUCTION

BY DR. MIRIAM BRANDT, ANSGAR DIEDERICHS AND, DR. GEORG NEHLS *(BioConsult SH GmbH & Co. KG)*,
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How does installation and subsequent operation of wind farms affect marine mammals? And is it possible to mitigate the effects of noise during installation? This chapter consists of three distinct studies looking to provide answers to these questions.

The first study investigates harbour porpoise *(Phocoena phocoena)* reactions to noise from wind farm construction. The process of driving steel foundations into the seabed during wind farm construction creates considerable noise. This study documents harbour porpoise reactions to the noise and found a disturbance effect to porpoises during piling up to about 18 km. Furthermore, it could be shown that potential hearing impairment at close range may occur. Porpoise activity around the construction site, however, returned to normal levels after only a few days.

Furthermore researchers investigated the efficiency of seal scarers deterring porpoises prior to piling of wind farm foundations. Seal scarers emit blasts of sound designed to repel seals and as this study shows can also be an effective means of mitigating the risk of injury to porpoises due to piling noise.

In a final study the population dynamics of harbour porpoises were studied using an individual-based simulation model aiming to predict the cumulative effects of wind turbines, ships and by-catch on the number of porpoises in the Inner Danish Waters. The model predicted that noise from ships and wind farms have a minor effect on the porpoise population size. By-catch in commercial fisheries may in contrast reduce the population size substantially.

SUMMARY 2006

Seals were studied to evaluate their use of the wind farms and the surrounding areas, the effect of construction and operation on resting behaviour and the population development in the area. Both wind farm areas were found to be part of much larger foraging areas used by seals. No general change in behaviour at sea or on land could be linked to the construction or operation of the wind farms. The only effect detected on land was a reduction in the number of seals on land during a single sheet pile driving operation at Nysted.

Only a slight decrease in porpoise abundance was found at Horns Rev during construction and no effect of the operation of the wind farm was seen. A clear decrease in the abundance of harbour porpoises was found at Nysted during the construction and operation of the wind farm. The effect has persisted after two years of operation of the wind farm, with indications of a slow recovery. At both sites, harbour porpoises inside the wind farm and up to 15 km from the wind farm reacted to pile driving operations.

Dorsal fin of harbour porpoise. PHOTO: JONAS TEILMANN

CHAPTER INTRODUCTION

Installation and operation of offshore wind farms lead to impacts on the marine environment, including marine mammals. Most offshore wind farms are installed on steel foundations with large piles driven into the seabed. This leads to considerable noise emissions into the water column, potentially inflicting injury on the sensory system of harbour porpoises.

The harbour porpoise is a protected species and must not be killed or injured by human activities and disturbance has to be limited. Permits for offshore wind farms often carry instructions to deter animals from the vicinity of the construction site, where potential injury may occur.

Though studies have already shown that pile driving causes harbour porpoises to leave areas with high noise emissions, the spatial and temporal scales of the impacts are still largely unclear. While disturbance during construction can only be mitigated by reducing noise levels from such operations, physical damage may be avoided by deterring harbour porpoises from the vicinity of the construction site before pile driving activities begin. For this purpose, seal scarers are deployed before pile driving activities. Seal scarers are devices emitting noise designed to keep seals away from fish farms. They are also used to deter harbour porpoises from areas where the marine mammal may be injured from strong piling noise. Although harbour porpoises have been reported to react strongly to seal scarer noise, the range and effectiveness of these devices have not previously been studied.

It is clear that we need to better understand the ways in which these animals respond to the installation and operation of offshore wind farms. Potential disturbance is greatest during the construction period when pile driving occurs. Therefore the aim of the first study is to investigate the spatial and temporal extent of such disturbance effect on harbour porpoises.

If seal scarers are to be used systematically as a mitigation measure during construction, we also need to test how animals respond to these devices. Therefore, the second study aims to investigate how effective a commercially available and frequently used seal scarer is as a deterrent for harbour porpoises.

Ultimately, the question in a management context is: what is the consequence of the observed wind farm effects on the population of harbour porpoise? Does it affect individual survival and reproduction and threaten the survival of the population? This is the focus of the third study, which, as the very first of its kind, developed an individual-based model to help address this very question.

PART 1

LONG-DISTANCE EFFECTS OF PILE DRIVING ON HARBOUR PORPOISES

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To assess the impacts of offshore wind farm construction on harbour porpoises, a profound knowledge of the behaviour of the species in relation to noise levels created by offshore pile driving is essential. The main task of the follow-up study was to complement the Horns Rev 2 monitoring study by DONG Energy, focusing on the long-distance temporal and spatial extent of disturbance and thereby helping to further substantiate to what extent pile driving displaces harbour porpoises from their habitat.

In the context of the Horns Rev 2 monitoring programme, sound measurements of pile driving noise were conducted and harbour porpoise activity was monitored within the area of the Horns Rev 2 wind farm. Harbour porpoises were monitored prior to and during construction of wind turbines using hydrophones to record porpoise echo-location clicks. The follow-up programme study added to this by monitoring harbour porpoise activity along a 50 km transect extending southwards from the wind farm.

Here the combined results of the two studies are presented to give the full overview.

Construction of monopile foundations at Horns Rev 2.
PHOTO: DONG ENERGY

METHODS:
SOUND MEASUREMENTS OF PILE DRIVING NOISE

Sound measurements of the pile driving noise were conducted at two measurement points during installation of one pile at the Horns Rev 2 wind farm. An autonomous recording buoy was deployed at a distance of 720 m from the pile and manual recordings were made from a ship at a distance of 2300 m. From these measurements, Sound Exposure Levels (SEL) were calculated.

MONITORING PORPOISE RESPONSES USING HYDROPHONES (PODS)

The occurrence of harbour porpoises was monitored a month before and during the entire construction period by continuous registration of their echo-location clicks using Porpoise Detectors (PODs). PODs are hydrophones equipped with data loggers especially designed to record and detect porpoise echo-location clicks. According to the manufacturer they have a detection radius for porpoises of about 300 m. Six PODs were deployed along a transect line reaching from inside the wind farm to the southeast. Distances to construction sites ranged from 0.5 km to 25 km. Data was recorded during the construction of 95 monopile foundations in 2009. An average pile-driving event lasted 46 minutes.

Porpoise recordings were analyzed using the parameter porpoise positive minutes per hour (the number of minutes during which at least one porpoise click was detected). The parameter is a relative measure of porpoise presence in the area during a given hour. The data obtained was then analyzed statistically using General Additive Model (GAM) procedures in which different parameters were tested for each of the six POD positions [Fig. 4.2].

Additionally, five PODs were deployed along a transect line reaching from inside the Horns Rev 2 wind farm to the construction site of the research platform FINO 3 in the German North Sea. The research platform was constructed at the same time as the wind farm construction took place. Distances of the PODs to the construction sites ranged from about 7 km to 47 km. The aim of this part of the study was to specifically investigate long-distance effects of pile driving in both areas.

RESULTS:
HARBOUR PORPOISES CAN SUFFER HEARING IMPAIRMENT

For the monopile construction for which sound measurements took place, 449 blows were necessary to reach the final penetration depth of 21 m according to the pile driver record file. The time from the first to the last blow was 30 min. At a distance of 720 m, during one pile driving event, the peak noise level reached 196 dB re 1 μPa, the SEL level reached a maximum of 176 dB re 1 μPa²s and a cumulative value of 170 dB re 1 μPa²s [Fig. 4.1]. At a distance of 2300 m from the pile driving, the peak noise level reached 184 dB re 1 μPa, the SEL level reached a

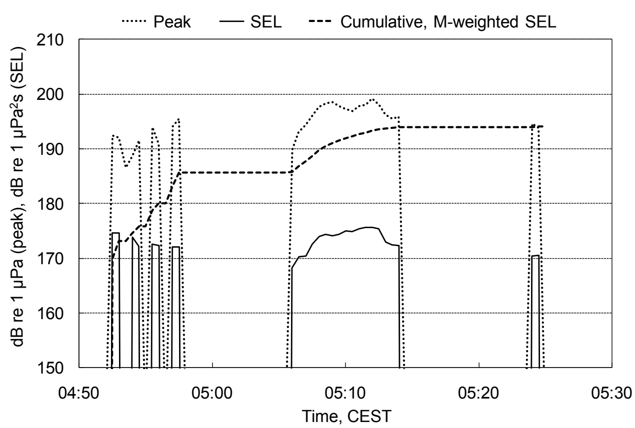

FIGURE 4.1 *Peak level and SEL for the one pile driving operation measured at a distance of 720 m. Also shown is the cumulative SEL. The difference between the non-cumulative unweighted and M-weighted SEL varied from approx. 4 dB to 7 dB. (Figure taken from Brandt et al. 2011).*

maximum of 164 dB re 1 μPa²s and a cumulative value of 157 dB re 1 μPa²s [Fig. 4.1].

For the group of high-frequency cetaceans such as harbour porpoises, the onset of hearing impairment (defined as a Temporary Threshold Shift (TTS)) has been estimated at 183 dB re 1 μPa²s SEL and Permanent Threshold Shift (PTS) at 198 dB re 1 μPa²s SEL. During our study the cumulative M-weighted SEL level reached a maximum of 194 dB re 1μPa²s at 720 m distance and a maximum of 182 dB re 1μPa²s at 2300 m distance. According to the above estimates harbour porpoises would not have suffered PTS at either a distance of 2300 m or 720 m. However, they could have suffered TTS immediately at a distance of 720 m and after about 2 min at a distance of 2300 m.

However, a recent study indicates that harbour porpoises may be more sensitive to noise as TTS could be experimentally induced at 199.7 dBpk-pk re 1 μPa and at a sound exposure level of 164.3 dB re 1 μPa²s. This implies that PTS is also likely to occur at lower noise levels, such as 179 dB re 1 μPa²s SEL. PTS could therefore have occurred in harbour porpoises at both distances for harbour porpoises that remain in the area for several minutes.

HARBOUR PORPOISES REACTED AT UP TO 20 KM DISTANCE

Porpoise detections were averaged over the baseline period prior to construction (8.4.-18.5.2008) and over the entire construction period (19.5-7.9.2008). A comparison of these values revealed that porpoise detections were significantly lower during construction at the closest POD positions at average distances of 2.6 km, 3.2 km and 4.8 km. No significant effect was found further away at average distances of 17.8 km and 21.7 km from the pile driving site.

However, analyses on a finer time scale (an hourly basis) revealed that porpoise detections significantly changed during the hours after pile driving at all distances studied [Fig. 4.2].

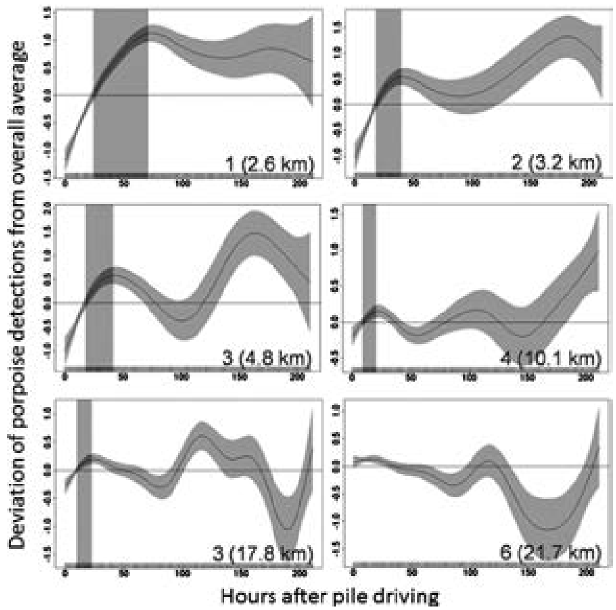

FIGURE 4.2 *The graph shows how porpoise activity differs from the overall average at the different hours after pile driving. The overall average is shown as the horizontal line at zero. The curve indicates average porpoise detections during a given hour and the grey shaded areas around the curve indicate the confidence intervals. If the confidence interval is below zero, this means that porpoise detections during that hour were significantly below the overall average; if it is above zero, porpoise detections were significantly higher. Figure taken from Brandt et al. 2011.*

At the closest distance to the construction site (2.6 km) porpoise detections were substantially below the overall average for up to 24 h after pile driving [Fig. 4.2].However, porpoise detections continued to increase, until levelling off at ~72 h after pile driving. At distances between 3.2 km and 4.8 km, the patterns were similar. The effect lasted from 18 h to 40 h at distances of 3.2 km and from 17 h to 42 h at distances of 4.8 km. At distances between10.1 and 17.8 km, the effect was substantially shorter, i.e. from

9 h to 21 h and from 10 h to 31 h, respectively. At 21.7 km distance, the shape of the curve differed: porpoise detections were higher than the overall average during up to ~35 h after pile driving, while fluctuating around the overall mean afterwards

This indicates that porpoise detections were temporarily reduced during and after pile driving at a minimum distance of up to 18 km. The duration of the effect on porpoise detections decreased as the distance to the pile driving site increased. This reduction in porpoise detections after pile driving is most likely linked to harbour porpoises moving away from the construction site. At the furthest distance studied (21 km), porpoise detections were higher than the overall average for about 30 h after pile driving. This implies that harbour porpoises at this distance showed no behavioural reaction to pile driving. Animals moving away from the construction site might have caused porpoise abundance and thus porpoise detections to temporarily increase.

The median time between pile driving events was 16 hours, during which porpoise activity did not fully recover at a distance of up to about 4.8 km. Consequently, porpoise detections were lower than expected during the entire five months of construction.

This is indicated by a significantly lower number of porpoise detections during the construction period as compared to the baseline period up to a distance of 4.8 km. At distances between 17.8 km and 21.7 km this difference between baseline and construction period is not as apparent due to a shorter lasting effect of pile driving on porpoise detections.

NO CLEAR RESULTS AT POD TRANSECT BETWEEN CONSTRUCTION SITES

Along the POD transect to the south, a significant reduction in porpoise detections after pile driving was detected at a distance of 7 km, no effect was found between 15 km and 37 km and a reduction occurred again at 46 km.

Preparation of monopile foundation at Horns Rev 2.
PHOTO: DONG ENERGY

However, this decrease in 46 km distance is unlikely to be related to pile driving activities at Horns Rev, as pile driving noise is expected to no longer be audible to harbour porpoises at about 50 km distance. The fact that no effects were found at 15 km is in contrast to results from the previous study and several methodological problems might be the cause of this deviance. First of all a different POD model had to be used, which meant that data were not directly comparable to the previous study and this also required a different data analyses method. Furthermore porpoise detections at these locations were rather low, which reduces the possibility to find effects. Finally, sound transmission in the area might have been different due to stronger sound absorption under different topographic conditions. Unfortunately measurements of pile driving sounds did not exist at these locations and therefore, the latter assumption could not be tested.

DISCUSSION:

REDUCING RISKS TO HARBOUR PORPOISES BY MITIGATION MEASURES

The study revealed that harbour porpoises responded to pile driving at Horns Rev 2 up to a distance of 18 km, which corresponds to other findings. With a maximum duration of two to three days close to the construction site, the effect is rather short but nevertheless lasted longer than reported in previous studies. Harbour porpoises are disturbed by pile driving over a large area but return to the wind farm within a few days after pile driving stops. Results from sound measurements also show that porpoises could potentially suffer hearing damage in the vicinity to the construction site, which shows the necessity to reduce this risk by applying appropriate mitigation procedures. In conclusion the measurements at Horns Rev 2 allowed us to relate the response of porpoises to actual noise levels of pile driving. This will help to assess the impacts of future offshore wind farm projects on porpoises.

Turbines at Nysted Offshore Wind Farm.

