# The effects of wind power on marine life

## A Synthesis

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VINDVAL

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This report is a translation of the previous report in swedish ”Vindkraftens effekter på marint liv” (Naturvårdsverket report no 6488).
Translated by Ellen Schagerström

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# Preface

There is a great need for knowledge concerning the impacts of wind power on humans, landscapes, the marine environment, birds, bats and other mammals. Previous studies of these environmental impacts have lacked an overall view of the effects. This has led to deficiencies in the processes surrounding the establishment of new wind farms. Vindval is a knowledge programme undertaken as a collaboration between the Swedish Energy Agency and the Swedish Environmental Protection Agency. Its aim is to gather and communicate scientific knowledge about the impacts of wind power on people and the natural environment. The programme continues until 2013.

Vindval comprises some 30 individual research projects, together with four synthesis projects. Syntheses are prepared by experts, who compile and assess overall research results and experience regarding the effects of wind power in four different areas – humans, birds/bats, marine life and terrestrial mammals. The results of this research and synthesis work will provide a basis for environmental impact assessments and for the planning and permitting processes associated with wind power installations. Vindval requires high standards in the review and approval of research proposals, in order to ensure high-quality reports. The same high standards apply to the reporting, approval and publication of research results from the projects.

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The contents of the report are the responsibility of the authors.

The Vindval Programme, October 2012

# Contents

# Summary

As in many other countries, an expansion of wind power is expected in Sweden during the coming decades. The expansion is driven by rising prices on electricity and the need for an increased production of renewable energy. Since wind conditions at sea are good and relatively constant, several offshore wind farms are planned in Swedish waters. Offshore wind power with a total effect of about 2500 MW has been granted permission and an additional 5500 MW are being planned for. Examples of granted projects are Storgrundet with an effect of 265 MW, Stora Middelgrund with an effect of 860 MW and Kårehamn with an effect of 48 MW. The largest offshore wind farm in Sweden today is Lillgrund in Öresund, with its 48 turbines with an installed effect of 110 MW.

Prior to this expected expansion, it is important to investigate the environmental impact of offshore wind power, and how possible negative effects can be minimized. This synopsis about the impact of wind power on the marine life in Swedish waters is based on more than 600 studies, most of which are scientific articles, but also reports by companies and authorities.

## Habitats and species in Swedish marine areas

Swedish marine areas are characterized by a unique salinity gradient that varies from marine conditions in Skagerrak to almost limnic environments in the Gulf of Bothnia. There are also vast differences between areas in terms of environmental factors such as insolation, temperature and wave exposure. This entails variation in species composition, dominance by different populations and structural differences in plant and animal communities. Therefore, this synopsis provides environment descriptions of three widely separated marine areas: the Swedish West Coast (Kattegat and Skagerrak), the Baltic Proper and the Gulf of Bothnia (Bothnian Sea and Bothnian Bay). The main focus is on occurrence of species and communities within the depth interval that is of interest for establishing offshore wind power in Sweden.

## Offshore wind power

There are mainly two types of foundation structures used in Sweden today: gravity-based foundations and monopile foundations. These are also the most commercially viable. Offshore wind farm projects affect the environment in different ways during installation, operation and decommissioning. The installation phase is assessed as having the largest impact on the environment, since high noise levels and sediment dispersal can affect marine organisms. A wind farm during operation can cause barrier effects as well as changes in the natural environment. The decommissioning phase can again enhance noise levels and lead to sediment dispersal in the wind park and its adjacent area.

# Effects on marine organisms and communities

Since marine environmental conditions vary between different locations as well as over time, it is difficult to make universal assessments of the effects of offshore wind power. This increases the importance of well-designed pilot studies and monitoring programs of the local environment. Also, location-specific surveys minimize the risk that costly measures to reduce negative impact are used when they are not needed. In general, installation and decommissioning of offshore wind farms should be planned so that sensitive reproductive periods for marine species are avoided. Particular consideration might also be needed for constructions in important growth and spawning areas for fish and marine mammals, or specific environments, such as offshore banks with high natural values. Below is a list of the effects that, according to existing knowledge and accessible literature, might affect marine organisms and communities. Each effect has been assessed after how long, and to what scale, it affects the marine life in the wind farm area.

### Acoustic disturbances during the installation

As monopile foundations are being driven into the sea floor, a lot of noise is generated that spreads in the water. Cod and herring can potentially perceive noise from pile driving at a distance of 80 kilometres, experiencing physical damage and death at just a few meters from the place of installation. For all types of work involving noise, flight reactions in fish are expected within a distance of about one kilometre from the source. The greatest risk of significant harm to fish populations exists if the installation overlaps with important recruitment areas for threatened or weak populations. Among the marine mammals, porpoises have proved to get both impaired hearing and behavioural disturbances from noise associated with pile driving. There are no studies indicating any long-term negative effects on any of the seal species occurring in Swedish waters. It is not possible to draw any general conclusions of the effects on invertebrates from pile driving noise, since the group is too large and diverse. The few studies that exist, however, show that oysters are relatively sensitive, whilst mussels are not affected at all. The effects of high noise levels can be reduced by, for example, successively increasing the power and thus the noise during piling, so that larger animals such as fish, seal and porpoises are intimidated at an early stage and leave the construction area well before high noise levels are reached.

### Sediment dispersal

Dredging work during the construction of gravitational foundations, and laying of cables between the wind turbines and land, can cause sediment from the bottom to whirl up and disperse in the water mass. The amount of sediment dispersed depends on the type of sediment, water currents and which dredging method is being used. Increased concentrations of sediment in the water affect mainly fish fry and larval stages negatively. Invertebrates are often adapted to re-suspension of sediment, since it occurs naturally in their environment. The sediment dispersal at the construction of a wind farm is often confined to a short period. The effects are also relatively small due to the fact that the bottom sediment is usually coarse-grained. The overall assessment is therefore that sediment dispersal is a limited problem for most animal and plant communities, but specific consideration should be taken and fish recruitment periods should be avoided.

### Introduction of a new habitat

The foundations of wind turbines can function as artificial reefs and attract many fish species, particularly around gravitational foundations which have a structurally complex erosion protection. At first there is often a redistribution of fish from nearby areas to the wind park foundations, but over time an actual increased fish production within the park is possible, as long as the park is large enough and the fishing pressure is low. The structure of the erosion protection can bring local positive effects for crustaceans such as lobster and crab, by functioning as shelter as well as increasing their foraging area. One example of a species that seems to increase locally around foundation structures on the Swedish West Coast and the Baltic Proper is the blue mussel. Which species that will dominate depends on the salinity in the area. There are no studies showing that foundation structures will facilitate the distribution of new species to Swedish marine areas. One reason for this might be that the total amount of hard bottom surface formed by the foundations and their structures is relatively small compared to natural hard bottoms.

### Turbine noise and boat traffic

Maintenance work on the wind turbines causes a certain increase in boat traffic in the area of an operating wind farm. Also, different parts of the turbines generate noise during operation that spreads through the water. The reactions of fish on noise from turbines and boat engines vary, but study results indicate that the effect on most fish species from noise produced in a wind farm is low. There are, however, no studies on long-term effects of stress due to an increased noise level or effects of noise disturbance on fish spawning behaviour. Porpoises especially, but to some extent also seals, are sensitive to noise disturbance. Today there are no studies showing negative effects from the operational sounds from a wind farm on populations of marine mammals. The noise of both strong winds and engines from ships often exceeds the underwater noise generated by operating wind farms.

### Electromagnetic fields

The electric cables leading from a wind turbine generates a magnetic field that decreases with distance from the cable. The expected effect on most fish species is low, but since the effect is ongoing throughout the entire operational stage, the risk should be considered in areas that are important to migrating fish species. No studies have been found that show how electromagnetic fields affect marine mammals. The few studies that have been found on invertebrates indicate that the electromagnetic fields around common transmission cables have no effect on either reproduction or survival.

### Exclusion of birds

Most birds do not avoid wind farm areas. An exception is several common diving ducks that avoid flying or swimming within wind farms and keep a safe distance of at least 500 meters to a turbine tower. The most common food for these species in the Baltic Sea is blue mussels. Areas within the Swedish economic zone where a large-scale expansion of wind power would have the greatest effect on the ducks, and thereby indirectly affect the benthic community, are the offshore banks in the central Baltic Proper, mainly Hoburg Bank and Northern Midsjö Bank, where two thirds of the oldsquaw populations in Europe overwinters. The level of impact will depend on the total area of the park, and the distance between the turbine towers. Large-scale studies are needed in order to assess if the effect might lead to substantial changes for the benthic community.

## Gaps of knowledge

The basis of this synopsis is research results from studies concerning single wind turbines or small wind farms, which in many cases is enough to assess the effects that can be expected on different groups of marine organisms. However, there is a lack of knowledge on how the large-scale wind power development will affect marine ecosystems in the long term. Since it is impossible to extrapolate this knowledge based on a single wind turbine or wind farm, further studies are needed where changes in larger parks are followed over long periods of time. Identified effects should also be weighed and put in relation to other human activities, as well as to today’s need of increasing the use of renewable energy and reduce environmental pollution. Since a large-scale expansion of wind power is expected along the coasts of many countries around the Baltic Sea and in the North Sea, there is a need for a coordinated international research program, for example an interdisciplinary EU-project.

# 1. Introduction

In a time of global warming and rising costs on energy, the necessity of renewable energy resources is increasing. Wind appears to be an ideal source of energy since the extraction produces very low emissions of greenhouse gases and other environmentally hazardous substances (Martínez et al. 2009).

A major expansion of wind power is taking place throughout the world, especially in the industrialized and densely populated countries of Western Europe, but also in China and USA. Although wind power is considered a clean energy source it can cause problems as it competes for space with other human activities on land. Wind power can thereby be perceived as disturbing as the windmills obscure the horizon. There is therefore a substantial construction of offshore wind power in many European countries. By building offshore, more energy can be harvested per time unit and larger windmills can be erected than on land, since the constructions are not limited by the capacity of the road network.

The relatively low prices of electricity in Sweden have meant that the profitability of offshore wind power has been low. The increasing integration of the Nordic electricity net to the European net and the planned German nuclear decommissioning are likely to drive up prices and make it economically feasible to expand the offshore wind power also in Sweden. At the time of writing, offshore wind power with a combined capacity of about 2500 MW have been authorized in Sweden, and a further 5500 MW are under development. Examples of authorized wind power projects are Storgrundet with an effect of 265 MW, Stora Middelgrund with an effect of 860 MW and Kårehamn with an effect of 48 MW. Today, Lillgrund in Öresund with its 48 wind turbines and 110 MW of installed capacity is the largest offshore wind park in Sweden. For updated information on offshore wind power projects in Europe, visit the Global Offshore Wind Farms database (www.4coffshore.com/offshorewind).

Before this anticipated expansion, it is important to investigate whether wind power causes any negative effects on the environment and how such effects can be counteracted and/or reduced. For seven years (2005 - 2012) The Vindval research program have performed studies with this objective. Vindval is a partnership between the Swedish Energy Agency (Energimyndigheten) and the Swedish Environmental Protection Agency (Naturvårdsverket), where the former finance and the second run the program. The total budget includes approximately 70 million SEK divided on two periods of the program. The program has funded about thirty projects, half of which are linked to offshore wind power (Box 1). At the end of the latest period of the program, Vindval started four synopsis projects to compile the knowledge generated within the program and in other national and international studies. This synopsis report is the result of one of the projects and concerns the effects of wind power on the marine life in Swedish subtidal marine areas. The other three projects have compiled knowledge on the effects on birds and bats, terrestrial mammals on shore and human interests.

## 1.1 Literature use and target group

The conclusions and recommendations in this synopsis are mainly based on published scientific literature but also to a lesser extent on reports from companies and government agencies in Sweden and abroad. Information on offshore wind power in Sweden is also based on reports produced within the Vindval research programme. Descriptions of habitats are based on data from the Swedish EPA inventories of the offshore banks (Naturvårdsverket 2006, 2010). Information from abroad is collected from reports published in wind power projects in Denmark (through Energistyrelsen, Dong Energy and Vattenfall) and Great Britain (through the British database COWRIE; Collaborative Offshore Wind Research Into the Environment). The IUCN-report; "Greening Blue Energy: identifying and managing the biodiversity risks and opportunities of offshore renewable energy" (Wilhelmsson et al. 2010), has been an important source of inspiration. For example, the presentation on the assessments of the effects of wind power, have been modelled after the structure used in the IUCN - report.

The information presented in the synopsis can serve as a basis for environmental impact assessments and in planning and approval processes at local, regional and national levels. It can also provide knowledge to all who want to know more about the biological aspects and effects during the construction and establishment of offshore wind power in Swedish marine areas.

**Box 1**

**REPORTS FROM VINDVAL CONCERNING EFFECTS OF WIND POWER ON MARINE LIFE (PUBLISHED IN SWEDISH WITH ENGLISH SUMMARIES)**

Miljömässig optimering av fundament för havsbaserad vindkraft (Naturvårdsverket 5828)
Hur vindkraftverk påverkar livet på botten – en studie före etablering av vindkraft (Naturvårdsverket 5570)
Bentiska processer på och runt artificiella strukturer i Sveriges kustvatten (Naturvårdsverket 6414)
Havsbaserad vindkraft – ekologiska risker och möjligheter (in press)
Effekter på fisk av marina vindkraftparker (Naturvårdsverket 5580)
Vindkraftens effekter på ålvandring (Naturvårdsverket 5569)
En studie om hur bottenlevande fauna påverkas av ljud från vindkraftverk till havs (Naturvårdsverket 5856)
Studier på småfisk vid Lillgrund vindpark (Naturvårdsverket 5831)
Effekter av undervattensljud från havsbaserade vindkraftverk på fisk i Bottniska viken (Naturvårdsverket 5924)
Partikelrörelser uppmätta vid ett vindkraftverk. Akustisk störning på fisk i anslutning till vindkraftverk (Naturvårdsverket 5963)
Akustisk störning på marint liv i anslutning till vindkraftverk – en fortsättning vid Lillgrund (in press)
Effekt av pålningsljud på fiskbeteende (Naturvårdsverket 6437)
Effekter av en havsbaserad vindkraftpark på fördelningen av bottennära fisk (Naturvårdsverket 6485)
Effekter av havsbaserad vindkraft på pelagisk fisk (Naturvårdsverket 6481)
GIS-baserade metoder för att kartlägga fiskars livsmiljöer i grunda havsområden (Naturvårdsverket 6427)
Blankålsvandring – Vindkraft och växelströmsfält (Naturvårdsverket 6479)

## 1.2 Report disposition

This synopsis report consists of six chapters. This first chapter is a description and summary of the project. The following chapter describes the marine habitats in Swedish marine areas, focusing on habitats that are of interest for the establishment of wind farms. Chapter 2 describes the offshore wind power from the technical perspective, with respect to the installation, operation and decommission. Chapter 4 deals with expected impacts from offshore wind power on the marine life. Based on existing knowledge, we describe the different ways that offshore wind power can affect organisms and communities in the sea, followed by an assessment of the magnitude of these effects in space and over time. Table 2 on page 46, lists where each impact is presented in the report. Chapter 5 reports what possible measures can be taken to reduce the environmental effects from wind power. The final chapter provides a brief presentation of the gaps of knowledge that have been identified during the work with this synopsis work. Last of all, is a list of the species mentioned in the report.