PHOTO: NYSTED OFFSHORE WIND FARM

Deployment of acoustic datalogger (POD) outside the Horns Rev Wind Farm. PHOTO: ELSAM A/S

PART 2

MITIGATING RISK OF PILING NOISE INJURY TO HARBOUR PORPOISES

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Offshore pile driving noise during wind farm construction may lead to hearing damage in harbour porpoises in the vicinity of the construction site. To avoid such injuries, acoustic deterrent devices (seal scarers) are used to deter porpoises from the vicinity of the construction site prior to the start of pile driving. In order to assess whether such deterrent devices are effective, the reactions of porpoises to seal scarer sound were studied at various distances and sound levels. We investigated the response of harbour porpoises to a Lofitech seal scarer by conducting two studies. One study applied visual observations of porpoise reactions to the seal scarer sound from the top of a cliff in coastal waters of the Danish Baltic Sea. The other study used a combination of mainly passive acoustic monitoring (PODs) and to some extent aerial surveys in offshore waters of the German North Sea. Measurements of the seal scarer noise levels were conducted at both sites.

METHODS:
SOUND MEASUREMENTS

The seal scarer emits pulsed signals at high frequencies between 13.5 kHz and 15 kHz with intervals ranging from less than 1s to 90s. Signal strength is about 189 dB re 1 μPa @ 1 m according to the manufacturer.

Noise measurements of the seal scarer were conducted at various distances at two study sites. The first was in the Baltic Sea near Fyns Hoved, where visual observations of porpoise reactions took place, and secondly in deeper North Sea offshore waters, comparable to the study site that used PODs to study porpoise reactions to the seal scarer.

VISUAL SCANS AND THEODOLITE TRACKING

Visual observations of porpoise reactions to the seal scarer were conducted from a cliff in the Baltic Sea off Denmark during calm weather conditions. A central marker buoy was deployed 150 m in front of the coast, where a boat was anchored from which the seal scarer was operated. Nine additional buoys were deployed up to 1 km to mark the observation area.

An area with a 1 km radius around the seal scarer was observed for porpoise presence. Theodolite tracking of observed individuals or mother-calf groups enabled determination of the animals' position by using the known height of the observation point and the horizontal angle of the animals' position. Nine days without, and seven days with, seal scarer activity were monitored using a blind trial procedure. After a minimum of one hour of baseline data collection, the seal scarer was switched on for four hours, as soon as a porpoise could be tracked within a radius of 150-700 m from the boat.

In addition responses of harbour porpoises to the seal scarer were studied while it was deployed at greater distances (between 1.3 and 3.3 km) from the porpoise.

DETECTING PORPOISES USING HYDROPHONES

At a second study site in offshore waters off the German North Sea, porpoise responses to the seal scarer were studied using a different approach. This approach was necessary because direct visual observation of porpoises in this area was extremely difficult. At this location, porpoises were monitored by deploying 16 PODs, which are described in the study above, at distances from zero to 7.5 km from where the seal scarer was activated.

A total of ten trials with the seal scarer activated were conducted, separated by at least four days. During each trial the seal scarer was deployed from a boat and switched on for four continuous hours. Porpoise detections before and during seal scarer activity were then compared.

AERIAL SURVEYS OF PORPOISES

In addition to the POD recordings, two aerial survey flights were conducted in the German North Sea in order to gain data on porpoise density and how this may change during seal scarer activity. On the day of the first seal scarer trial, one survey was conducted prior to and one during seal scarer activation. The survey was conducted within a 990 km² area around the seal scarer and with a maximum distance of 15 km to the seal scarer deployment site.

RESULTS:

SOUND MEASUREMENTS OF THE SEAL SCARER

Sound levels of the Lofitech seal scarer as a function of distance are depicted in [Fig. 4.3]. The estimated measurement uncertainty is ±3 dB. The level decrease with distance is significantly stronger at the Baltic study site than in the North Sea. This is probably related to stronger sound absorption in the more shallow waters at the Baltic study site. The mathematical function fitted to the measurements enabled us to estimate the sound levels that porpoises were exposed to when at specific distances to the seal scarer.

Two harbour porpoises. PHOTO: JONAS TEILMANN

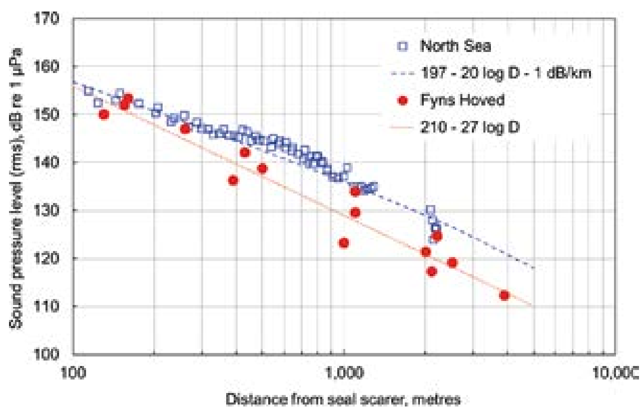


FIGURE 4.3 *Measured noise levels (125 m averaging) of the Lofitech seal scarer signal versus distance to the seal scarer at shallow waters near Fyns Hoved (red dots) and in deeper North Sea offshore waters (blue squares).*

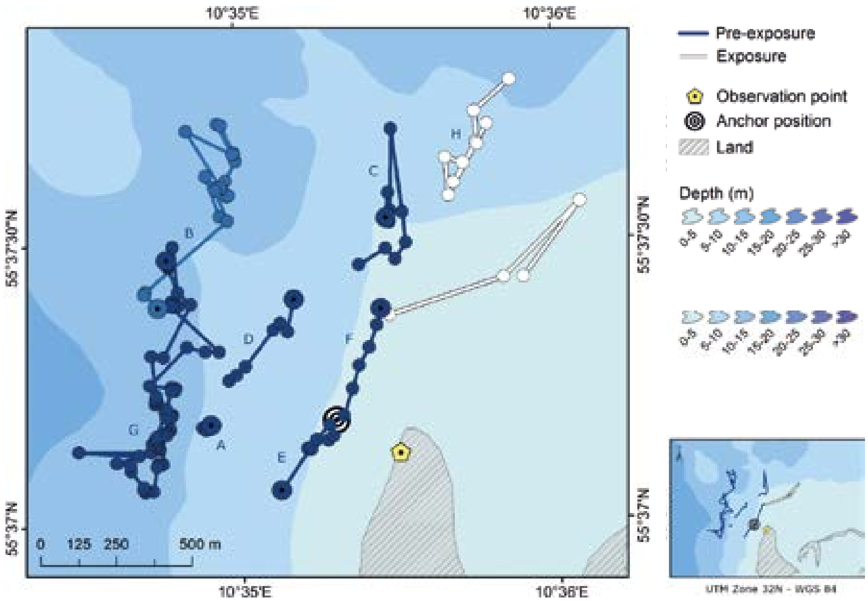


FIGURE 4.4 *Map showing the porpoises tracked before and during seal scarer operation. Enlarged points mark the last porpoise surfacing location just seconds before the seal scarer was activated. Only one porpoise out of seven could still be seen after the seal scarer was switched on (track F). In addition the only other track that could be obtained during seal scarer activity is shown (track H), where the porpoise showed the closest approach distance of 800 m. The seal scarer was positioned at the central anchoring position indicated by the black concentric circles. Track B is shown in lighter grey to distinguish it from track G. Figure taken from Brandt et al. in press (a)*

PORPOISE SIGHTINGS DECLINED IN RESPONSE TO THE SEAL SCARER

The number of harbour porpoises seen within the 1 km radius around the seal scarer declined significantly from a mean of 31 sightings/4 h when the seal scarer was not active to a mean of only 0.3 sightings/4 h when it was active, a 99 % reduction. The 1 km observation radius corresponds to an approximate minimum sound level of 129 dB re $1\mu Pa_{rms}$, according to the sound measurements above.

PORPOISES DO NOT COME CLOSER THAN 800 M

During the seven trials when the seal scarer was active (28 h in total), two harbour porpoise sightings were obtained during standardized scans at a distance of about 1000 m. One porpoise was only spotted once. The other one could be tracked over 11 min and approached the seal scarer at 800 m [Fig. 4.4, track H]. This animal was milling about, repeatedly resurfacing and changing its swimming direction, which may indicate that it was feeding in the area. About 25 min later a porpoise was again spotted between scans at a distance of 800 m to the seal scarer. This could have been the same animal observed earlier. In two additional trials a porpoise was seen at distances beyond 1000 m. All five observations were of single adult porpoises. The closest approach distance of 800 m corresponds to a sound level of about 132 dB re $1\mu Pa_{rms}$. This sound level may therefore represent the maximum sound level from a seal scarer that porpoises tolerate under certain situations. *Figure taken from Brandt et al. in press a.*

Porpoises avoided the seal scarer at up to 2.4 km distance. Of the seven porpoise groups that were tracked within the 1 km radius, six immediately disappeared when the seal scarer was switched on and were not spotted again within the observation area [Fig. 4.4]. Only in one instance [Fig. 4.4, track F] the porpoise could still be tracked during seal scarer activation. It swam away to the north and around the peninsula. By contrast, no such behaviour was recorded without seal scarer activation.

The clear reduction in porpoise sighting rates within a 1 km radius around the seal scarer and the fact that in most cases porpoises immediately disappeared upon exposure to the seal scarer at distances between 300 – and 1100 m (relating to noise levels between 128 and 143 dB re 1μPa$_{rms}$) point to a very strong reaction at close range. Porpoises most likely left the vicinity of the seal scarer in a relatively far and fast movement under water.

Fifteen additional trials were conducted where porpoises were first tracked without the influence of the seal scarer and later exposure to seal scarer noise at distances between 1.1 km and 3.3 km so that their reactions could be observed. At distances of 1.1 km and 1.7 km (noise levels between 123 dB re 1μPa$_{rms}$ and 128 dB re 1μPa$_{rms}$) to the seal scarer, porpoises also disappeared immediately (or after they resurfaced once). During four trials at distances of 1.6 km, 1.9 km, 2.3 km and 2.4 km (noise levels between 119 dB re 1μPa$_{rms}$ and 124 dB re 1μPa$_{rms}$), porpoises showed avoidance reactions towards the seal scarer by turning around and swimming away from it [one example in Fig. 4.5]. In two cases at distances of 2.3 km and 2.5 km, reactions could not be judged due to an approaching boat and porpoises swimming into glare. In one case at a distance of 2.2 km (noise level: 120 dB re 1μPa$_{rms}$), a mother-calf pair swam away from the seal scarer 1 min and 40 sec after its activation. It is unclear

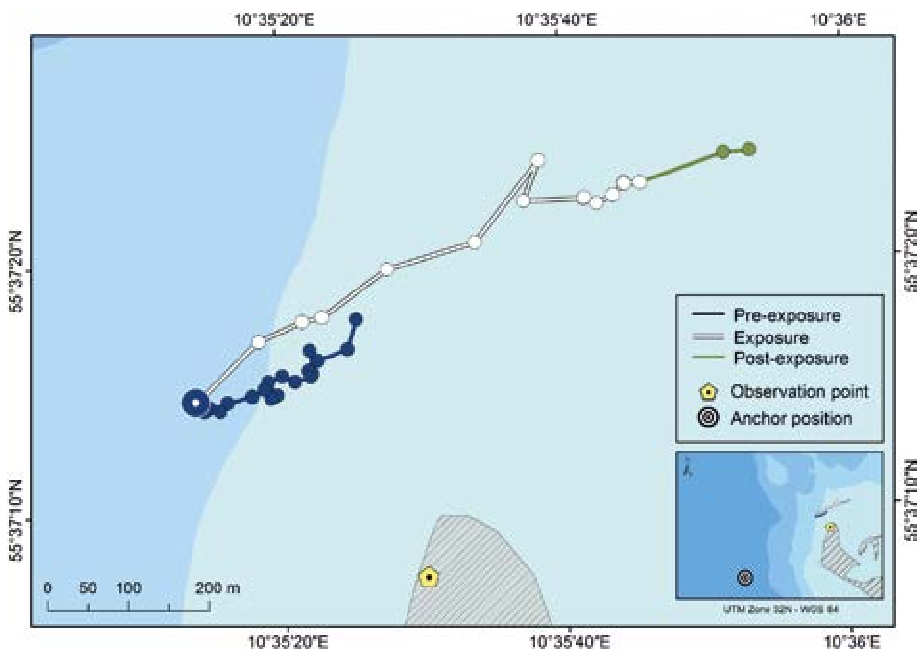


FIGURE 4.5 *Harbour porpoise track as an example of a clear avoidance reaction to seal scarer noise by when animals turned and swam further away from the seal scarer after its activation. The position of the seal scarer is indicated by the black concentric circles (anchor position) in the inlet map. Figure taken from Brandt et al. in press (a).*

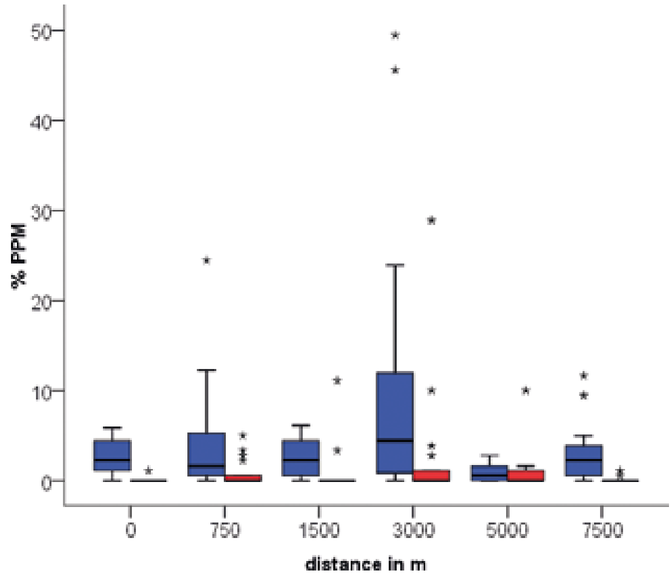


FIGURE 4.6 *Harbour porpoise activity before (blue bars) and during (red bars) seal scarer activity shown as box-whisker plots with outlets. Figure taken from Brandt et al. in press (b).*

whether this was a delayed avoidance reaction or caused by other reasons. No porpoise reactions towards the seal scarer were found in distances 2.1 km, 2.6 km, 2.9 km, 3.1 km, 3.1 km, and 3.3 km, corresponding to noise levels between 115 dB re 1µPa$_{rms}$ and 121 dB re 1µPa$_{rms}$. Instead the animals continued swimming around the same area without markedly increasing their distance to the seal scarer. During the four baseline tracks when the seal scarer was not switched on, porpoises did not show any obvious avoidance reaction.

This shows that, if the animals were at distances between 1.6 km and 2.4 km from the seal scarer (and thus exposed to lower noise levels between 119 dB re 1µPa$_{rms}$ and 124 dB re 1µPa$_{rms}$), porpoises still showed avoidance reactions towards the seal scarer. However, the reaction was less strong than at closer distances, when porpoises completely disappeared. There also appeared to be some variability in the animals' reactions to the seal scarer, as not all animals reacted at distances between 2.1 km and 2.4 km (ca. 119-121 dB re 1µPa$_{rms}$) and one mother-calf pair might have reacted after a 1.5 min delay. This variability could be related to differences in sensitivity between individual animals, differences in behavioural context or variations in sound transmission.

At distances above 2.6 km (noise levels below 119 dB re 1µPa$_{rms}$), avoidance reaction by porpoises was no longer found. This result is similar to studies of captive porpoises' reactions to seal scarer sound.