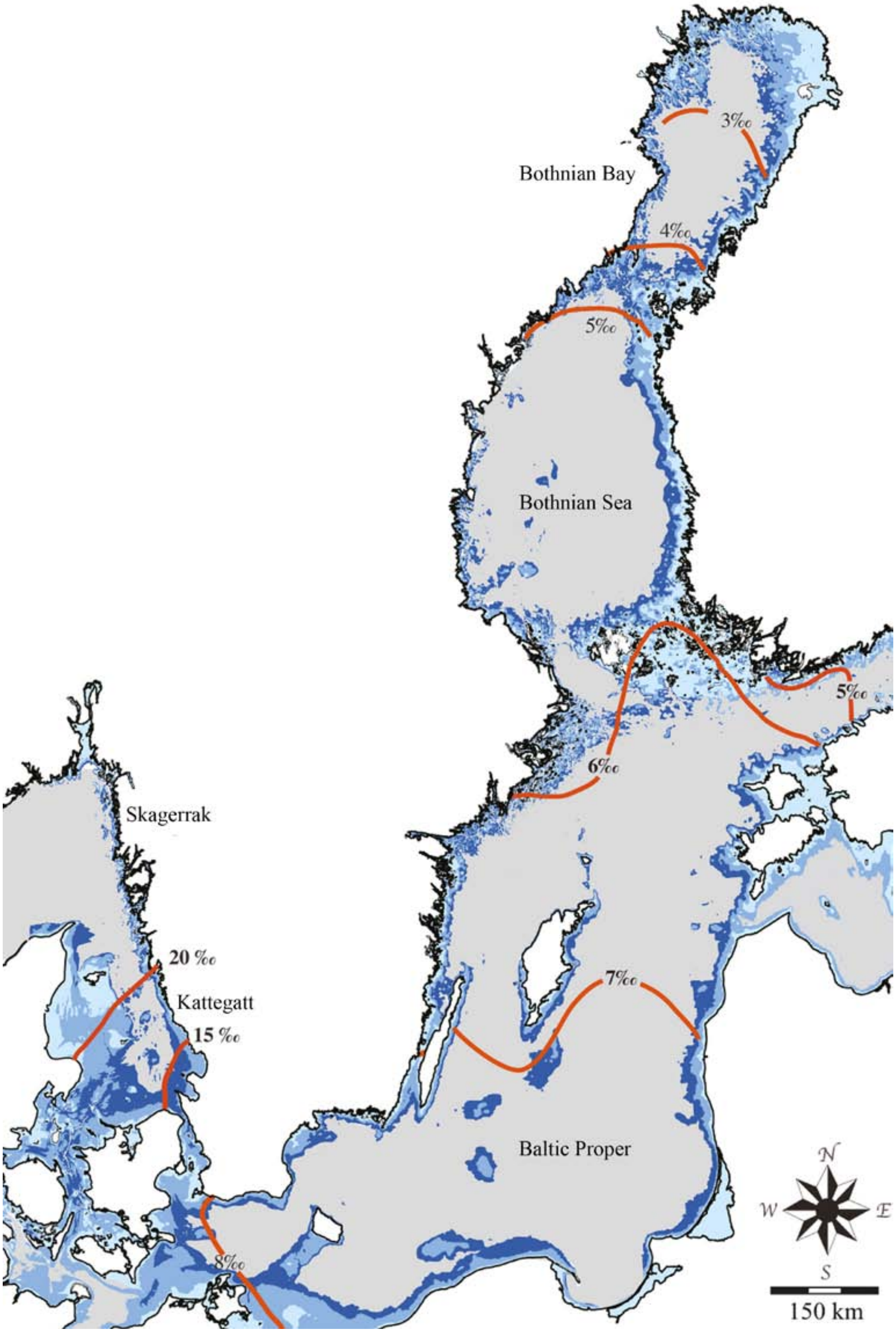
# 2. Habitats and species in Swedish marine areas

The marine areas of Sweden are characterized by a unique salinity gradient that varies between oceanic salinities in Skagerrak down to almost limnic conditions in Gulf of Bothnia (map 1). Temperature and light also differs quite a lot from the temperate areas in the south to the subarctic conditions in the north, where the ice often covers the coastal areas up to six months per year. These naturally differing environmental conditions lead to large variations in plant and animal compositions. A great species richness on the Swedish West Coast turns into a much more frugal but unique blend of marine and fresh water species in the Baltic Sea. Therefore, the following environment descriptions are divided into three marine areas: the Swedish West Coast (Kattegat and Skagerrak), Baltic Proper and Gulf of Bothnia (Bothnian Sea and Bothnian Bay), respectively.

Since offshore wind parks are mainly established in the depth range of 5–40 meter, focus is on descriptions of the underwater environments in this depth range and the species of invertebrates, fish and marine mammals that along with plants and algae form the natural community there. Parts of the recommendations may apply to the construction of wind power in fresh water, provided the animal and plant communities are similar to those outlined in this report. Shallow areas at sea, known as offshore banks, are of particular interest for the establishment of offshore wind power in Sweden. This is because the wind conditions at the banks are very good, while the depths are moderate. Offshore banks are usually defined as shallow areas of sand or blocks that are surrounded by deeper water. They are usually far from the coast, which makes them less affected by human activities, such as nutrients from agriculture and sewage outlets and other polluting substances from industries, than more coastal areas.

**Box 2**

**Red listed species**
The Red List of ArtDatabanken (Swedish Species Information Centre) is an account of the chances of survival for Swedish species. Within the Red List, species are classified as: regionally extinct (RE), critically endangered (CR), endangered (EN), vulnerable (VU) or near threatened (NT). There can also be a data deficiency concerning the species (DD). What classifications have been made for the red listed species mentioned in this report is presented in the species list on page 73. For the latest classifications, visit: www.artfakta.se.




Map 1. Salinity levels (in permille) of surface water in Swedish marine areas. Colours denote different depth intervals: light blue = depth between 0 to 20 meters, medium blue = depth between 20 and 30 meters, dark blue = depth between 30 and 40 meters and grey = areas deeper than 40 meter. Offshore wind power is commonly established at depths between 5 to 40 meters.

## 2.1 The Swedish West Coast

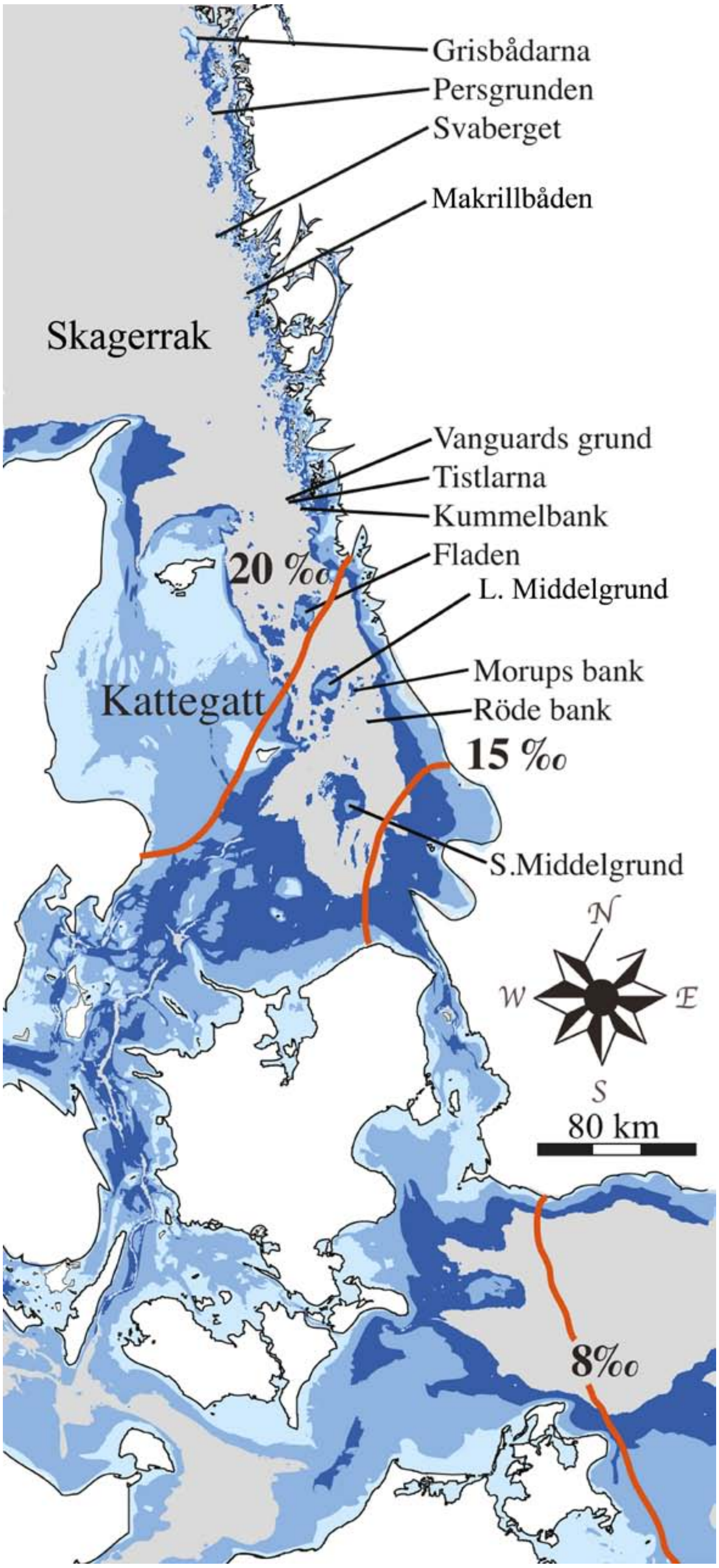
The Swedish West Coast consists of Skagerrak and Kattegat, two areas that in many ways represents widely differing marine habitats. Skagerrak has an average depth of 220 meters, whereas Kattegat is a shallow sea with an average depth of only 23 meters. The Swedish coast of Skagerrak is dominated by an archipelago area with many rocky islands, while the coast along Kattegat is relatively sandy, shallow and open to the sea. The upper water layer in Kattegat and the eastern parts of Skagerrak are, down to a depth of about 10–20 meters, composed of brackish water from the Baltic Sea. Here, the salinity varies between 15 permille in the south to more than 25 permille in the north. The upper water layer is delimited downwards by a marked halocline. Below this halocline, and also in the western parts of Skagerrak, the water originates from the North Sea, and has a salinity of about 32–35 permille.