EFFECTS OF SEAL SCARER FOUND AT UP TO 7.5 KM

At the North Sea test site, porpoise detection decreased during seal scarer activity at all the POD positions studied [Fig. 4.6]. However, the decrease was only statistically significant in distances 0 km, 0.75 km, 3.0 km and 7.5 km, but not in distances 1.5 km and 5.0 km. On the other hand, as can also be seen in [Fig. 4.6], porpoise activity at these positions was already quite low or quite variable before the start of the seal scarer activity, which made detection of a statistically significant effect difficult.

The deterrent effect of the seal scarer on porpoises reached much further than during the study at Fyns Hoved. This is not surprising as the differences in topography led to less sound absorption with distance at this site [Fig. 4.3]. The maximum distance at which an effect on porpoise detection was still observed was at a sound level of about 113 dB re 1µPa$_{rms}$ according to the measurements in North Sea waters. This is lower than the 119 dB at which porpoises were found to still avoid the seal scarer at the Fyns Hoved study site. It has to be considered, however, that at such large distances and during rougher sea states, sound levels can vary greatly. This means that sound levels might have temporarily also been above 113 dB during the present study.

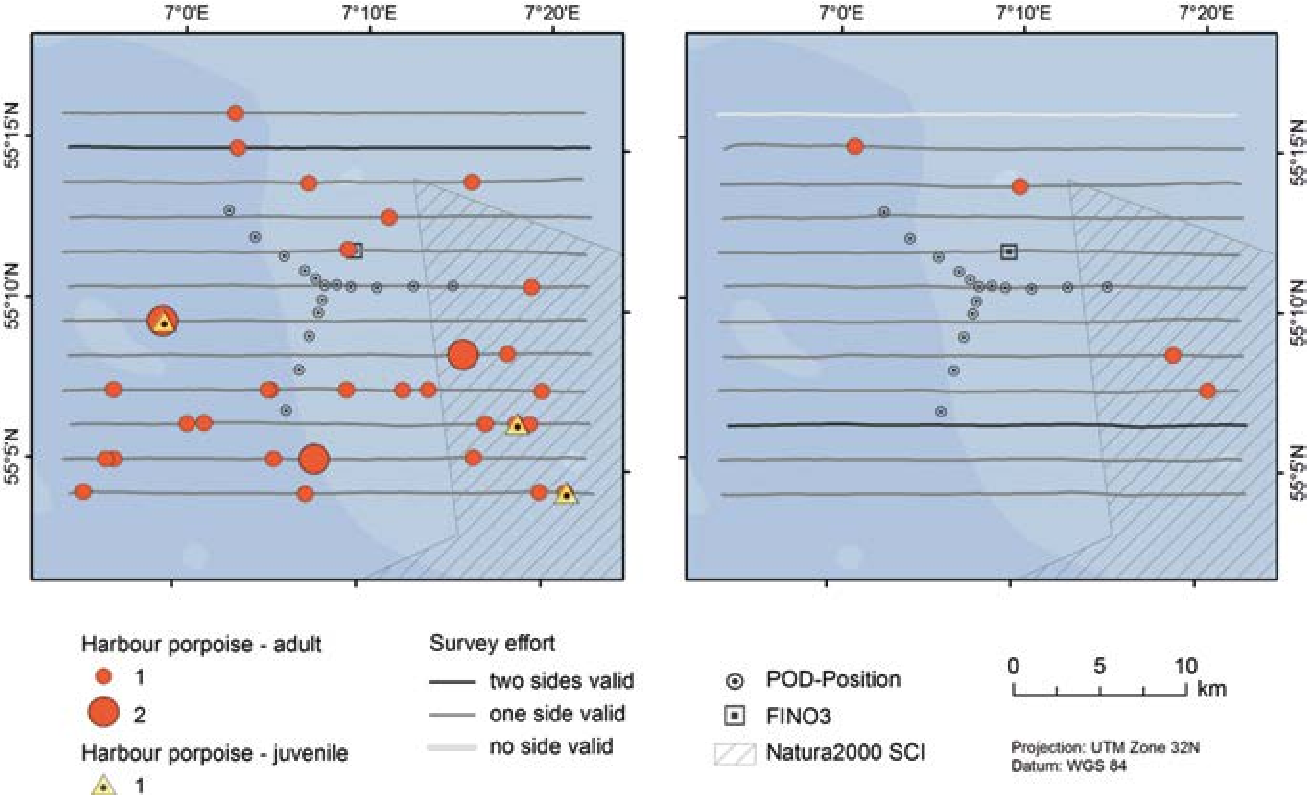


FIGURE 4.7 *Harbour porpoise sightings and survey effort during the aerial survey on 10 August 2009 before (left) and during (right) seal scarer deployment. Figure taken from Brandt et al. in press b.*

PORPOISES WERE DETECTED BY PODS AT ALL DISTANCES

Even though there was an obvious and significant reduction in porpoise detections during seal scarer deployment at the nearest distances, there was not complete deterrence of all porpoises. At all distances, occasional porpoise clicks were recorded by PODs during seal scarer activity. At the nearest distance this was only during the first trial, when porpoise clicks were recorded for two minutes. This accounts for about 0.13 % of the time that the POD recorded data at this position during seal scarer activity. During seven out of ten trials porpoise clicks were recorded by at least one of three PODs deployed at a distance of 750 m. Here the longest time in which a porpoise was detected was 9 min.

AERIAL SURVEYS CONFIRM DECREASE IN PORPOISE ABUNDANCE

Harbour porpoise density as calculated from aerial surveys declined from 2.4 porpoises/km^2 to only 0.3 porpoises/km^2 during seal scarer activity. With similar survey effort and sighting conditions during both flights, a total of 38 porpoises were sighted during the first survey before the seal scarer was activated, while only four porpoises were seen when the seal scarer was active [Fig. 4.7]. This shows that the decrease in porpoise detections caused by the seal scarer sound was indeed due to animals leaving the area and not just decreasing echo-location activity.

RESULTS CORRESPOND TO PREVIOUS STUDIES

In general, the results on porpoise reactions are also in line with earlier studies testing other types of seal scarers. One study found a reduction in sightings up to the maximum observed distance of 1.5 km, while another study even observed an effect at up to 3.5 km. The closest approach distances found were 645 m during one study and 200 m during the other study. However, these studies did not provide any information on sound levels and transmission, and this is likely to differ substantially between areas due to topography and hydrodynamics. The present study is the first to demonstrate porpoise reactions in the field to known sound levels and it provides essential information for judging the effectiveness of a seal scarer during pile driving procedures.

Nysted offshore wind farm at hub height.
PHOTO: NYSTED OFFSHORE WIND FARM

DISCUSSION:

SEAL SCARERS – A USEFUL TOOL DURING WIND FARM CONSTRUCTION

The present study documents, that the use of a seal scarer prior to pile driving greatly reduces the risk of exposing porpoises to harmful noise emissions. During the study at Fyns Hoved a complete deterrent effect occurred within a range of about 800 m down to noise levels of 132 dB re 1µPa_{rms} and incomplete deterrence effects were found at up to 2.4 km and down to noise levels of about 119 dB re 1µPa_{rms}. At the North Sea study site, the deterrent effect was not complete, even in the immediate vicinity of the seal scarer. However, a significant deterrence effect was found at up to 7.5 km, translating to a sound level of about 113 dB re 1µPa_{rms}. Such differences between the two studies are most likely linked to higher variability in sound transmission at greater distances and at varying sea states at the North Sea study site. Differences in behavioural reactions might also be linked to different habitat functions. Porpoises may be less likely to leave an area due to seal scarer sound if there is an abundance of easily available food resources in the area, whereas they might leave an area at lower noise levels if they are only passing through. Observations of porpoises at Fyns Hoved showed that they were often involved in feeding activity, whereas the behaviour of porpoises at the North Sea study site is not known.

The distances at which porpoises could potentially suffer hearing damage during pile driving activities at offshore wind farms greatly depend on the sound level during pile driving. Source levels vary widely depending e.g. on the type of foundation used and the topography of the site. Therefore the range at which porpoises are at risk from injury should be considered specifically for each project.

Helicopter servicing turbine at Horns Rev Offshore Wind Farm. PHOTO: VATTENFALL

PART 3

EFFECTS OF WIND FARMS ON PORPOISE POPULATION DYNAMICS

JACOB NABE-NIELSEN, JONAS TEILMANN AND JAKOB TOUGAARD, DEPARTMENT OF BIOSCIENCE, AARHUS UNIVERSITY

Several studies indicate that porpoises sometimes react to noise, but it remains unknown whether this influences the number of animals that can live in a given area. Noise and other types of disturbances may affect population dynamics by preventing animals from foraging in resource-rich areas. Disturbances may also cause the population to become more fragmented, making isolated sub-populations more prone to extinction. The effects of noise therefore depend on where the noise is emitted as well as on how the animals react to it. In this study we use an individual-based model (IBM) to study how disturbances affect the foraging behaviour of the porpoises in the inner Danish waters. In order to better support future management initiatives we also evaluate the population effects of by-catch in commercial fisheries as well as noise emitted from wind farms and large ships.

METHODS:
INDIVIDUAL-BASED SIMULATIONS

In order to predict the population effects of noise and by-catch, we developed an IBM that simulated the birth, growth, movement and death of individual porpoises. Their fine-scale movements, which were simulated using a half-hour time scale, were very similar to those of a real animal equipped with a dead-reckoning data logger. On coarser time scales, the simulated animals produced

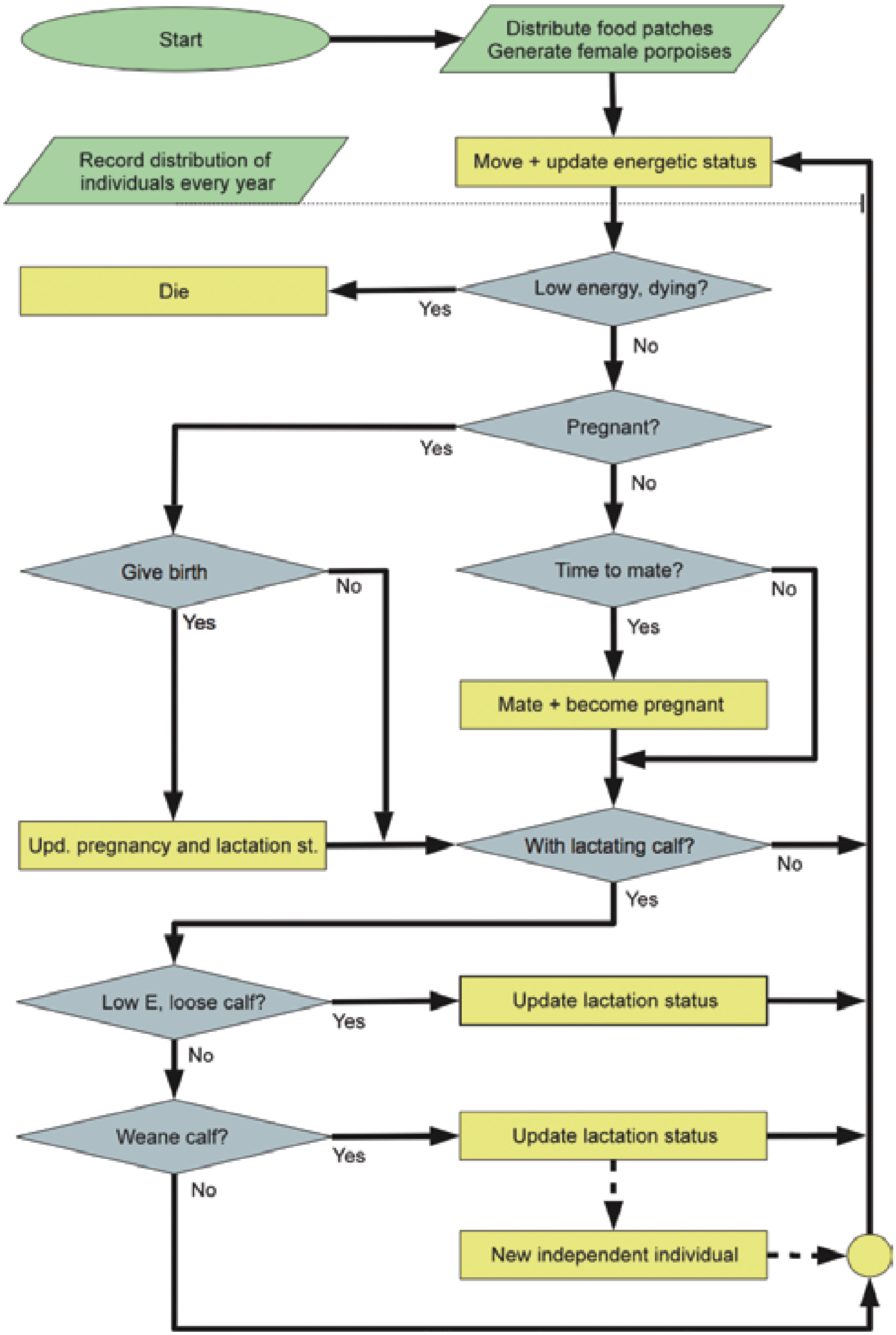


FIGURE 4.8 *Life history traits that were incorporated in the porpoise model. The adult mortality and the risk of losing a lactating calf were related to the animals' energy status.*

home ranges and dispersal patterns that closely resembled those of satellite-tracked animals.

The population dynamics in the model were ultimately driven by the energy status of each individual. Animals gained energy when they encountered food and used energy at a rate that depended on the season and on whether they were lactating, just as for real animals. The food in the randomly distributed food patches replenished following a logistic growth curve after being eaten by an animal. After approximately two days the food levels had recovered completely. The highest possible food densities in different parts of the landscape were derived from the distribution of satellite-tracked animals using a maximum entropy model. The maximum food levels were therefore higher for patches in the areas that real porpoises frequently used. The energy status of the simulated animals influenced their mortality and the likelihood that they abandoned lactating calves [Figure 4.8]. It did not influence their probability of giving birth. Birth rates were obtained from literature.

In addition to food patches, the landscape included land, and in some scenarios also wind turbines and large ships. The simulated porpoises turned slightly towards the area with deepest water when approaching land. Ships and wind turbines also caused them to turn away, but their tendency to turn depended on the amount of noise they were exposed to. As porpoises' exact behavioural response to noise from operating wind turbines is unknown, we adjusted their reaction in the model until the simulated porpoise densities were half as high close to turbines as they were 300 m away from them. Several studies suggest that this is a worst-case scenario for how strongly porpoise densities are affected by operating wind turbines. The porpoises' tendency to turn away from the ships, which are much noisier than the turbines, was scaled relative to the level of noise that reached the porpoises. The effects of noise from ships were studied using a realistic number of ships on the deep-water routes through Kattegat and on the Odden-Aarhus fast ferry route [Figure 4.9]. The simulated porpoises' tendency to move away from noisy objects was halved every time step, and after five half-hour steps their movements were no longer affected.