The offshore banks of Kattegat are largely composed of bedrock, shells, gravel, and boulders. Bottoms composed of maërl (loose lying coralline algae), which are considered especially worthy of protection, are also present in these areas. The larger offshore banks are Fladen, Groves Flak, Lilla Middelgrund and Stora Middelgrund as well as the shallow areas around Läsö (map 2). There are only a few small banks in Skagerrak. Most offshore banks on the Swedish West Coast have high conservation values and high biodiversity (Naturvårdsverket 2006, 2010). According to the natural value assessment of the offshore banks (Naturvårdsverket 2010) Svaberget outside Smögen had the highest collected natural value in Skagerrak. In Kattegatt, the offshore bank Fladen, located northwest of Varberg, had the highest species diversity and also a high number of red-listed species.

### 2.1.1 Fish on the Swedish West Coast

SPECIES RICHNESS AND SPECIES COMPOSITION

The Swedish West Coast is the most diverse of Sweden's marine areas when it comes to fishery. Available information on fish distribution in shallow marine areas is much more detailed for Kattegat than for Skagerrak, since there is a deficiency in inventories of fish at the Skagerrak offshore banks. This description therefore mainly reflects results from studies in the Kattegat. Based on the external environmental conditions, particularly the higher salinity, the fish community in Skagerrak is expected to have higher species richness and a higher production potential than the community in Kattegat. Several local stocks along the Swedish West Coast are severely reduced today, and have in many places completely disappeared. The main reason for this is too high fishing pressure. Examples of species that have been affected strongly are cod, *Melanogrammus aeglefinus* and *Pollachius pollachius* (Fiskeriverket 2011).




Map 2. Offshore banks on the Swedish West Coast. Colours denote different depth intervals: light blue = depth between 0 to 20 meters, medium blue = depth between 20 and 30 meters, dark blue = depth between 30 and 40 meters and grey = areas deeper than 40 meters.

About eighty species of marine fish are estimated to reproduce in Swedish waters (Gärdenfors 2010). The number of fish species encountered in a particular survey will depend on the method used. For example, a total of 70 fish species was noted on and near offshore banks in the inventories of Kattegat during the 2000s. Of these 40 species were noted at fyke net fishing, 30 species at bottom trawling and 45 species in connection with SCUBA inventories and sampling of benthic fauna. A total of 86 species were registered for the Swedish West Coast in the Board of Fisheries (Fiskeriverket) database of survey fishing with fixed gear for the years 2009–2010 (Fiskeriverket 2011). Some common species on the Kattegat offshore banks were cod, *Limanda limanda, Ctenolabrus rupestris, Trisopterus minutus, Pleuronectes platessa, Chelidonichthys lucernus, Merlangius merlangus and Trachinus draco* (Naturvårdsverket 2010).

About twenty species on the Swedish West Coast are considered to be rare and declining species, requiring special consideration at planning and risk assessment according to the ArtDatabanken Red List. Of these, nine are cartilaginous fish, namely sharks and rays (Gärdenfors 2010). Inventories at Kattegat offshore banks found, of the red listed species, mostly cod, eel, *Anarhichas lupus, Pollachius pollachius, Molva molva, Cyclopterus lumpus, Merlangius merlangus and Zoarces viviparus*, but also *Enchelyopus cimbrius, Melanogrammus aeglefinus and Squalus acanthias* (Naturvårdsverket 2010).

#### ESPECIALLY IMPORTANT HABITATS FOR FISH

Regarding the spatial distribution of fish in Kattegat, there is a general effect of depth, in that shallower areas have higher species richness and individual abundance than deeper areas. The species richness is often higher in areas with high salinity, the presence of bottom currents and clearer water (Fredriksson et al. 2010).

Fish can migrate over a wide area during its juvenile period, but tend to reassemble at the location where it was born for its reproduction (Svedäng et al. 2007). This means that local spawning grounds can have a major effect on the number of fish in an area much larger than the spawning ground. The behaviour of returning to the spawning ground at the time of reproduction is known as homing behaviour. This can lead to a genetic distinctiveness of individuals and fish populations from different spawning areas.

The Swedish West Coast contains a mixture of fish from local stocks and fish stocks that spawn further away, e.g. in the North Sea or in some cases the Baltic Sea, and the fish that use the Swedish West Coast as a nursery area. Herring, cod, mackerel, *Pleuronectes platessa, Belone belone* and *Cyclopterus lumpus* are all examples of species that are represented by both stocks which migrate from the surrounding areas and by local stock. Even juvenile eel that are brought by ocean currents from the Atlantic to the Swedish West Coast, settle along the Swedish West Coast (Fiskeriverket 2011).

Shallow habitats along the coast, such as hard bottoms or open sand and mudflats, are particularly important spawning grounds for fish. Information on spawning grounds on offshore banks is relatively limited. Known spawning grounds for cod in Kattegat are Lilla and Stora Middelgrund, Morups bank and an area along the coast of Halland, ranging from Falkenberg and south towards Laholmsbukten (Vitale et al. 2007). Another common species that depends on offshore habitats for its reproduction is herring, which lay their eggs on sand, gravel or stone, and in some cases on the vegetation. The eggs stick to the substrate and are aerated by the water current. Skagerrak and Kattegat herring consists of several different stocks from spawning grounds in the North Sea, western Baltic Sea and local stock. At the offshore banks in the Kattegatt and Skagerrak, mainly in areas between Sotenäset and Väderöarna, as well as outside Orust, Tjörn and Hisingen are local spawning grounds for herring (Rosenberg et al. 1982).

In the assessment of natural values on the Kattegat offshore banks, fish communities from six different offshore banks were compared: Fladen, Lilla Middelgrund, Tistlarna, Morups bank, Röde bank and Stora Middelgrund (Naturvårdverket 2010). The largest combined natural values for fish were noted at Fladen, but Lilla Middelgrund was judged to have consistently high natural values. A separate comparison was made for the parts of the offshore bank shallower than 20 meters. Even then, the highest natural values were from Fladen, but Morups bank came in second place. The other banks that were included in the comparison had similar values in terms of fish, with the exception of Röde Bank, which was ranked as having the lowest natural values (Naturvårdsverket 2010).

### 2.1.2 Marine mammals on the Swedish West Coast

The marine mammals on the Swedish West Coast consist mainly of harbour porpoise and harbour seal. The porpoise populations have been inventoried twice during the last fifteen years: 1994 and 2005 (Teilmann et al. 2008). There are today about 14 000 porpoises in all of Kattegat and the western part of the Baltic Sea (Teilmann et al. 2008), which should be compared to the 1994 inventory that estimated about 22 000 animals. Although this decline is not statistically significant it has created a lot of concern over the porpoise stock status in these waters. The calculations for the Skagerrak stock from the most recent inventory has not been published, but presumably these are about the same number of animals as in Kattegat.

There are about 15 000 harbour seals on the Swedish West Coast (Karlsson et al. 2010). The Swedish West Coast harbour seal population is divided into several large colonies at the Koster Islands, Väderöarna, Nidingen and Hallands Väderö. There are also smaller, scattered residential areas along the Swedish coast and in the Danish areas. Harbour seals are coming out of the water to dry out the coat, rest and to nurse their pups in May-June, and again to change their coat in August. Harbour seals make long foraging trips from the colonies and can be found throughout the inner coastal area between Skåne and Bohuslän. Besides porpoises and harbour seals, there are a few grey seals on the Swedish West Coast. They do sometimes reside on Koster Islands and the Danish Anholt in the Kattegat. These grey seals probably originated from stocks in the North Sea rather than from the Baltic Sea (Härkönen et al.

2007). However, at Sweden's and Denmark's southernmost seal colonies, Måkläppen at Falsterbo and Rødsand at Danish Lolland-Falster, some 50 grey seals from the Baltic Sea population reside (Härkönen et al. 2007).

### 2.1.3 Benthic flora and fauna on the Swedish West Coast

On bottoms deeper than 20 meters, the relatively stable and high salinity in the southern Kattegat and up to the north of the Skagerrak makes the bottom fauna species composition and individual numbers fairly similar in the two areas. On a typical such bottom with a good supply of oxygen, it is common to find about 70 species per square meter, divided on about 4,000 individuals and with a total weight of approximately 150 gram wet weight. The most common animal groups are molluscs, crustaceans, polychaetes and echinoderms. Commercially important crustaceans such as lobster, Norway lobster and shrimp, are found in Sweden only in the Skagerrak and Kattegat as their distribution is limited by the low salinities in the Baltic Sea. Above the cline, the variation in salinity, wave exposure and temperature are higher, which affects the animal community composition and number of individuals and cause greater fluctuations than below the cline. (Rosenberg et al. 2004).