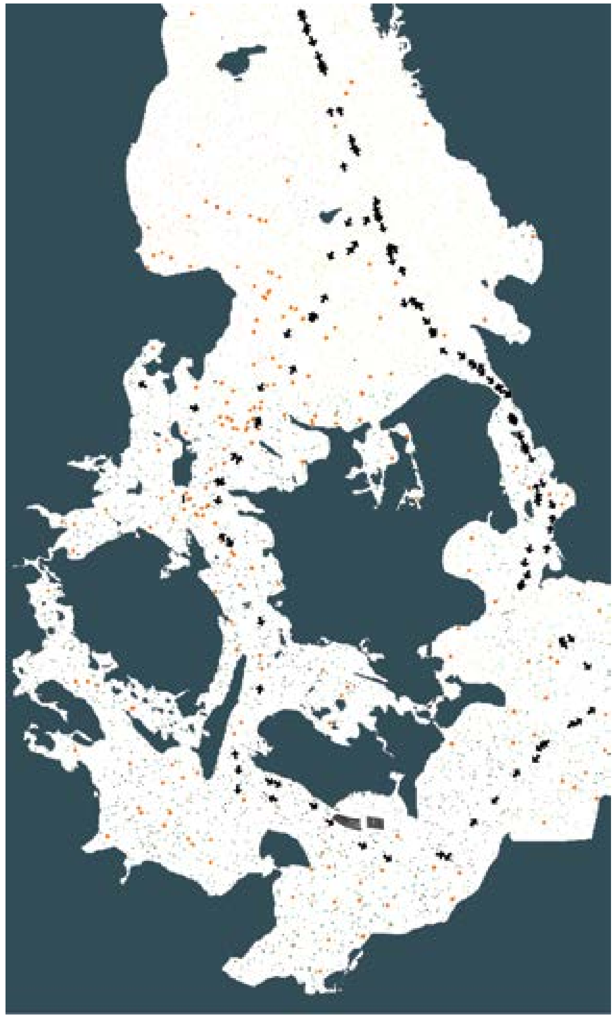


FIGURE 4.9 *Example of simulation where porpoises (orange dots) foraged for patchily distributed food (green dots) while being disturbed by large ships and existing wind farms in the Inner Danish Waters (black arrows and dots, respectively).*

Nysted Offshore Wind Farm. PHOTO: NYSTED OFFSHORE WIND FARM

In scenarios that included an added mortality due to by-catch, 1.7 % of the individuals in the population were removed every year. ASCOBANS suggested that a by-catch rate of <1.7 % would ensure that the population could be maintained at ≥80 % of its carrying capacity. This by-catch rate would correspond to approximately 230 animals per year for the population in the Inner Danish Waters.

We evaluated the cumulative effects of disturbances and by-catch based on four different scenarios:

1. A reference scenario without anthropogenic effects
2. A scenario that included the existing turbines in the inner Danish waters
3. A scenario that included existing wind turbines and 1.7% by-catch annually
4. A scenario that included the existing wind farms and a realistic number of large ships, but no by-catch

Each animal in the model represented approximately 25 real female porpoises. We evaluated the population effects of different management actions using the population sizes recorded every year on 1 July over a period of 40 years. Five simulations were produced for each management scenario. As it took up to 10 years for the population dynamics to stabilize, we excluded the first 10 years of each simulation. The mean population size, which was the main result of the simulations, was an emergent property of the model, i.e. its value could not be predicted from the input parameters without using the model.

RESULTS:

SMALL EFFECTS OF DISTURBANCES

The population size fluctuated within each year and between years for all scenarios [Figure 4.10A]. The number of independent animals in the model always increased in the spring when lactating calves were weaned. This happened eight months after their birth, like in nature. The increasing population size resulted in reduced food availability and decreasing energy status for the porpoises. This, in turn, increased their probability of dying. During summer months the increased mortality was balanced by recruitment, but in the autumn the population size started decreasing. This had two causes: all calves had been weaned, so no new animals joined the population, and the decreasing water temperatures resulted in increasing energy expenditure and increased mortality.

In addition to the within-year fluctuations, the yearly population sizes varied over time. This apparently stochastic variation in population dynamics between years was the result of a complex interplay between local resource depletion and replenishment, combined with the simulated animals' ability to migrate to new geographical regions when they experienced decreasing energy levels. These factors were responsible for gradual and unpredictable changes in population size between years and between scenarios. This occurred even though disturbance intensities and the spatial distribution of the resources were kept constant.

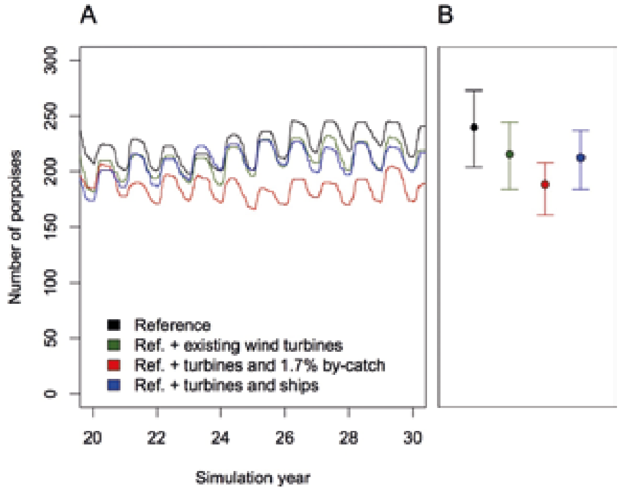


FIGURE 4.10 *Simulated effects of existing wind turbines (the Nysted and Rødsand II, Sprogø and Samsø wind farms), by-catch and ships on porpoise population dynamics: A: daily population sizes over a 10-y period, one simulation per scenario; B: mean and range of population sizes on 1 July over years 10–40 for five replicate simulations per scenario.*

REALISTIC MOVEMENT PATTERNS

In nature animals often move in ways that help them maximize food intake, either by moving at random among scattered food items or by actively moving towards areas where they know food to be present. In our model the way animals move affects their foraging efficiency, which in turn affects their energy levels and the dynamics of the population. It also determines how often they encounter wind turbines and ships, and when they are influenced by disturbances. We therefore tested that the movements of the simulated animals closely corresponded to those of real animals.

The foraging behaviour of the simulated animals emerges from two different mechanisms: By default they follow a correlated random walk, where turning angles and movement speeds are related to those in the previous half-hour step. This part of the model was parameterized based on tagging data, where a porpoise was equipped with a fine-scale data logger that recorded its 3D movements (dead-reckoning). Alternatively, the animals may use a spatial memory to navigate back to patches where they found food in the past. Their tendency to employ this movement mode increases when the random walk has not enabled them to find food for some time. The combination of these two mechanisms allows the model to produce emergent home ranges and fine-scale movements that closely resemble those observed for satellite-tracked animals. This enables the modelled animals to respond to disturbances in a realistic way.

CALIBRATION OF ENERGY USE

The two input parameters that we knew the least about were food distribution and the rate at which food replenished after being eaten by an animal. The maximum entropy model only provided an indirect estimate of the relative food availability in different parts of the landscape. The exact size and distribution of food patches and the number of prey items, and therefore also the amount of

Feeding harbour porpoises with great black-backed gull. PHOTO: ANDERS LIND-HANSEN

energy that porpoises could extract from the patches, was unknown. Instead we calibrated the animals' energy use to achieve an equilibrium population size of 200 animals. Here, energy use was measured on the same relative scale as food availability. The population size in the calibrated model fluctuated only little between years.

SMALL POPULATION EFFECTS OF WIND FARMS

According to the model, disturbances from large ships and established wind farms only had a minor impact on the porpoise population studied [Figure 4.10B]. The average summer population size was 10 % lower in the scenario that included wind farms than in the reference scenario. The population size did not decrease further when ships were also included in the simulations, whereas the inclusion of 1.7 % by-catch annually caused the population to decrease another 10 %.

IT MATTERS HOW FAST THE FOOD RECOVERS

The food replenishment rate had a large effect on population dynamics and on how strongly wind turbines and ships affected the population. In a previous study (Nabe-Nielsen et al. 2011), where food recovered slowly (after approximately 10 days), and where energy use and mortality were calibrated slightly differently, the animals rapidly depleted the food locally, causing them to disperse towards areas with high food levels. As all animals dispersed simultaneously, the food levels rapidly dropped in these high-quality areas as well, resulting in population collapse. Afterwards the population gradually recovered. In this environment the mean population sizes in the reference scenario and scenarios that included wind farms were indistinguishable, whereas ships caused the population size to decrease.

The reason why food recovery rates influence the relative impact of ships and wind turbines is related to the fine-scale foraging behaviour of the simulated porpoises. Animals acquire food by returning to previously visited food patches, if this allows them to find more food than they would by moving at random. When food recovers slowly, as in the earlier simulations by Nabe-Nielsen et al., the animals find only little food when returning to previously visited patches, which causes them to predominately move at random. Such random movements often result in decreasing energy levels, which causes the animals to disperse towards high-quality areas such as the Great Belt. In these areas they are exposed to high levels of noise from ships, which explains why ships have a stronger impact on the porpoise population when food replenishes slowly. The situation is different when food recovers more rapidly, like in this study. Here, porpoises often return to the same food patch repeatedly, as they keep finding food there. The porpoises that forage close to wind turbines also return to the same patch repeatedly, but as the turbines scare them they only return after having tried to find food elsewhere for a long time. This causes them to have relatively low energy levels and an increased risk of dying, which eventually results in a reduced population size.

DISCUSSION:

MULTIPLE FACTORS AFFECT THE POPULATION

The results illustrate the importance of considering the cumulative impact of different anthropogenic effects when managing the porpoise population. Neither ships, wind farms nor by-catch in commercial fisheries had any large effect on the simulated population when considered in isolation, but together they may result in large population declines.

When comparing the predicted impacts of by-catch, ships and wind farms on porpoise dynamics it should be remembered that the estimated effects of wind farms are worst-case scenarios. Wind farms are likely to have a smaller population effect because animals usually get less scared by turbines than assumed in our simulations and because their tendency to move away from turbines is likely to decrease faster than assumed. Porpoises may even become accustomed to the constant noise emitted

Nysted Offshore Wind Farm. PHOTO: NYSTED OFFSHORE WIND FARM from the turbines and spend more time in their vicinity than in other areas with unpredictable disturbances.

It should be noted that the effects of commercial gillnet fisheries might be more complex than revealed by our results. Our model assumes that the by-catch rate is independent of the animals' age, which may not be realistic. Data indicates that younger animals are more likely to be by-caught, which would reduce the population effects of by-catch, as these animals have a lower reproductive value than the adults.

Our model clearly demonstrates that food availability and the replenishment of local food resources can have large effects on porpoise population dynamics. Food may replenish more slowly than assumed in this study, causing wind turbines to have a smaller impact on the porpoise population than estimated here. The large impact of food availability on the porpoise population dynamics also suggests that the largest effect of commercial fisheries could be through their effects on the porpoises' prey rather than through their direct effects on mortality.

As the model is based on rather limited data for some of the key input parameters it is important to note, however, that the exact outcomes of the model need to be treated with caution. The model suggests that particularly the distribution and dynamics of the porpoises' prey and their exact behavioural response to noise may influence the simulations. More field data is therefore needed for these parameters in order to substantiate the outcome of the model.

Although the simulations in this study assumed that porpoises reacted very strongly to noise, which is clearly a worst-case scenario, wind turbines only had a minor effect on the population size. There was no indication that noise from existing wind turbines or ships could affect the long-term survival of the population.

Harbour porpoise with calf. PHOTO: ANDERS LIND-HANSEN

IAPEME VIEWPOINTS

DR. KLAUS LUCKE,
IMARES, WAGENINGEN UR, THE NETHERLANDS

The biggest challenge to study the effects of offshore wind turbines on harbour porpoises is currently the understanding of cumulative effects as well as the type and range of behavioural reactions induced by this activity. In short: How are animals going to react to the construction of a second wind farm in an area, and what are the effects on population levels? These aspects are highly complex, but they are the key to our understanding of noise-induced effects on harbour porpoises. We especially need a reliable way to predict the reaction of harbour porpoises to varying levels of noise (i.e. a dose-response function).

Every wind farm developer has to provide an environmental impact assessment; each covering different site-specific aspects. However, all these assessments are usually conducted on a relatively small temporal and spatial scale. In contrast, the construction of Horns Rev 1 and Nysted offshore wind farms was accompanied by a wide variety of environmental studies, providing important data for determining and understanding the basic effect of these wind farms on the marine environment. When Horns Rev 2 was commissioned, the Danish offshore wind industry was faced once more with the challenge of estimating the cumulative effects of two full-scale wind farms 14 kilometres apart. The studies presented in this book represent important contributions in this context. Here, for the first time, a study was collaboratively funded by sources from different countries. This is of special importance as only an international approach will provide the necessary means for studying and understanding the large-scale effects.

The acoustic studies of the presence of harbour porpoises at Horns Rev 2 by Brandt and colleagues might at first glance be surprising because of the duration and distance over which effects were demonstrated. However, the results still fit into the expected variance. It is clear that mitigation of noise-induced effects on the hearing of the animals is of primary importance if constructors are to continue to use pile driving for installing the turbine foundations. By investigating the acoustic properties and the effectiveness of acoustic deterrence devices, Brandt et al. also contributed considerably to this aspect with their study on potential mitigation methods.

Assessing behavioural effects on a population level (e.g. the PCAD model) is hampered by the complexity of biotic and abiotic interactions and will not easily provide generally applicable results. The individual-based model developed by Nabe-Nielsen and colleagues, on the other hand, provides a much more directly applicable tool for assessing the behavioural effects of wind turbines on harbour porpoises. It especially allows for differentiation between effects of wind turbines from the wide range of other anthropogenic activities at sea which might be equally or even more disturbing to the animals.

5

BIRDS
WIND FARMS AFFECT COMMON SCOTER AND RED-THROATED DIVER BEHAVIOUR

BY SIMON B. LEONHARD, JOHN PEDERSEN, PER N. GRØN, *(Orbicon)*, HENRIK SKOV *(DHI)*, JEROEN JANSEN *(Wageningen Imares)*, CHRIS TOPPING AND IB KRAG PETERSEN *(Aarhus University)*

The results from the monitoring programme up until 2006 suggested that the common scoter and the red-throated diver were avoiding the Horns Rev wind farm, leading to a potential loss of feeding area.

A habitat suitability model was developed for cut trough shells and razor clams to explore the influence of the food supply on the observed spatial and temporal variation in the occurrence of common scoters in the general area. The model provided useful information on the relationship between common scoters and their prey.

Aerial surveys conducted in 2007 found high common scoter densities within the Horns Rev 1 offshore wind farm, suggesting habituation to have occurred. Changes in food supply might also have influenced this result. The model developed to assess cumulative effects of multiple wind farms on the red-throated diver population, suggested there would be very small impacts of the three wind farm development scenarios considered for Danish waters and the Baltic Sea.

SUMMARY 2006

Hazards presented to birds by the construction of the Horns Rev and Nysted wind farms include barriers to movement, habitat loss and collision risks. Radar, infra-red video monitoring and visual observations confirmed that most of the more numerous species showed avoidance responses to both wind farms. Slightly extended migration distances are unlikely to have consequences for any species. Neither site lies close enough to nesting areas to affect reproduction. Post-construction studies showed almost complete absence of red-throated divers and common scoters within the Horns Rev Offshore Wind Farm, and significant reductions in long-tailed duck densities within the Nysted offshore Wind Farm. Of the 235,000 common eiders passing Nysted each autumn, collision modelling and monitoring show that only a very small proportion were likely to collide. Whilst the effects found are unlikely to have major consequences on the overall populations involved, assessing the cumulative effects of these and other developments remains a future challenge.

Ensis sample. PHOTO: JENS CHRISTENSEN

CHAPTER INTRODUCTION:

ARE COMMON SCOTERS AND RED-THROATED DIVERS ADAPTING TO OFFSHORE WIND FARMS?

Seabirds tend to avoid offshore wind farms, and a consequence of this reluctance is that otherwise suitable food resources are made inaccessible to the birds, a phenomenon known as displacement. The follow-up programme focused on improving the understanding of displacement effects for the common scoter *(Melanitta nigra)* and the red-throated diver *(Gavia stellata)*, both having been found, during the 2000-2006 demonstration programme, to be largely absent from inside the Horns Rev wind farm area after construction of the farm.