The Halland coast is exposed to westerly winds and the bottoms down to 20 meters depth are erosion bottoms or transport bottoms, which means that they consist primarily of sand and gravel, as opposed to deeper waters, which are mainly characterized by finer-grained sand and clay. The regular action of wind and waves in the shallower areas results in lower animal density and biomass than in deeper waters. On bottoms shallower than three meters, the number of species is low, but productivity can in many places be very high during the summer months. It is mainly crustaceans such as shrimp and amphipods, and various species of mussels, which account for the high production and makes these shallow areas very important as nursery areas and feeding grounds for many fishes.

Differences in water level caused by tides are at most 0,25 metres in the Skagerrak. High winds associated with changes in high and low pressure can cause considerably larger changes in water levels, causing differences in the range of one meter or slightly more.

If there is sufficient appropriate substrate on a hard bottom, attached macroalgae species are mainly limited by the depth of light penetration. The distribution can generally be described as green algae dominating close to the surface, below these mainly brown algae and the deeper parts dominated by red algae. In addition to light, the algal distribution is also controlled by nutrient availability and competition for space. In areas with clear water, some algae grow down to 25–30 meters. Also the microscopic planktonic algae, which constitute the food base for several marine filter feeding invertebrates, are dependent on light for their photosynthesis. They are therefore generally found in large amounts above the thermocline. The most common animals on rocky bottoms are blue mussels, barnacles, sea squirts, sponges, and sometimes various soft and hard corals.

## 2.2 The Baltic Proper

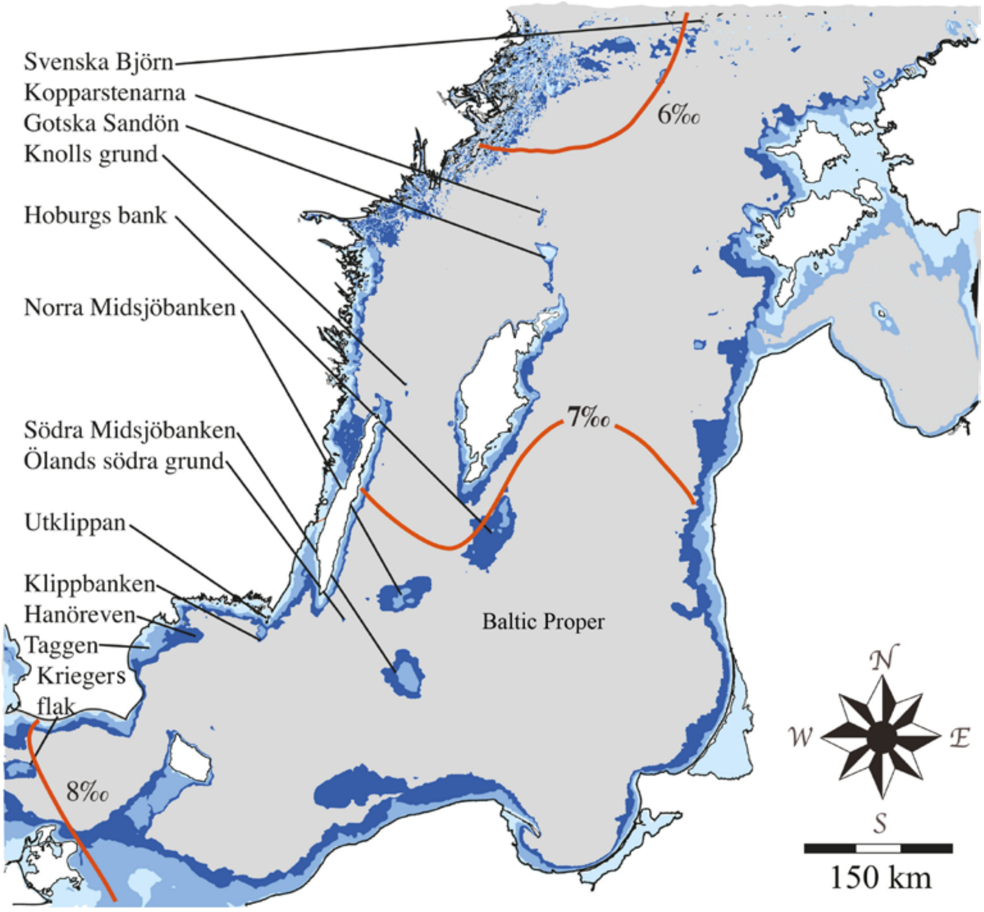
The Baltic is a shallow sea. Its only connection with the Northern Sea and the Atlantic is via the narrow Danish Straits (Seifert et al. 2001). At irregular intervals, seawater penetrates through the straits, and accumulates mainly in the Baltic Sea's deepest areas due to salty water being heavier than brackish. The surface water salinity is only one fifth of the salinity of the oceans since it is diluted by fresh water from rivers and other waterways (Winsor et al. 2001). The low salinity gives the Baltic Sea a very special flora and fauna, which consists of marine species, freshwater species and a few brackish water specialists. The number of species is relatively low, but some of them are present in large amounts (Bonsdorff 2006, Ojaveer 2010). The Baltic Sea is atidal, but water level variations of up to two meters in amplitude may occur. The main factors that affect the sea level are air pressure, wind and ice conditions (Hunicke and Zorita 2008). Periods of high water levels are common between October and March, and longer periods of low water levels occur frequently in spring (Malm and Kautsky 2003).

The more than ten areas that the Swedish Environmental Protection Agency has defined as offshore banks in the Baltic Proper are located at least ten nautical miles from the nearest land formations (map 3). Most banks are about ten meters deep, but some may be as deep as 30 meters below the surface (Naturvårdsverket 2010). Most of the offshore banks are made up of glacial clay and covered with movable moraine material, boulders, stones, gravel and sand (Naturvårdsverket 2006). The wave impact on the substrate is significant and ripple marks have been observed down to 30 meters on sandy bottoms (Naturvårdsverket 2006). Hoburgs Bank, together with Northern and Southern Midsjöbanken are the offshore bank areas that, according to the inventories of the Swedish EPA, have the highest natural values. This is largely due to the unique geomorphology of the banks and their large areas of important habitats (Naturvårdsverket 2010).

### 2.2.1 Fish in the Baltic Proper

SPECIES RICHNESS AND SPECIES COMPOSITION

In the Baltic Sea, marine fish often occur side by side with freshwater species, especially in the coastal area. The total number of species is lower than on the Swedish West Coast since the distribution of several marine species is limited by low salinity. Meanwhile, a lot of freshwater species are added. For the Baltic Proper a total of 66 fish species were recorded in the Board of Fisheries database of survey fishing with fixed gear during the period 2009–2010 (Fiskeriverket 2011). The coastal areas are dominated by freshwater species such as *Perca fluviatilis* and *Cyprinus carpio*. The marine species herring, sprat and cod are common in offshore areas, but they often wander into the coastal area in search of food. Herring also migrates in to the coast for its reproduction.




Map 3. Offshore banks in the Baltic Proper. Colours denote different depth intervals: light blue = depth between 0 to 20 meters, medium blue = depth between 20 and 30 meters, dark blue = depth between 30 and 40 meters and grey = areas deeper than 40 meters.

When test fishing with nets at the offshore banks of the Baltic Sea in the 2000s, 16 species of fish were noted, but the total number of fish species is probably higher. The results from test fishing are strongly connected to what type of gear that is being used, and several species, especially slim or small species and highly sedentary species, are not caught in survey fishing performed with nets. The most common species that occurred in the exploratory fishery was *Platichthys flesus*, cod and *Psetta maxima*. At the inventories of deeper waters using bottom trawls, the predominant species was cod, which accounted for 90–100 percent of the total number of individuals in the catch (Naturvårdsverket 2010).

Red listed fish species were present at all offshore banks, in particular cod. Other red listed species found were lumpfish and eel pout, with the highest incidence at Gotska Sandön and Hoburgs Bank, and *Merlangius merlangus* that occurred sparingly at Hanö Bank. For the most recent classification according to the Red List 2010, see the species list on page 73. Other species observed at offshore banks that are of interest in planning issues were *Coregonus spp*., *Pleuronectes platessa* and *Psetta maxima*. These species are not endangered but has an uncertain stock situation in parts of the Baltic Proper (Fiskeriverket 2011, Gärdenfors 2010). Sharks and rays are not present in the Baltic Proper.

### ESPECIALLY IMPORTANT HABITATS FOR FISH

The distribution of fish in the Baltic Sea is highly dependent on the prevailing environmental conditions, salinity being the most important. The salinity varies both geographically, decreasing inwards in the Baltic Sea, but it also varies over time. In the Baltic Sea, long periods of high salinity can transition into periods of lower salinity, which can affect the species composition of these areas (Diekmann and Möllmann 2010). In years of higher salinity, the marine species reach further into the Baltic Sea and vice versa. Fish in shallow offshore areas are also affected by depth, bottom topography and the presence of bottom currents. However, there is no general pattern for all species, the response in relation to these factors vary among different species. Analysis of fish distribution patterns also suggests that the abundance of fish is higher at greater distances from land. This may reflect a response to natural variations in environmental conditions, but also to differences in human influence, such as a higher fishing pressure in the coastal area (Bergström et al. 2011).

The importance of the offshore banks as spawning and nursery areas in different seasons is in not well documented. Few offshore banks are investigated and the inventories that have been conducted are merely representative of the season when the survey was conducted. The available information shows that some of the offshore banks are important spawning grounds for certain fish species. For example, a high incidence of adult *Psetta maxima* was noted at four offshore banks, mostly in the shallower areas, during survey fishing in early summer (Naturvårdsverket 2010). *Psetta maxima* spawn during early summer, which coincides with the time of the survey fishing. It is possible that the offshore banks are visited by other species correspondingly during other parts of the year. The shallow and relatively productive offshore banks are likely to be good nursery areas for many species, especially species of marine origin such as cod. Although fresh water species can stay in the open sea during juvenile growing periods and for overwintering, they occur mainly in coastal areas where they have their spawning grounds (Ljunggren et al. 2010).

In the natural value assessment of offshore banks in the Baltic Proper, ten areas were compared: Northern Midsjöbanken, Öland's southern base, Hoburgs Bank, an area east of Gotland, Gotska Sandön, Klippbanken, Utklippan, Hanö reefs, Taggen and an area southwest of Taggen (map 3). The highest natural values of fish were listed on Hoburgs Bank and the more coastal area at the area east of Gotland, but high values was also recorded on northern Midsjöbanken. The areas with the lowest natural values were Taggen and the area southwest of Taggen. When only areas shallower than 20 meters at each offshore bank were compared it altered the outcome slightly, so that Northern Midsjöbanken scored the highest values followed by Hoburgs Bank (Naturvårdsverket 2010).

Picture 1. At an inventory, spawning turbot, *Psetta maxima,* was found on several offshore banks in the Baltic Proper (Photo: Inge Lennmark).

### 2.2.2 Marine mammals in the Baltic Proper

Marine mammals are not directly affected by differences in salinity and oxygen concentration in the Baltic Proper. However, the distribution and species composition of their feed are controlled by such environmental factors, resulting in effects on mammal populations and can lead to seasonal migrations. The stocks of marine mammals in the Baltic Proper have varied over the last 100 years. In the early 1900s there were viable populations of both porpoises and grey seals in the Baltic Proper, but due to hunting, pollution, bycatch and for porpoises, also long winters with plenty of ice, decimated the populations sharply, reaching very low levels at the end of the 1960s (Berggren and Arrhenius 1995, Hårding and Härkönen 1999,). In the 1960s, regulations for hunting and pollutant emissions were introduced, which contributed to the recovery of the grey seal populations. Today there are over 20 000 grey seals in the Baltic Proper (Karlsson et al. 2010). In addition to grey seals, there is a very small (a few hundred animals) but viable population of harbour seals in the Kalmar Sound. These seals are red listed because the population has such low genetic variation (Gärdenfors 2010).

The harbour porpoise has not returned at the same rate as the grey seal. Bycatch and the severe ice-winters in the 1990's are probably some of the causes. Even the nearby populations in Denmark seem to be declining. It is possible that the recovery of harbour porpoise in the Baltic Proper is dependent on immigration from Kattegat and that the populations in Kattegat and the Danish areas are not large enough to support a recolonization of the Baltic

Proper. Today the estimated number of porpoises in Baltic Proper amount to a maximum of a few hundred animals (Berggren et al. 2002, Loos et al. 2010). Other whale species occur only as temporary guests in the Baltic Proper.

### 2.2.3 Benthic flora and fauna in the Baltic Proper

The composition of the benthic communities in the coastal areas of the Baltic Proper depend on the formation of the coastline, and is influenced by environmental factors such as temperature and salinity and the presence of ice and wave erosion.

From Southern Roslagen to northern Småland the coastline consists largely of rift valley terrain with a large element of rocky shores. Outside the coastline is a vast archipelago that reaches its greatest extent outside Stockholm. The archipelago thins out outside Östergötland while the coastline is broken up by several mile long bays that characterize the landscape down to the northern coast of Småland at Tjust and Misterhults archipelagos (Nordiska Ministerrådet 1984). The land uplift in the Baltic Proper's archipelago is apparent but decreases southward. From Oskarshamn and further south there is instead some subsidence (Ågren and Svensson 2007).

The coastline from central Småland to northeastern Blekinge is even, with vast and calcareous gravel beaches and few, low islands (Nordiska Ministerrådet 1984). The coast of Blekinge consists of bedrock with plenty of coastal cliffs. Off the coast there is a relatively narrow archipelago. The archipelago is widest at Karlskrona, where a few large islands shield the broad internal bays. East of Karlshamn, the coast is deeply indented (Nordiska Ministerrådet 1984). The Gotland limestone plateau is sloping slightly to the southeast. The northwest coast consists of high cliffs that descend steeply into the sea, while the east coast is mostly of a flat moraine coast type alternating with sandy beaches. Outside the east coast down to ten meters depth, the limestone rock is in the day (Nordiska Ministerrådet 1984, Malm and Isaeus 2005). Also Öland consists of a low limestone plateau that slopes slightly to the east and north with a cliff coastline on the northwest side. The east coast is flat and open and limestone rock is exposed down to a depth of 15 m, about three kilometres from shore (Nordiska Ministerrådet 1984, Malm and Isaeus 2005). Open shallow beaches of sand and moraine dominate the eastern and southern coasts of Skåne. Cliff coastlines occasionally appear, for example at Stenshuvud and Baskemölla. At the coast of Skåne, there is a subsidence with accompanying erosion, particularly along the south coast (Nordiska Ministerrådet 1984).

The salinity increases from about six permille in southern Kvarken to about eight permille in the South Öresund (Winsor et al. 2001). From the Åland Sea and south, the number of marine organisms increases gradually (Bonsdorff 2006, Ojaveer 2010). The marine angiosperm *Zostera marina* (eelgrass) has its northern limit in the Åland Sea and forms large meadows of about one to five meters depth along the Swedish Baltic Proper coast.

The species occurs mainly on sandy and relatively wave exposed localities (Boström et al. 2003) and consists in the northern Baltic Proper only of large, very old clonal populations (Reusch et al. 1999). All along the coastline, the inner, freshwater diluted bays are dominated by limnic species (Selig et al. 2007, Hansen et al. 2008). Soft, shallow bottoms in sheltered bays are covered by rooted vascular plants such as various pondweeds, watermill foil and water-crowfoot and a number of stonewort species, several of them red-listed (Gärdenfors 2010). The largest group of invertebrates in sheltered bays are larval stages of various insects (Hansen et al. 2008).

One species considered being of great ecological significance, and known as a foundation species in the Baltic Sea is the bladderwrack, *Fucus vesiculosus*. If the conditions are good, bladderwrack grows in dense belts along cliffs and rocky shores, providing both protection and foraging area for many fish species and larval stages. In Gryt archipelago in Östergötland bladderwrack coexists with *Fucus serratus* and from central Öland and south, the two species are clearly belt forming on wave-exposed localities, with bladderwrack dominating in the upper zone (Malm et al. 2001). In many places in the archipelago, the hard bottoms continue significantly deeper than the maximum depth limit of the seaweed, which varies between 10–15 meters depth. On these hard bottoms the community is dominated by blue mussels and filamentous red algae (Malm and Isaeus 2005). In places where bladderwrack has disappeared, this red algae and mussel community can expand upwards to four or five meters depth where the red algae becomes replaced by brown and green filamentous algal species (Malm and Isaeus 2005). The coastline of Öland and Gotland are completely dominated by hard bottom communities. It is only in a few bays that *Zostera marina* and other rooted aquatic plants have a greater distribution. The formerly dominant seaweed stands of wrack have been replaced by filamentous algal communities along many coastal stretches. But especially along the coast of southeastern Öland there are still large areas of *Fucus serratus* (Malm and Isaeus 2005). The composition of the algal communities along the coastline of Skåne is similar in many places to the Öland and Gotland communities. Bladderwrack and *Fucus serratus* grows on boulders and rocks whilst greater depths are dominated by the red algae and mussels (Olsson 1999). On sandy bottoms wide meadows of *Zostera marina* occur. Along long stretches of the south coast, however, the sandy substrate is very mobile, causing an absence of higher vegetation (Olsson 2004).