For common scoters, two studies were conducted, one aiming to improve the understanding of the influence of availability and changes in food supply on the observed numbers and distribution patterns of common scoters, and another documenting the distribution of common scoters in the general area in 2007. Although, the results from the demonstration programme showed avoidance response, common scoters apparently changed distribution pattern during the period, and increasing numbers were found inside the wind farm.

For red-throated divers, a study was conducted with the objective of building a model to address the cumulative impacts of displacement on the overall population, looking at different scenarios for large-scale wind-farm development in Danish and Baltic waters.

PART 1

NEW FOOD RESOURCES FOR COMMON SCOTERS

SIMON B. LEONHARD (ORBICON), HENRIK SKOV (DHI), JOHN PEDERSEN (ORBICON), JEROEN JANSEN (WAGENINGEN IMARES) AND PER N. GRØN (ORBICON)

The southern part of the Danish North Sea, including the Horns Rev area, constitutes major staging and wintering grounds for large numbers of waterbirds. The single most numerous species using the area during winter is the common scoter, with more than 100,000 individuals regularly observed.

Common scoters are diving ducks that mainly feed on clams buried in the upper few centimetres of the seabed sediments. Like other diving ducks, common scoters tend to congregate in large flocks. This means that during the non-breeding period they can have a considerable local impact on populations of certain prey types. Conversely the abundance and accessibility of prey influence the local distribution and abundance of the common scoters.

Although bird displacement represents effective habitat loss, it is important to assess the relative loss in terms of the proportion of potential feeding habitats affected relative to the areas outside of the wind farm. For the common scoters, that proportion is relatively small and therefore likely to be of little biological consequence. However, the additional costs of more wind farms placed within same local area may constitute a more significant effect. However, the changes found in the distribution of common scoters may be a result of reasons other than the presence of the turbines. One reason could be changes in food supply or prey preferences rather than changes in the behaviour of the birds themselves. Changes in distribution and presence of the two preferred prey species in the Horns Rev area, the cut trough shell *(Spisula subtruncata)* and the American razor clam *(Ensis directus)*, are thought to affect the distribution patterns of common scoters. Improved knowledge of the

The American razor clam, an important food item for the common scoter at Horns Rev. PHOTO: MAKS KLAUSTRUP

Common scoter. PHOTO: THOMAS W. JOHANSEN/DONG ENERGY distribution of the available food resources therefore will be of great importance for future assessments of displacements of common scoters due to wind farm development.

METHODS:

MODELLING PREDICTS SUITABLE ENVIRONMENTS OF PREY SPECIES

To analyse the distribution of razor clams and trough shells, data on sediment and benthos were sampled from 2001 to 2010 [Figure 5.1]. These data were used in the development and calibration of a model describing the best suitable environments or habitat for clams exploited by foraging common scoters in their overwintering area at Horns Rev.

The design of the dynamic model was based on four elements, including a regional and local three-dimensional hydrodynamic model, an ecological model, a deterministic filter-feeding model and a habitat-suitability model.

The modelled habitat-suitability data were validated against independent data on the distribution of the two

PARAMETERS INCLUDED IN THE MODELS:

- Hydrodynamic model: water levels, currents, salinity and temperature.
- Ecological model: nutrients, carbon, phytoplankton, zooplankton, production and mineralisation.
- Filter-feeding model: energy balance, growth rate and concentration of food for clams.
- Habitat-suitability model: biomass and abundance of clams, sediment characteristics.

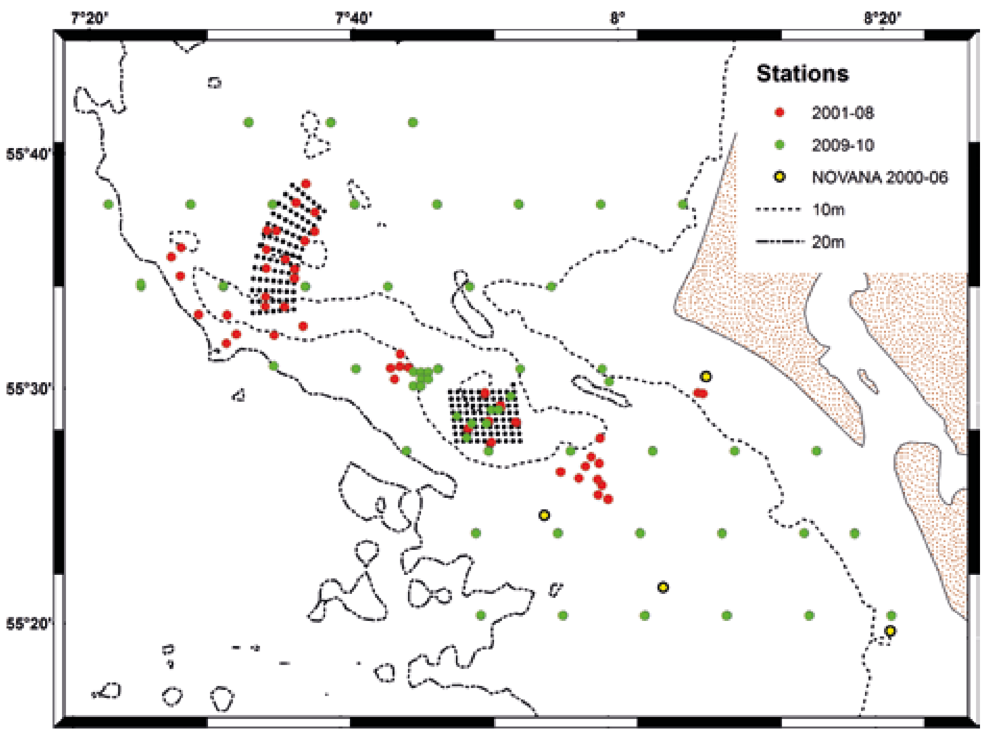


FIGURE 5.1 *Sampling locations for sediment and benthos during campaigns in 2001-2008 and in 2009-2010. Additional samples of clams from the national environmental monitoring scheme (NOVANA) used in the model are also indicated.*

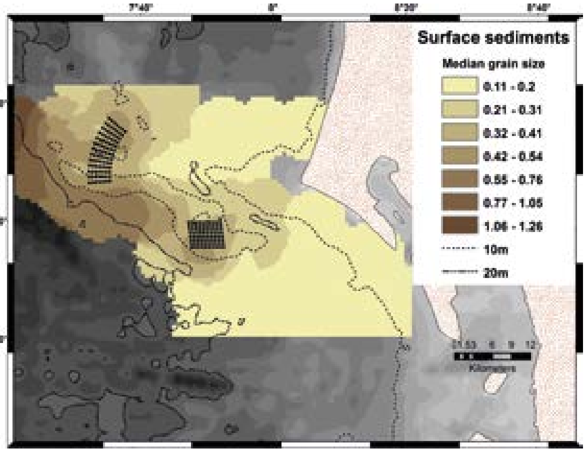


FIGURE 5.2 *Modelled grain size distribution in the surface sediment in the Horns Rev area. Coarser sediments are dominant more seaward on the slopes of Horns Rev.*

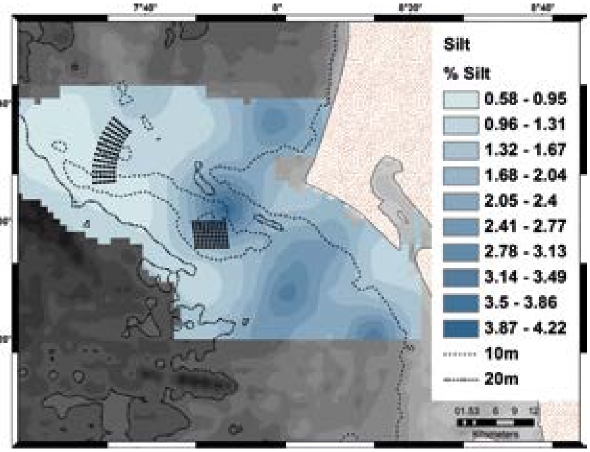


FIGURE 5.3 *Modelled distribution of the silt fraction in the surface sediment in the Horns Rev area. Finer sediments are dominant in the deeper parts and in the more landward areas of Horns Rev.*

clams from 2005-2006, and compared with data on the actual distribution patterns of common scoters in the Horns Rev area from 2000 and 2006.

RESULTS:
COMMON SCOTERS ADAPT TO NEW FOOD RESOURCES

Heavy winds, waves and strong currents often dominate the rough environment in the Horns Rev area. These conditions have a huge influence on the sediment structure and the distribution of prey items, and consequently also, indirectly, on the distribution of foraging common scoters.

HORNS REV – A HUGE ACCUMULATION OF SAND

Horns Rev is a huge accumulation of sand deposits up to 20 m in thickness. New sand is constantly accumulating, transported by currents along the coast of Jutland. Each year more than 500,000 m³ of sand is added to Horns Rev.

The seabed consists of almost pure medium-fine sand with no or very low organic content and a low fraction of fine particles. [Figure 5.2], [Figure 5.3]. In the rough conditions the seabed is constantly changing and the dunes and ripples in the seabed formed by tidal currents and waves are evidence of the significant sand transport in both northerly and the prevailing southerly directions.

The fine sand fraction is more frequently distributed along the coast north and south of Blåvandshuk, whereas the sediment is coarser around Blåvandshuk and offshore, especially in the south-western part of the reef area. There seems to be no distinct distribution patterns according to depth regimes.

Cut trough shells mainly feed by filtering the water for plankton.
PHOTO: SIMON B. LEONHARD

Common scoter (Melanitta nigra). PHOTO: SIMON B. LEONHARD

COMMON SCOTERS FEED ON CLAMS

The common scoters are not considered specialists in their choice of prey but, within their foraging depth regimes, they feed on any locally abundant prey that is accessible in an ingestible size. The bird mainly forages at water depths of less than 10 m, but is capable of diving up to 20 m. Diving at greater depths requires more energy, but besides this, the local distribution and abundance of common scoters are determined by a complex combination of more factors, including visibility, foraging techniques, prey detection, individual prey preferences and the energy content of prey.

Dietary studies from Horns Rev show that common scoters mainly feed on clams, but digestibility of the prey species varies greatly, due to high variability in shell size, shape and thickness between the different species and age classes of clams. Within the depth regime for foraging common scoters, various clams, thought to be suitable as prey species, were found [Table 5.1].

Larger and older clams are often buried deeper in the seabed, they have thicker shells and their accessibility and digestibility for foraging common scoters is therefore considerably lower than for younger clams. Common scoters can eat clams with shell lengths of between 5 and 40 mm, but even longer elongated clams, like the razor clams, have reportedly been eaten of up to 90 mm in length. All of the most common clam species, including the razor clam and the cut trough shell, found in the area were represented in ingestible size classes [Figure 5.4].

From our dietary studies, the preferred prey species for common scoters foraging in the Horns Rev area seem to be the American razor clam and the cut trough shell

[Table 5.2]. Common scoters have also been reported feeding on smaller tellinids, among these the bean-like tellin which were also abundant in the reef area, and on the common mussel which has become very abundant on turbine foundations in the wind farms. However, so far neither of these species seems of importance to the common scoters in the Horns Rev area.

AMERICAN RAZOR CLAM – A NEW PREY SPECIES

The American razor clam was first recorded along the Danish west coast in the early 1980s. It has since rapidly colonized exposed coastal sandy seabeds, like those found in the Esperance Bight and offshore sand banks like Horns Rev. Huge numbers of shells of this invasive species can now be seen washed ashore on the beaches along the North Sea coast. The rapid colonization seems to be a

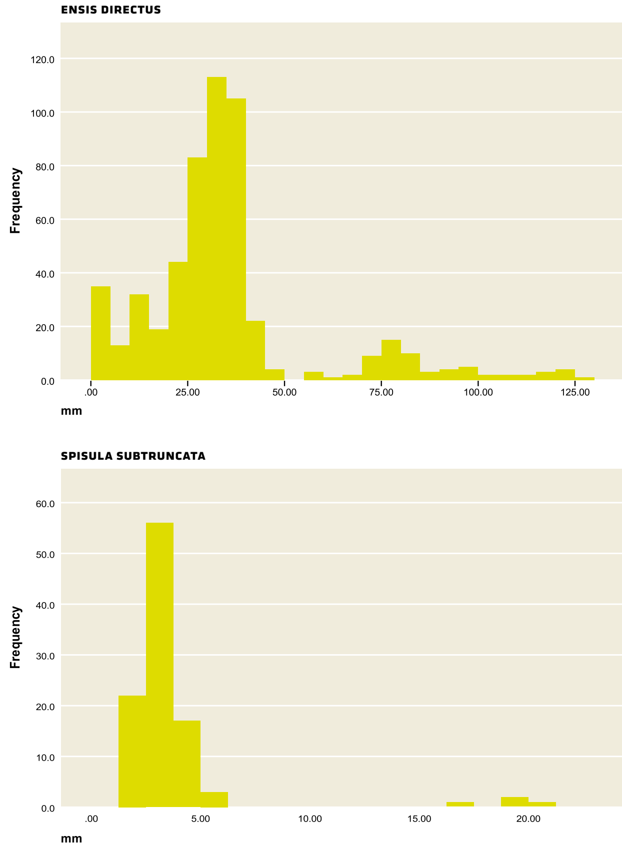


FIGURE 5.4 *Shell length size frequency distribution of the American razor clam and the cut trough shell at Horns Rev.*

PREY TYPE	SCIENTIFIC NAME	COMMON NAME	ABUNDANCE		BIOMASS	
			no./m²	Kol Sum %	g/m²	Kol Sum %
Elongate prey	*Ensis directus*	American razor clam	89	48,6%	20,5	71,5%
Ovate brittle shelled	*Tellina fabula*	Bean-like tellin	5	3,0%	0,2	0,7%
Ovate hard shelled	*Nucula nitidosa*		42	22,7%	1,5	5,2%
	Spisula solida	Thick trough shell	25	13,8%	1,8	6,3%
	Spisula subtruncata	Cut trough shell	11	6,1%	0,4	1,5%

TABLE 5.1 *The most common clam prey species in the Horns Rev area autumn 2010.*

FOOD ITEM	N	FREQUENCY OF OCCURRENCE
Ensis directus	47	29
Spisula subtruncata	10	3
Hediste diversicolor *	6	4

TABLE 5.2 *Stomach content of 29 common scoters from Horns Rev. *Hediste diversicolor is a bristle worm living in shallow waters close to shore. N is total number of prey found.*

Shells of razor clams washed ashore at Blåvandshuk © Per N. Grøn/DONG Energy

result of plentiful and suitable habitats, occupied by very few natural or indigenous species, and lack of natural predators. However, the preference for American razor clams by common scoters seems to be of even more recent origin, and this has also been recorded from other coastal areas of the North Sea. Prior to the introduction of the American razor clam, the cut trough shell was the main food source for wintering common scoters in coastal areas off the Dutch coast and off the western coast of Denmark. However, since 2004 the cut trough shell has suffered from reproductive failure and the presence of this clam has declined in the coastal areas of the southern North Sea.

The American razor clam spawns in spring, and in the autumn the length of the youngest group reaches 30-60 mm. In the Horns Rev area, when feeding on razor clams, common scoters primarily eat young clams no older than two years and less than 100 mm in length. These young clams are only buried in the uppermost 10 cm of the sediment and therefore accessible for foraging common scoters. The razor clams are buried in a vertical position in substrate, and although the razor clams may be accessible, they can avoid enemies such as the foraging diving ducks by retracting extremely fast into the sediment using their powerful foot.

DIFFERENT HABITAT PREFERENCES FOR PREY SPECIES

The habitat suitability models predicted the potential occurrence of cut trough shell and razor clams at Horns Rev.