On the offshore banks in the Baltic Proper, a community of filamentous algae, mainly *Polysiphonia fucoides, Rhodomela confervoides and Ceramium virgatum* occur. The vast blue mussel communities that expand on the offshore banks are an important source of food for diving ducks (Naturvårdsverket 2006). In the offshore bank inventory of the Baltic Proper by Naturvårdsverket, no red listed invertebrates or macroalgae were noted (Naturvårdsverket 2010). However, the species compositions of the natural bottom communities in these shallow areas are unique in the world (Naturvårdsverket 2010), both through its mix of marine and freshwater species, and through their special adaptation to the low and stable salinity conditions.

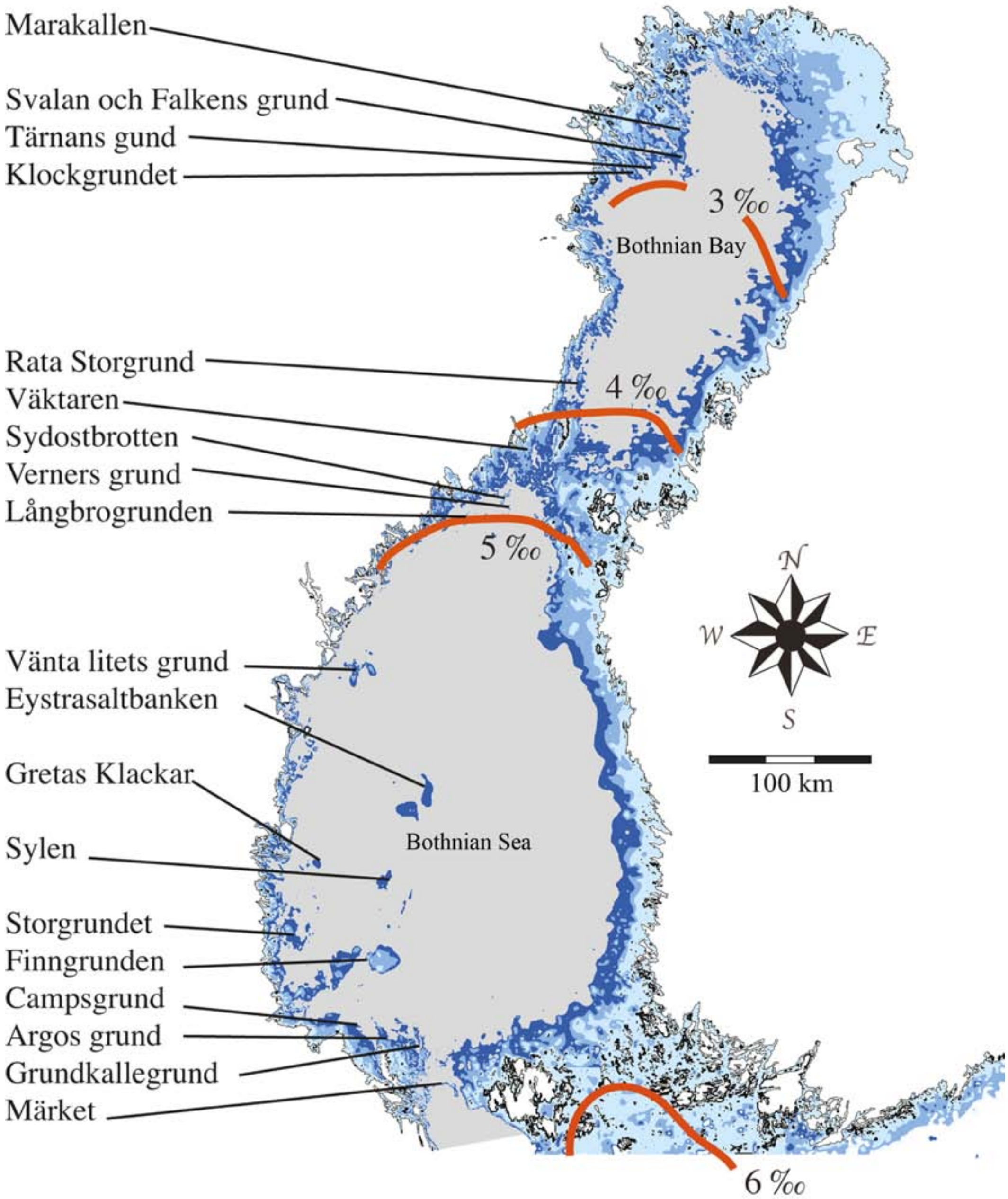
Picture 2. The blue mussel communities are abundant on the offshore banks in the Baltic Proper (Photo: Inge Lennmark).

## 2.3 The Gulf of Bothnia

The Gulf of Bothnia consists of the Bothnian Bay in the north and the Bothnian Sea in the south. The coastline of the Gulf of Bothnia is shallow and indented with alternating gravel and shingle beaches. In the northernmost parts, from Piteå to Haparanda and south around Umeå, there are broad coastal plains with forested archipelagos. The landscape between Piteå and Umeå consists of rock hill terrain with open coastlines (Nordiska Ministerrådet 1984). Land uplift is evident throughout the area, with about 10 millimetres per year (Ågren and Svensson 2007).

In the Bothnian Sea, the coastline of Västernorrland and northern Medelpad is characterized by high mountains that steeply descend into the sea at many places. The coast is indented with very deep bays. The inner bays are dominated by sand and clay sediment that gradually change to moraine and shingle beaches towards the sea. In the outer regions, bedrock cliffs are also common (Nordiska Ministerrådet 1984).

The southern coast of Norrland from southern Medelpad to the north of Gästrikland, is a slightly undulating rocky and moraine coast with a large element of shingle beaches. The coast gets progressively flatter going southwards. The coastline is largely dented with a thin ribbon of large and small islands. In flat coastline areas, there is distinctive land uplift. The coastline along the Gävle Bay and northern Roslagen is a flat moraine coast with elements of rock only in the southern part. The archipelago is narrow but rich in islands, with mainly forested islands (Nordiska Ministerrådet 1984). The land uplift is just over half a meter per century, which has a high effect on the flat coastline (Ågren and Svensson 2007).




Map 4. Offshore banks in the Gulf of Bothnia. Colours denote different depth intervals: light blue = depth between 0 to 20 meters, medium blue = depth between 20 and 30 meters, dark blue = depth between 30 and 40 meters and grey = areas deeper than 40 meters.

### 2.3.1 Fish in the Gulf of Bothnia

SPECIES RICHNESS AND SPECIES COMPOSITION

The relative importance of freshwater species is higher in the Gulf of Bothnia than in the Baltic Proper. In open water, however, marine species are most common, represented mainly by herring and sprat. Other marine species occur mainly in the outer water areas of southern Gulf of Bothnia, especially in years with higher salinity when, for example, cod migrates into the Baltic Proper (Diekmann and Möllmann 2010).

During survey fishing with nets at offshore banks in the Gulf of Bothnia, a total of 11 fish species were found. The most common species were herring, sprat, eelpout and *Triglopsis quadricornis*. During survey fishing at the Marakallen offshore bank in Gulf of Bothnia, 7 species were found. The most common species was *Triglopsis quadricornis*, but also herring and *Coregonus spp.* were common. The other species found were *Osmerus eperlanus, Coregonus albula, Perca fluviatilis* and *Gymnocephalus cernuus* (Naturvårdsverket 2010). In Gulf of Bothnia 29 species of fish were registered in the Board of Fisheries database of survey fishing with fixed gear during 2009–2010 (Fiskeriverket 2011).

Picture 3. Eelpout, *Zoarces viviparus,* is listed as near threatened in the ArtDatabanken Red List 2010. It was one of the most common species caught at test fishing with nets on offshore banks in the Gulf of Bothnia (Photo: Inge Lennmark).

Of the red-listed species, primarily eelpout is common on offshore banks in the Gulf of Bothnia. Survey fishing at Storgrundet noted a high frequency of eelpout females with fertilized roe, mainly at depths less than 10 meters, suggesting that the ground is a spawning ground for eelpout (Storgrundet Offshore AB 2009). No red-listed species were noted at Marakallen in Gulf of Bothnia, but the presence of *Coregonus spp.* was relatively high. Coregonus species have experienced declining populations and reduced growth in the Gulf of Bothnia during the 2000s (Florin 2011). Although the species is not red-listed, there are reasons for concern related both to fishing pressure as well as to the impact on coastal spawning grounds from eutrophication and construction. The species might also have been negatively affected by the relatively high water temperatures in recent years (Gärdenfors 2010, Naturvårdsverket 2010).