The distribution of the two prey communities of razor clams and cut trough shell are distinctly separated in the Horns Rev area. The distribution is determined

Common scoter is one of the numerically important birds at Horns Rev PHOTO: DANIEL BERGMANN

by the sedimentary habitats, which in turn are strongly affected by currents near the seabed. The supply of food for the benthic clams and their feeding is affected by the near-seabed current. Furthermore an increasing level of wave erosion or frequent re-deposition of sediments affects mortality and distribution of the clams.

The models showed that the habitats of the two clam species are quite distinct, and they only overlap slightly [Figure 5.5 and Figure 5.6]. The main area over the reef is unsuitable for cut trough shells, due to the sediment of medium to coarse sand and steep slopes; an environment in which seabed turn-over frequently occurs due to strong currents and waves. Instead the community of cut trough shells prefers the flat areas of fine sediments found in the offshore areas of Esperance Bight and at Cancer [Figure 5.5].

The community of razor clams, on the other hand, prefers the medium-sized sediments and slopes above the reef and to the northwest of the reef [Figure 5.6]. The clams are able to survive the frequent re-deposition of seabed sediment in these areas due to their deep penetration into the sediment. The occurrence of the American razor clam was higher in the central and north-western part of the reef area compared to the southern and eastern part. This is mainly due to the geo-morphology and the rich food supply. The area of high habitat suitability for razor clams included the western part of the Horns Rev 1 wind farm site and most of the Horns Rev 2 site. Generally, in offshore areas of the North Sea deeper than 15 m, the occurrence of razor clams drops sharply in response to low supply of phytoplankton at the seabed.

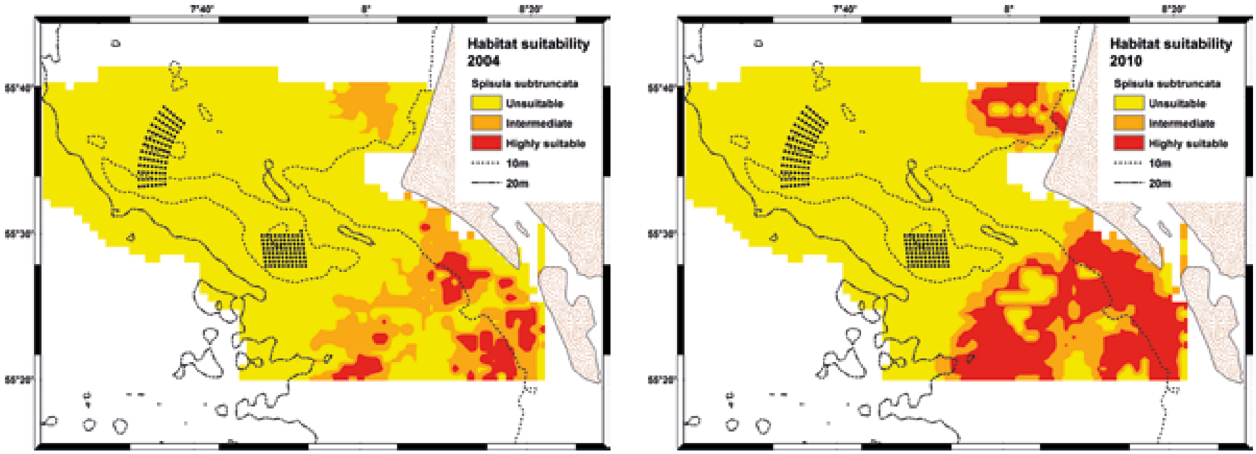


FIGURE 5.5 *Modelled habitat suitability for cut trough shell on Horns Rev in 2004 and 2010.*

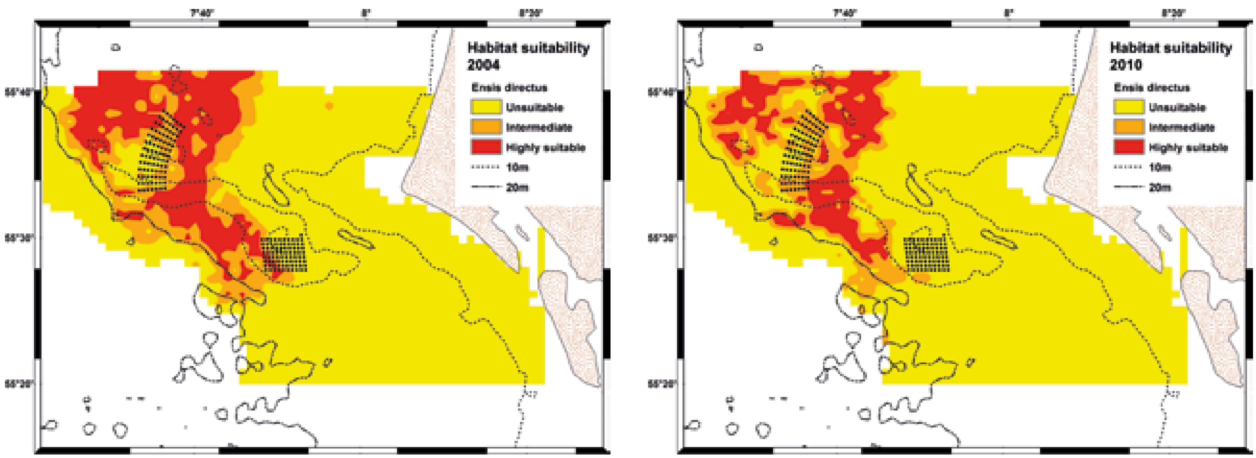


FIGURE 5.6 *Modelled habitat suitability for American razor clams on Horns Rev in 2004 and 2010.*

HIGH OVERLAP BETWEEN PREDICTED FOOD AND COMMON SCOTER DISTRIBUTION

The actual observed distribution pattern of common scoters in areas where they are capable to dive for food, shows a high overlap with the predicted areas of high suitability of their preferred prey species [Figure 5.7].

The eastern and shallower part of the area, marking the preferred habitat for trough shells, has historically been the area where the largest concentrations of common scoters have been observed. Common scoter distribution in the region has been surveyed during nation-wide waterbird survey campaigns and during international waterbird projects. The latest of these monitoring programmes was carried out during the offshore wind farm development in the Horns Rev area. During the previous surveys ranging from 1969 to 1994, the largest flocks of common scoters were always located along the coast in the Esperance Bight, at Fanø or at Cancer.

The dramatic shift in distribution patterns of common scoters observed during the 1999-2006 surveys, and especially since 2004, is likely to be a result of changes in the abundance of prey species. In 2000 larger areas of the Esperance Bight and close to the coast to Blåvandshuk were found to be highly suitable for cut trough shells [Figure 5.5], and common scoters were abundant. No common scoters were found further offshore in the reef area, where low suitability for cut trough shells was predicted. At that time razor clams were already present in the reef area, but the resource of cut trough shells along the coast seems to have been sufficient to feed the overwintering population of common scoters. Or perhaps the common scoters might not yet have become accustomed to feeding on this new prey type. However, large numbers of common scoters have been observed in the offshore areas of the reef since 2004 in areas of high modelled habitat suitability for American razor clams [Figure 5.6].

In 2005/2006, the common scoters were less numerous at the reef in autumn compared to winter and spring. This was in spite of the fact that autumn offers numerous and easy accessible small razor clams in the reef area. It is likely that the redistribution of common scoters in the reef area from autumn to spring reflects changes in prey preferences following the changes in the accessibility of species, the distance to shore and the required effort of foraging. In the beginning of the winter, when the common scoters arrive to the overwintering area, it is most likely that the common scoters prefer to feed on the cut trough shells. When food availability can become scarce as a result of the birds' own predation later in the winter, they move further offshore to feed on the razor clams. The exploitation of the razor clam resources later in the overwintering season may also be a result of the higher energy cost for the common scoters, diving at greater depths and in more exposed areas at the reef, compared to the shallower waters and more sheltered areas close to the coast.

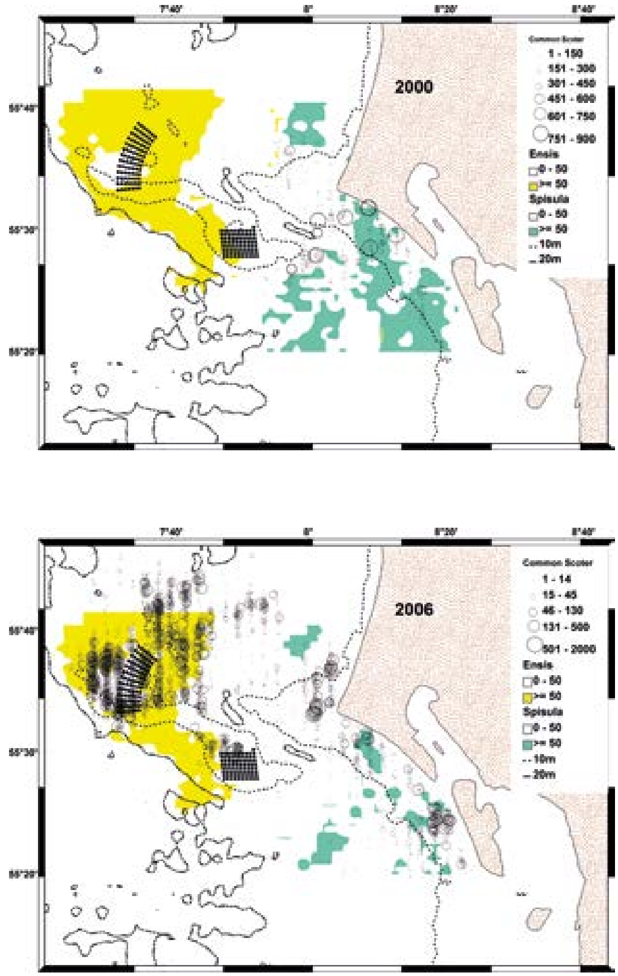


FIGURE 5.7 *Modelled high suitability areas for preferred prey species (yellow: razor clams, blue: trough shells) compared to the actual observed distribution (circles) of the common scoters in 2000 and 2006.*

In the Horns Rev area, it has not been documented whether the change in the distribution patterns of the common scoters is related to a general decline in the availability and biomass of the trough shells. The trough shells have shown a general decline in population size in Danish waters since 2004, as seen in other coastal parts

Common scoters and velvet scoters at Horns Rev Offshore Wind Farm PHOTO: © JENS CHRISTENSEN/DONG ENERGY

of the North Sea. However, there is clear evidence that the new and invasive American razor clam, which has effectively adapted to the environmental conditions in coastal areas of the North Sea, now plays a significant and important role as a supplementary food source for the common scoters in the area.

HABITAT SUITABILITY MODELS PROVIDE NEW OPPORTUNITIES

The habitat suitability models for cut trough shells and razor clams have provided a means for extrapolating the results of the biological sampling carried out in relation to the two wind farms on Horns Rev and the whole area around Horns Rev. The models also make it possible to make estimates for the whole period of the baseline and post-construction investigations (2000-2010).

The habitat suitability models have proved useful in the description of the distribution patterns of the prey of common scoters, and the models can serve as a useful predictive tool in the planning process for development of future offshore wind farms in order to minimise cumulative impacts.

Specifically, the models may be useful for:

- Improving predictions of likely changes in common scoter distribution arising from natural dynamic changes in the marine environment;

- Evaluating more accurately the potential loss of habitat, should common scoters be displaced from offshore wind farms due to disturbance.
- Assessing the potential impact of cumulative habitat loss for common scoters arising from displacement from wind farms;
- Avoiding conflicts in future offshore wind energy schemes associated with important areas for common scoters.

DISCUSSION:

MODELS CAN BE IMPROVED WHEN NEW DATA BECOME AVAILABLE

Benthic habitats are not stable, and weather conditions at Horns Rev only allow small windows for sampling of species and habitats. Therefore interpretation and generalization of results from the benthic surveys has to be cautious. This is not least the case in relation to describing the variation of the food sources for the large number of common scoters in the area. However, the models have provided valuable information on the distribution of food supply for the common scoters. In addition, knowledge on the major habitat factors for these clam species has been gained.

The model application was founded on a process-based approach that integrates ecosystem models and statistical models, and it can be further developed and updated as future field data become available.

Foraging common scoters at Horns Rev PHOTO: © THOMAS W. JOHANSEN

COMMON SCOTERS UTILIZED THE HORNS REV 1 OFFSHORE WIND FARM AREA

IB KRAG PETERSEN (AARHUS UNIVERSITY)

Ornithological investigations of waterbird numbers and distribution in the study area around the Horns Rev 1 wind farm began in 1999. As part of the demonstration programme on the environmental impact of offshore wind farms, a total of 34 surveys of bird distributions were conducted in the period from 1999 until 2005. In late 2005 and early 2006 six additional surveys were conducted in relation to the Horns Rev 2 EIA (Environmental Impact Assessment) process.

Results from the demonstration programme concluded that the distribution of red-throated/black-throated divers and common scoter were adversely affected by the presence of the wind turbines at Horns Rev.

INCREASING NUMBERS OF COMMON SCOTERS

However in late 2006 and early 2007 Vattenfall A/S maintenance crews and helicopter pilots reported increasing numbers of common scoters present within the wind farm site. On that background a series of four surveys of waterbird distribution in the area was scheduled during January to April 2007.

During three out of four surveys in 2007 more common scoters than during any previous surveys were recorded within the foot print of the wind farm. On 25 January 2,112 birds, on 15 February 4,624 birds, on 3 March 1,359 and on 1 April 35 common scoters were encountered in the wind farm area.

Analyses of common scoter encounter rates in six 2x2 km grid cells within the wind farm area compared to encounter rates in 14 2x2 km grid cells in the periphery of the wind farm site showed no significant difference from the three earlier surveys, while significantly lower encounter rates within the wind farm during a survey on 1 April [Figure 5.8] were recorded. Based on the summed data set from 2007 there was no significant difference between encounter rates in the wind farm site and the periphery.

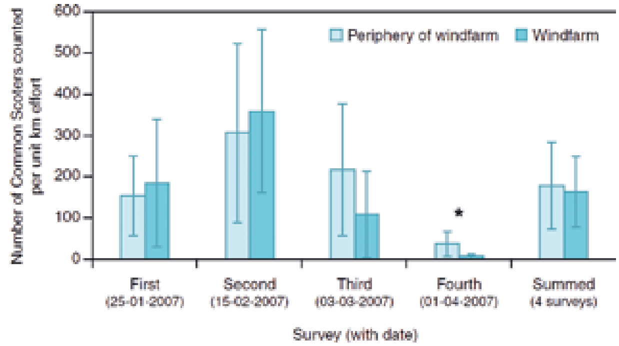


FIGURE 5.8 *Mean encounter rates of common scoters within six 2 km x 2 km grid squares covering the Horns Rev wind farm (open histogram columns + 95% confidence intervals) and in the 14 2 km x 2km grid squares immediately surrounding these 6 grid squares (shaded histogram columns). Student t-tests corrected the unequal variance of the first three surveys. In the fourth survey a significantly lower encounter rate in the wind farm was recorded. For the summed data set (4 surveys) there was no significant difference.*

We therefore conclude that common scoter may indeed occur in high densities between wind turbines at sea, but this is only likely a number of years after construction. A relationship between benthos availability and the distribution of common scoters in the area was demonstrated (see part 1 of this chapter). Thus, we cannot exclude the explanation that this reflects changes in food supply rather than a change in the behaviour of the birds themselves.

ASSESSING CUMULATIVE EFFECTS ON BIRD POPULATIONS

CHRIS TOPPING AND IB KRAG PETERSEN (AARHUS UNIVERSITY)

Red-throated divers are long-lived birds with a high annual survival rate and a low annual reproduction rate. They appear in Danish waters during autumn, winter and spring and are strictly marine birds, except during the breeding season. The species is listed in annex 1 of the EU Birds Directive and therefore the species needs attention in the Environmental Impact Assessments when planning for establishment of offshore wind farms in Denmark and other EU countries. Experience from Denmark and the United Kingdom indicates that red-throated divers are displaced from wind farm areas and their near surroundings.

The aim of the present study was to evaluate to which extent such displacements could potentially impact the species at the population or subpopulation level. For that purpose a model was designed to evaluate the impact of marine wind farms on red-throated divers migrating through or overwintering in inner Danish waters. The study was performed for three scenarios of offshore wind farm development; one reflecting the present status of the study area and two future scenarios with medium or high development rate respectively.

The model simulated the movement of red-throated divers to and from breeding locations and used a function of density and environmental conditions to determine their energy balance.

METHOD

DENSITY ESTIMATES, CALIBRATION AND BATHYMETRIC DATA

The study area was divided into 500x500 m cells in a rectangular grid. This resulted in more than 1 million grid cells, of which less than 50% are in marine areas. The rectangular model area covers the entire Baltic Sea and eastern North Sea.

Our knowledge of the birds' temporal and spatial distribution patterns during winter is poor. A description of general distribution patterns in Danish waters was modelled from survey data for the winter of 2008, but the quality of the spatial model for red-throated divers prevented the use of this data for this purpose. In earlier surveys, surface covering density model estimates are available from four smaller areas in the Danish waters. The areas were surveyed frequently from 1999 up until 2007. These surveys were all performed as part of the EIA (Environmental Impact Assessment) or environmental monitoring programmes relating to offshore wind farm projects. The four areas are Horns Rev, Aalborg Bugt, Omø Staalgrunde and Rødsand. Data on spatio-temporal distribution of wintering/migrating red-throated diver

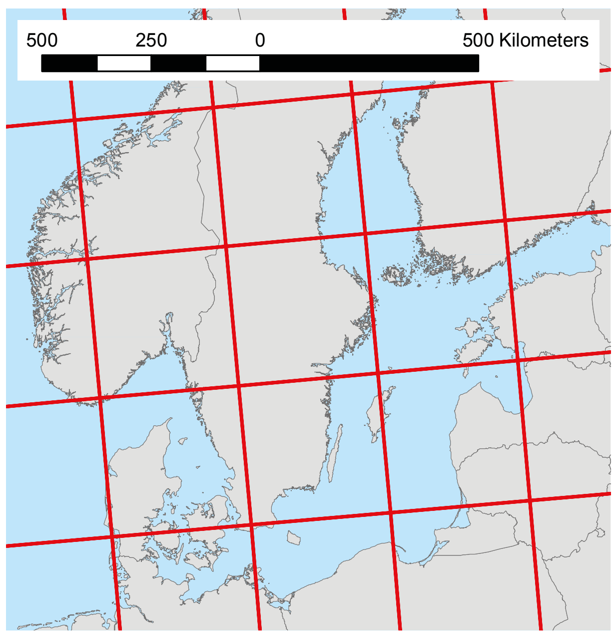


FIGURE 5.9 *The model landscape was based on a rectangular area that covers the entire Baltic Sea and eastern North Sea.*

from these areas were used to calibrate the model.

In addition migration timing was used for the calibration, extracting data from the Danish Ornithological Society's database (www.dofbasen.dk), from the Swedish Environmental Protections Agency's database on species (http://www.artportalen.se) and from a migration observation point in northwest Estonia.

For all marine grid cells a bathymetric depth was extracted using a bathymetric data set from the BALANCE project (http://www.balance-eu.org/). Likewise a distance to nearest coast was calculated. Modelled hydrographical data were obtained from the MyOcean platform (http://www.myocean.eu.org/). Sea surface temperature data were extracted for all marine grid cells every six days throughout 2008.

The locations of the offshore wind farms (see figs. 4, 5 and 6) in the scenarios were provided by the Danish Energy Agency.

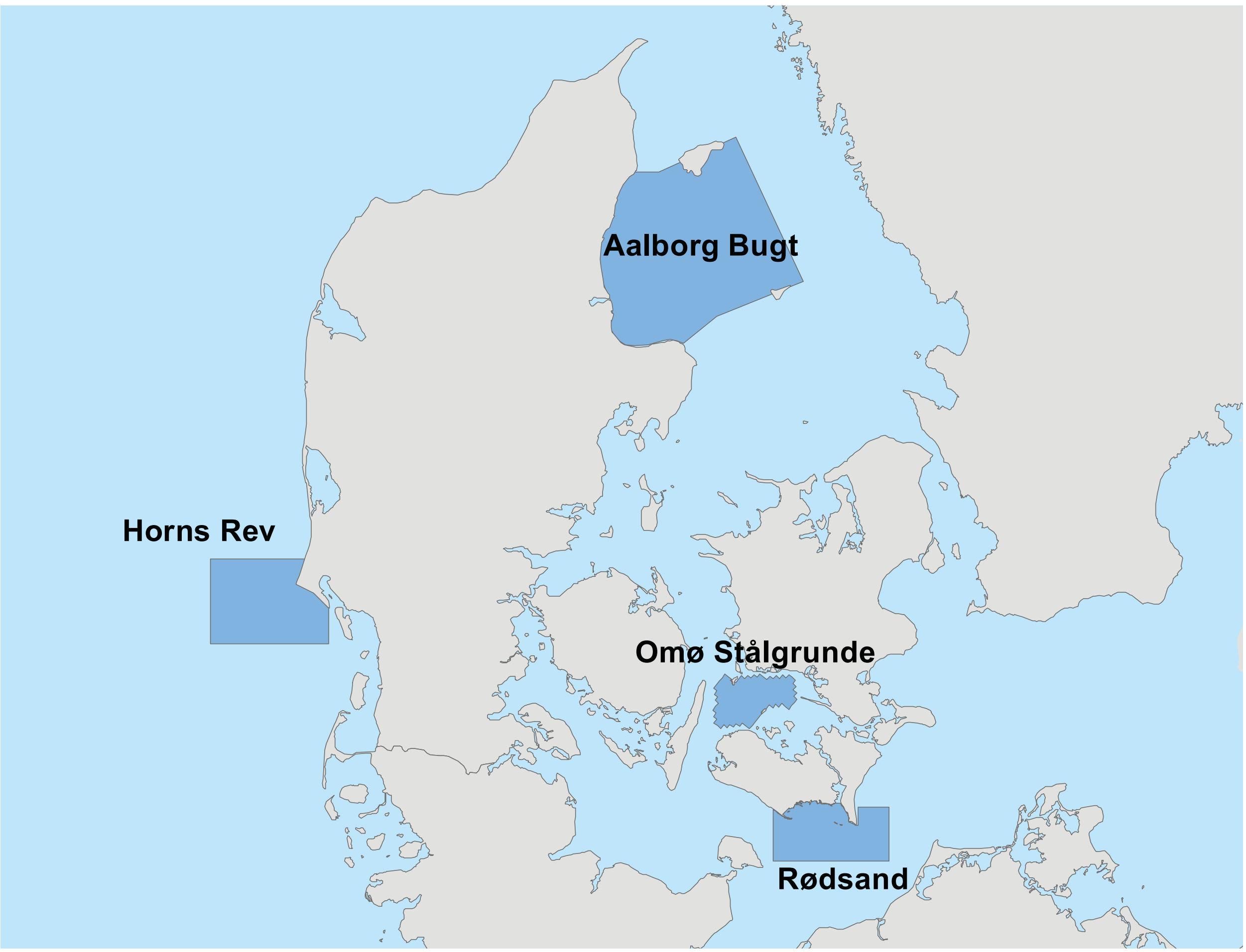


FIGURE 5.10 *The four areas where surveys were conducted. Horns Rev, Aalborg Bugt, Omø Staalgrunde and Rødsand*

MODEL APPROACH – THE STRENGTHS OF THE AGENT-BASED MODEL

We designed an agent-based model (ABM) specifically for this project. An ABM is a computer model for simulating the actions and interactions of autonomous individuals in a defined virtual world, with a view to assessing their effects on the system as a whole.

Agent-based models (ABMs) are gaining popularity in most scientific fields due to their ability to describe complex systems from first principles. Yet, they are also criticized for being 'black boxes' and impossible to fully understand. This is mainly due to the difficulty of testing, documenting and communicating the wealth of mechanisms built into such models. However, testing these complex adaptive models has been aided by recent advances in pattern-oriented modelling (POM), which is becoming a widely used framework. POM evaluates model behaviour and reduces parameter uncertainty by comparing model responses to real-world data at multiple hierarchical levels. The greater the number of real-world patterns the model can predict simultaneously, the greater the confidence in the model.

In developing the red-throated diver ABM we have used pattern-oriented modelling. This is an iterative process preceding a sensitivity analysis, and this part is not further addressed here.

To be reliable, the model should be able to simulate migration, matching the patterns of birds found in the inner Danish waters by aerial counts. Verifying this was not a simple task since there is much information that is not known. For instance, these birds are migratory and some spend the winter in this area, but not all do, and neither this proportion nor the total bird population is known. Additionally, we know little about the details of migration for these birds. We primarily only have counts of stationary birds and observations of day migrations. Hence, there is no data currently available on migration routes, proportions of birds crossing landmasses, nor details of night migration. Another constraint is that we cannot measure direct impacts in the field, only avoidance. As a result, impacts will be assessed as relative cumulative effects of disturbance to the migration route.

Red-throated diver (Gavia stellata). PHOTO: MARK MALLORY

MODEL DESCRIPTION & POM DEVELOPMENT

Initially it was hypothesized that water temperature and prey (fish) availability might be the drivers for movement of the birds; moving away from poor weather in winter, and pressing against a colder climate gradient in summer. Unfortunately there is too little data on important factors such as fish availability to be able to predict this with any degree of certainty; hence this driver could not be used. The major processes in action in Version I of the model were:

1. The date of starting migration from both winter and summer quarters.
2. Location suitability assessment using water temperature and water depth as quality determinants.
3. A density-dependent factor that decreases location suitability with increasing bird density
4. A direction of preferred movement (summer or winter migration).

Red-throated diver with remains of breeding plumage. PHOTO: WWW.GRAYIMAGES.CO.UK

The next major model version (Version II), used depth and temperature as well but added a migratory-urge driven movement. Hence the major difference between these two versions was:

- The rate of movement was altered depending on the distance to goal relative to the time left before the goal should be reached. So, birds with a long way to their goal but a short time would move faster.

Version II provided a good temporal fit, but did not capture the spatial details of observed bird distributions. Major deviations were found in the number of birds present in Danish waters during winter, and also in the movement pattern of birds to and from the breeding ground. This pattern was more diffuse than migratory bird observations would suggest.

The selected version (Version III) of the model incorporated breeding ground location as a parameter. This allowed differentiation in timing of migration movements and also in location of over-wintering grounds. Version III differed from Version II in the following:

1. Each bird was given a specific breeding region. Each region was assigned on the basis of input files describing the locations and proportion of population assumed to breed there.
2. Subsequently the location of breeding area determined the timing of breeding migration. The further from the over-wintering grounds the breeding location was, the later migration would start towards them.
3. Given the rules specified for Version II above, this combination resulted in a system of migration typified by long flights late in the season for long-distance migrating birds, and early short distance movement for birds with less distant breeding locations.

Tests of the model acknowledged it as structurally capable and able to re-create the diver patterns observed in the real world. Therefore it was selected for further testing.

At the beginning of each simulation, the Baltic population of red-throated diver was set to be 10,000 birds. This must be regarded as an arbitrary population size. The estimated population size of red-throated diver in

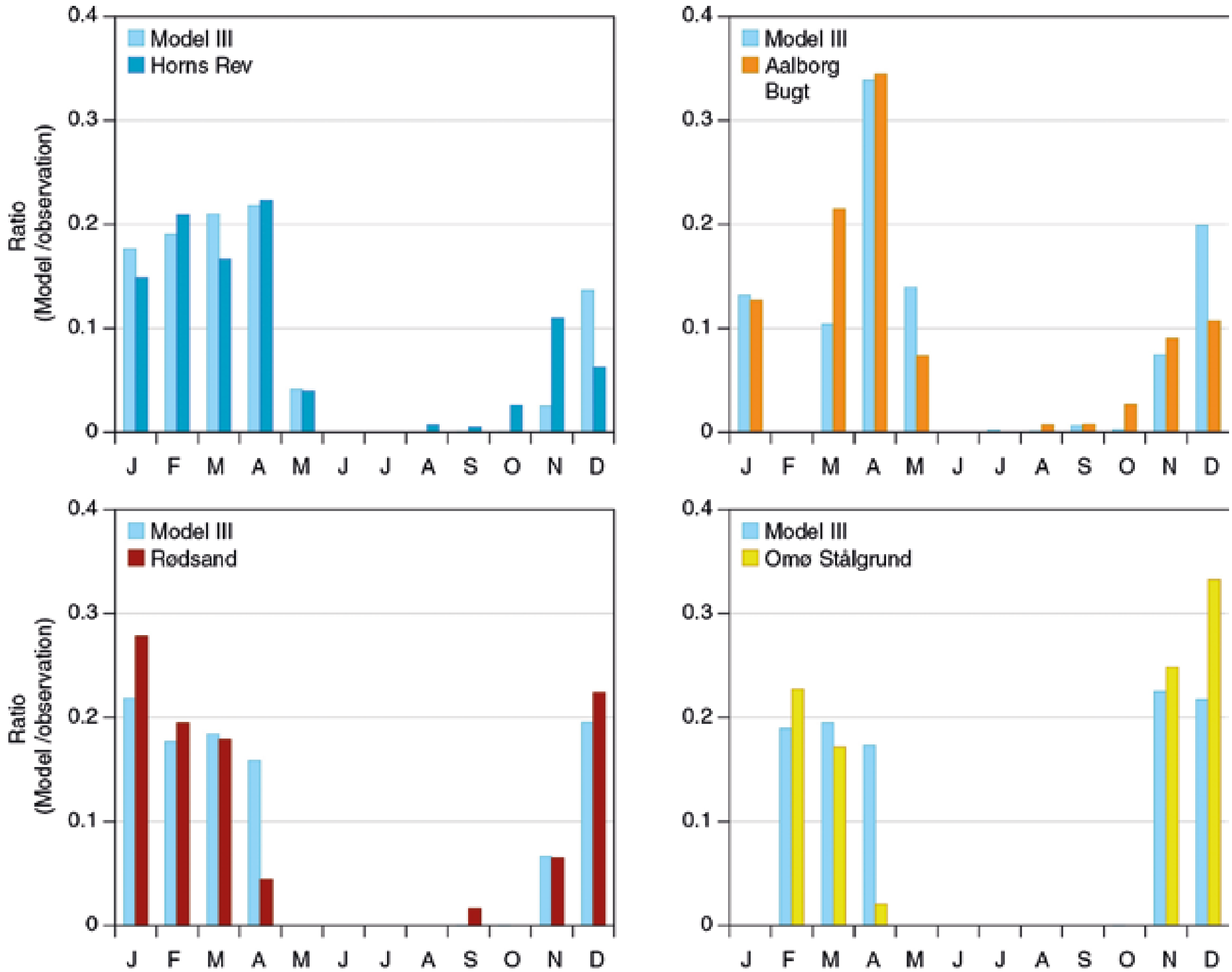


FIGURE 5.11 *Fit of modelled diver numbers with observed numbers at four sites by Hill climbing fitting of model version III. The columns show the ratio between modelled and observed Diver densities by month and sub-area.*

Western Palaearctic is 150,000-450,000. The size of the Baltic part of that population is unknown, but is expected to be considerably higher than 10,000 individuals.

Pattern Oriented Modelling (POM) testing was carried out by comparing the deviation from observed bird counts in space and time to those created by the model. All versions of the model were subjected to calibration in an attempt to find an acceptable fit to the observed diver spatio-temporal distributions.

Version III testing indicated an excellent fit to the observed data and was subjected to an initial hill climbing (step by step) fitting process. Stationary counts were considered to be of greater significance than migration observations, and hence, migration observations were only used as a secondary guide to fitting. The results of the fitting were a very close fit to the stationary bird counts, and an acceptable fit to migration observations.

This fitting process resulted in two interesting observa-

FIGURE 5.12 *The distribution of offshore wind farms used in the Scenario 1 model run.*

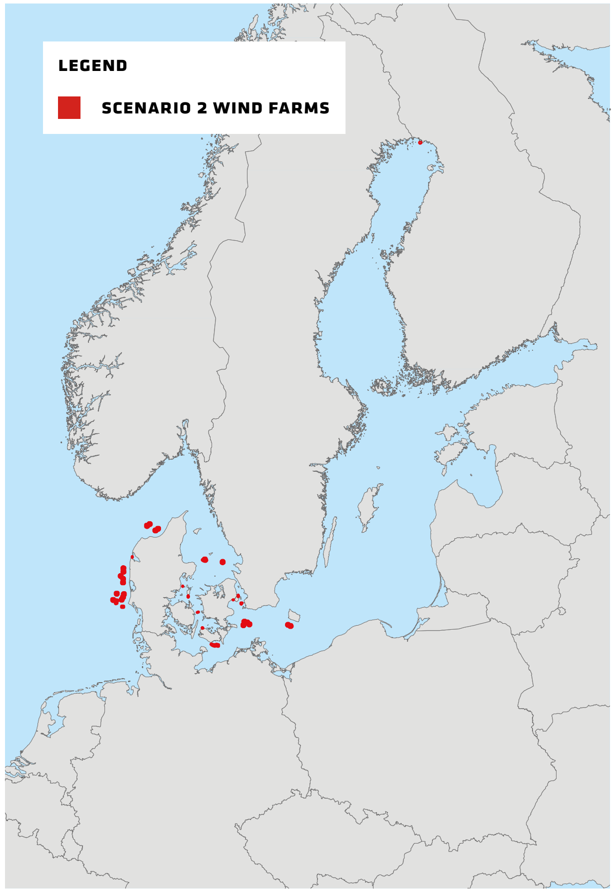


FIGURE 5.13 *The distribution of offshore wind farms used in the Scenario 2 model run.*

tions. The first was that the only way a good fit could be obtained was to incorporate a delay in long-distance migration starting date of more than 60 days. Secondly, the fit was not improved by delaying the start of the return migration. This may indicate more synchronized return migration.

Of the 16 parameters tested, the model was relatively sensitive to ten parameters, either in measure of fit, population size or both. The model was most sensitive to dates of breeding departure and return, and to the parameter that controls the direction of winter migration.

SCENARIOS

Analyses were performed for three scenarios of offshore wind farm development in the Danish parts of the North Sea and in the Baltic. Scenario 1 is a description of the 2010 development stage of offshore wind farms in Danish waters and a not complete description of existing offshore wind farms in the remaining parts of the Baltic. Two Swedish offshore wind farms in Kalmarsund are not represented.

In Scenario 2 all wind farms from Scenario 1 are present, along with those covered by the development plan for offshore wind farms as published by the Danish Energy Agency.

With Scenario 3 we have included plans reaching further into the future, both for Danish and Baltic waters.

Scenario 3 contains all wind farms from Scenarios 1 and 2 and in addition to that it has a collection of sites at a very early stage in the planning process. Scenario 3 can thus be regarded as a speculative scenario. The model was subsequently used to evaluate these three scenarios, for:

- Populations designated as near (breeding grounds in Norway & Sweden),
- Intermediate (breeding grounds in Finland)
- Far (breeding grounds in Russia).

Each scenario was run 120 times at which point confidence limits between scenario results did not overlap.

The endpoint information used for these scenarios was the total number of birds in the population after 10 simulation years (denoted as population size). Given the results of the sensitivity analysis, this endpoint was clearly sensitive to changes in the model and was therefore considered a reliable measure of impact on the population.

In the model, bird death was set as a result of a bird having a negative energy balance. The energy balance is affected by the energy intake of the birds and their energy expenditure. Expenditure is in terms of movement, whilst intake is affected by the quality of the grid unit in which the bird finds itself, and the number of other birds there. The quality of the grid unit is determined by depth of water, distance to shore and temperature. It is therefore dynamic, changing with season as temperature changes. As a result of these movements new energy intakes are calculated.

Wind farms will affect the population size endpoint by removing habitat from the model. There is an assumption that the birds will simply avoid wind farms by a distance of 500 m [incorporated in the red areas, Figures 5.12 - 5.14]. Model birds may fly over or around these obstructions, in effect treating them precisely as dry land. Collisions with wind turbines are not incorporated in this model.

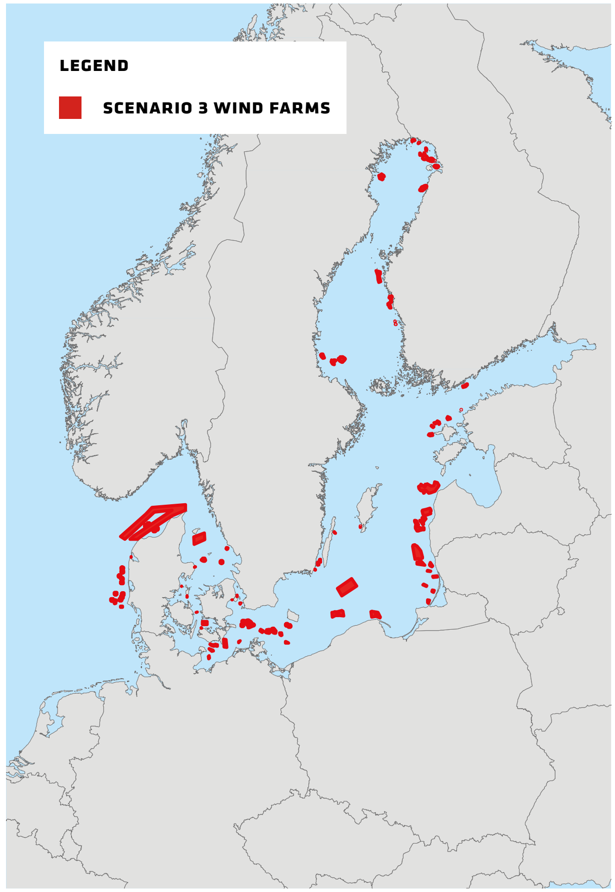
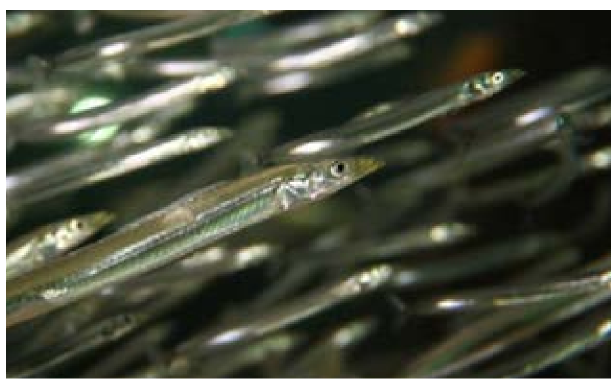


FIGURE 5.14 *The distribution of offshore wind farms used in the Scenario 3 model run.*



Sandeels. PHOTO: MIKAEL VAN DEURS

RESULTS:

VERY SMALL IMPACT OF WIND FARM SCENARIOS

The primary result of the simulation of the three scenarios was that there was a detectable, but very small, impact of the wind farm scenarios on the number of extant birds. Even scenario 3, where 15,000 km² were classified as wind farms, resulted in less than 2% change in the population levels. Indications were that populations classified as being from intermediate distance breeding grounds were impacted to a larger degree, but still in the region of 2%.

DISCUSSION AND CONCLUSION

A USEFUL TOOL WITH ROOM FOR IMPROVEMENT

The results of this study indicate that the effect of additional offshore wind farms as seen in Scenario 2 would have trivial impact on the overall Baltic flyway population size, with a decrease of only 0.1%. For comparison scenario 3 showed a decrease of 1.7%.

	S1	S2	S3
MEAN	8790.0	8782.7	8639.9
SD	159.0	134.6	132.2
N	180	180	180
95% CI	23.2	19.7	19.3
DIFFERENCE	nA	-0.1%	-1.7%

TABLE 5.3 *The mean population estimates for 180 model iterations for scenario 1 (S1), scenario 2 (S2) and scenario 3 (S3) respectively, modelled for the entire model population. Standard deviation and 95% confidence intervals are given. "Difference" indicates the modelled change in population size, where negative values indicate a population decline*

The difference between Scenario 1 and Scenario 2 is that areas with plans for future offshore wind farms in Danish marine areas have been added. However in this scenario no offshore wind farms were added in the remaining parts of the Baltic. This may explain the relatively small impact on the Scenario 2 data, both in relation to the entire population and when separated into the three migration-distance groups.

Scenario 3 had far more wind farms in both Danish and Baltic marine areas. As a consequence the indicated impact from the presence of more wind farms was higher. Comparing the results for the three groups of far, intermediate and short distance migrants shows that the birds that migrate intermediate distances are impacted more than the two other groups. This is likely to be caused by the fact that the far migrants utilize the Baltic to a limited extent. The short migrants mainly use the western parts of the Baltic. In contrast the intermediate migrants utilize parts of the Baltic with wind farms over a relatively long period of time, and thus this part of the population seems to be affected more by the offshore wind farm scenarios.

Our knowledge about the biology of red-throated divers in this flyway population is limited, which led to a number of shortcomings in the creation of this model. First of all the estimated size of the population is very uncertain, and there is no knowledge about sub-populations. In the process of developing the model we learned about data from a satellite transmitter tagged red-throated diver from northeast Greenland. It migrated from the breeding ground to southeast England in three steps, and likewise in huge steps back to the breeding grounds in the very same place as the preceding spring/summer. This led to the theory that the birds migrating through the Baltic perform a leap-frog migration. Far distance migrators leave the wintering grounds late and migrate fast to the breeding grounds, while short migrating individuals more gradually move eastwards in the Baltic from late winter/early spring. When the different migration strategies were

	FAR			NEAR			INTERMEDIATE		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
MEAN	9074.2	9062.5	9018.7	9124.2	9116.4	9007.7	8781.3	8761.1	8625.9
SD	54.0	55.1	57.6	43.1	40.8	46.6	100.2	126.5	121.6
N	180	180	180	180	180	180	180	180	180
95% CI	7.9	8.0	8.4	6.3	6.0	6.8	14.6	18.5	17.8
DIFF (%)		-0.1%	-0.6%		-0.1%	-1.3%		-0.2%	-1.8%

TABLE 5.4 *The mean population estimates for 180 model iterations for scenario 0 (S0), scenario 1 (S1) and scenario 2 (S2) respectively, modelled for three migration strategies, far migrating populations (Far), short migration populations (Near) and intermediate migration populations (Intermediate). Standard deviation and 95% confidence intervals are given. "Difference" indicates the modelled change in population size, where negative values indicate a population decline.*

entered into the model it greatly improved the accuracy.

Another shortcoming was that the density estimates used to calibrate the model were tiny compared to the size of the general study area, and spatially restricted to Danish waters, and thus far from evenly distributed across the study area. This meant that our fitted model, although using the best available data, may be biased by small variations in the precise density estimates used.

A third important limitation was that the model builds on habitat utilization in a simple form, with no possibility to differentiate changes over time in habitat importance to the red-throated divers. A particular area could for example potentially be of far higher importance as a staging area in spring than in autumn. Such temporal changes could not be implemented in the present model state.

Therefore, the results of this modelled approach must be considered and used with great caution. The model builds on a number of assumptions that are difficult to verify. The present results should be considered as indications of a potential impact level on the diver population from offshore wind farms. As our knowledge improves, the value of the model developed here has a potential to provide more specific answers to aid planning of future wind farms. Input data for model calibration from a larger geographical range could improve the model. The incorporation of the UK east coast into the model landscape could also improve the model.

IAPEME VIEWPOINTS

PROFESSOR BOB FURNESS,
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Offshore wind farms may affect birds directly through collision mortality, barriers to flight lines, or displacement from habitat. Danish offshore wind farms are providing important insights relevant to wind farms currently being developed in many other countries. Barrier effects appear to be trivial, and collision risk appears to be very low, at least for these Danish wind farms and the seabirds that are common in Danish waters.

However, displacement effects appeared to be a potential problem for a few seabird species. Red-throated divers, birds that are particularly sensitive to human disturbance and artificial structures, were very rarely encountered between turbines at Horns Rev whereas they had been present in the area before construction. Common scoters were almost never encountered between Horns Rev turbines in the first five years after construction.

The recent studies reported here focused on displacement effects on common scoters and red-throated divers. Surprisingly, since 2006 common scoters occurred at equal densities within and outside the wind farm. This was initially interpreted as a change in behaviour of these birds as they got used to the presence of the wind farm. However, the change may be a response to altered food supplies. It has become clear that common scoters will forage on the invasive alien American razor clam, a shellfish that has increased in the region since its recent arrival. This shellfish occurs in deeper water than common scoters' other preferred food, the cut trough shell, and common scoter distribution alters depending on abundances of these two molluscs. The research shows strong influences of hydrography and sediment transport affecting mollusc abundance, and that mollusc abundance alters common scoter distribution. These dynamic processes appear to be overwhelmingly important for the birds, and make it difficult to see any effect of the wind farm on common scoter distribution.

In contrast, red-throated divers continue to avoid offshore wind farms, showing a stronger adverse response than any other seabird. By developing an 'agent-based model', it has been possible to assess how much the red-throated diver population of the Baltic flyway may be affected by loss of foraging habitat due to their avoidance of offshore wind farms. Existing and planned wind farms were predicted to reduce red-throated diver numbers by only 0.1%. Even under the extreme case of maximum likely future development of offshore wind farms in Danish waters and throughout the Baltic, the model suggested red-throated diver numbers would decline by only 1.7%.

This modelling work is complex, and depends on many assumptions and simplifications. On the other hand it represents a novel and important approach to assessing displacement impact of offshore wind farms on particularly sensitive seabird species. The very small impact of even the most intensive scenario suggests that offshore wind farm displacement effects on seabirds will generally be negligible. However, improving the data on which this modelling is based, and the application of this approach for the whole of the North Sea, would be a valuable extension of this work so elegantly developed in Denmark; especially considering the rapid development of offshore wind farms in many sectors of the North Sea, and the proximity between some of these and Special Protection Areas established for wintering populations of red-throated divers.

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SUBJECT INDEX

All over the world, governments are investing in renewable energy to reduce their dependency on fossil fuels and to curb carbon emissions. A crucial tool in this transformation is the exploitation of wind energy, and significant growth in offshore wind deployment is projected.

In light of this historic transition, it is of fundamental importance to continually improve the basis for planning decisions by incorporating new research on the environmental impacts of wind farms. The Danish environmental monitoring programme and its follow-up programme have led to the important conclusion that, with proper spatial planning, it is possible to construct offshore wind farms in an environmentally sustainable manner that does not lead to significant damage to nature. This book summarises the key research findings on the impacts on fish, marine mammals and birds.

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