### ESPECIALLY IMPORTANT HABITATS FOR FISH

The freshwater species in Gulf of Bothnia spawn in the coastal area, for instance in sheltered bays, near freshwater outflows and on flooded meadows. The main spawning season is during early spring and early summer (Ljunggren et al. 2010), but species such as *Coregonus albula* and other *Coregonus* species spawn mainly in coastal areas during early autumn (Kaljuste and Heimbrand 2009). Salmon and some strains of *Coregonus* species migrate regularly between nursery areas in open waters and their spawning areas on the coast or up in the rivers (Saulamo and Neumann 2002). Of the marine species in Gulf of Bothnia, herring spawn in shallow offshore areas as well as in the coastal area, while the cod does not reproduce in the Gulf of Bothnia.

The herring, which is a particularly important species in the Gulf of Bothnia, can spawn in various types of areas, but the optimal environment for spawning is often considered to be near deep areas that ascend steeply up to more sheltered environments (Aneer 1989, Karås 1993). Spawning takes place mainly during spring and early summer, but autumn spawning herring are present. This temporal resolution can be genetic or be controlled by water temperature, so that temperature and food supply affect how quickly the herring reach a sexually reproductive age. At the same time, reproduction does not seem to be successful at too high water temperatures (Aneer 1985, Rajasilta 1992, Rajasilta et al. 1997). Outside spawning season herring occurs in water bodies that provide optimal conditions for foraging and growth in relation to the prevailing water temperatures, i.e. with a temperature optimum just below +15 °C (Karås 1993). During hydro acoustic surveys in the Bothnian Sea in early spring, most of the herring were observed at typical wintering areas in deeper waters, particularly between 50–90 m depth, and the species occurred only rarely at the offshore banks (Kaljuste et al. 2009). When survey fishing with nets at Finngrunden during May, the herring was, however, frequent (Nikolopoulos and Wikström 2007), and 94–97 percent of the herring caught were sexually mature (Naturvårdsverket 2010).

The share of offshore banks that have been surveyed in the Gulf of Bothnia is too low to be able to make general predictions of fish distribution patterns. This is particularly true in the Gulf of Bothnia, where the survey fishing has only been performed at Marakallen. A comparison of the natural values of the three largest offshore banks in the southern Gulf of Bothnia, Finngrundet Eastern Bank, Finngrundet Western Bank and Storgrundet shows considerable similarity in fish community structure and composition. The number of species was slightly higher at Finngrundet Western Bank than in the other areas (Naturvårdsverket 2010). The Vänta Litets Bank in the northern Gulf of Bothnia was estimated to have a somewhat lower conservation value, although this may be because the area was fished at a significantly lower water temperature. During a hydroacoustic survey conducted in the spring, the amount of fish was about the same on the Vänta Litets bank as on Storgrundet and Finngrundet Western Bank. Larger herring individuals were more common in the northern and central parts than in the south of the Gulf of Bothnia (Naturvårdsverket 2010, Kaljuste et al. 2009).

The fish community at Marakallen in the Gulf of Bothnia had a similar number of species and species composition as the offshore banks in the southern Gulf of Bothnia and the density of fish were as high or higher. In the area there are no marine predatory fish but *Perca fluviatilis* that is a freshwater predatory fish. The offshore bank Marakallen and an area west of this, Norrströmsgrundet, were included during 2009 in an overall hydroacoustic survey in which offshore banks and more coastal areas were compared to each other. In these studies a total of seven fish species were noted, with herring and *Coregonus spp*. as the most common species. The other species were *Coregonus albula*, sprat, *Osmerus eperlanus, Gymnocephalus cernuus* and *Triglopsis quadricornis*. *Coregonus albula* were more common inshore than at the offshore banks at the time of the investigation, because it was conducted during spawning time for *Coregonus albula*. The geographical distribution of herring was relatively even. The species that were more common at the offshore banks than in the coastal area was *Coregonus spp*., herring and *Gymnocephalus cernuus*. The total number of individuals and biomass were similar in coastal and offshore areas studied (Kaljuste and Heimbrand 2009).

Picture 4. Many freshwater species live in the Gulf of Bothnia, among them the common predator perch, *Perca fluviatilis* (Photo: Inge Lennmark).

### 2.3.2 Marine mammals in the Gulf of Bothnia

The two marine mammals that predominate in the Gulf of Bothnia are the ringed seal and the grey seal. Porpoises and other whales are extremely rare. There are between 7,000 and 11,000 ringed seals in the Baltic Sea, with the largest share of the Swedish population residing in the Gulf of Bothnia

(Karlsson et al. 2010). The ringed seal is considered to be a relic from the Baltic Ice Lake, which has its origin in the Arctic, and remained in the Baltic Sea after the last ice age (Amano et al. 2002). It gives birth to its young in cavities in the ice and feed mostly on small schooling fish such as sprat, herring and *Coregonus albula*. In addition, ringed seals eat a lot of shrimps and isopods such as *Saduria entomon*.

Ringed seals and grey seals are specialized in giving birth to their pups on the ice. In the Gulf of Bothnia the grey seals and ringed seals carry out seasonal migrations whose extent depends on the season, ice distribution and prey fish's movements. This seasonal variation is poorly described in the literature, but both grey and ringed seals may travel very long distances in a short time. However, there are no documentations showing that any of these species, or the small population of harbour seals in the Kalmar Sound, move out into the Kattegat.

### 2.3.3 Benthic flora and fauna in the Gulf of Bothnia

The salinity increases from less than one permille in the northern archipelagos of the Gulf of Bothnia to around four permille in the southern part of the North Quark (Winsor et al. 2001). This salinity is too low for most marine organisms and too high for many freshwater species. The natural number of species is therefore low (Bergström and Bergström 1999). The shallow bottoms along the coast are exposed every year to severe abrasion by sea ice, which further prevents the establishment of hard bottom dwelling marine species (Perus et al. 2007). A few larger organisms are found on stones and boulders, such as the moss: *Fontinalis antipyretica*, the threadlike green algae: *Cladophora,* and the freshwater sponge: *Ephydatia fluviatilis* (Pettersson 2007). The benthic flora and fauna is derived primarily from fresh water and is concentrated to soft and sandy bottoms. Vascular plants and stoneworts dominate the flora and the number of species is highest in the northern archipelagos, decreasing southwards with the rising salinity (Pettersson 2007).

The salinity of the Bothnian Sea rises from around four permille in the Northern Quark to about six permille in the Åland Sea (Winsor et al. 2001). Sea ice occurs almost every year in the coastal areas but the thickness of the ice is less than in the Bothnian Bay and thus the abrasion by ice is often not as extensive (Perus et al. 2007). Many hard bottoms benthic organisms in the Baltic Sea who are dominant further south, such as the *Semibalanus balanoides*, blue mussels, *Rhodomela confervoides, Furcellaria lumbricalis*, bladderwrack and the recently described *Fucus radicans* (Bergström et al. 2005) have their northern distribution limits in the Northern Quark or just south of it (Bergström and Bergström 1999). *Fucus radicans* reproduces by cloning and is endemic to the Baltic Sea (Pereyra et al. 2009) which may make it sensitive to environmental changes and thus worth extra concern for protection (Bergström et al. 2005). The inner bays all along the coast, that are diluted with freshwater are dominated by rooted aquatic plants, stoneworts and other freshwater species. Within the group Characeae (stoneworts) are a number of red listed species (see Gärdenfors 2010).

The vegetation reaches down to about 20 meters on the offshore banks in the Gulf of Bothnia (Naturvårdsverket 2010), which is significantly deeper than in the coastal zone (Perus et al. 2007). On the shallow banks in the southern Bothnian Sea, some of which partly reach up to the surface, large areas of bladderwrack and *Fucus radicans* have been observed (Naturvårdsverket, 2010). The banks in the Gulf of Bothnia are species poor. Below 10 meters depth, the communities are more or less monocultures of *Sphacelaria arctica* with occasional *Rhodomela confervoides* and blue mussels (Naturvårdsverket 2010). The Vänta Litets bank offshore Sundsvall has dense mussel populations according to inventory data.

# 3. Offshore wind power – requirements and properties

The impact of a wind power project on its surroundings depends to a great extent on the choice of construction and building method. The choice of construction is determined by the external factors the different parts of the construction must withstand. An offshore wind farm must, in addition to the forces of the construction itself, be able to withstand strong impact from waves, strong wind and sometimes ice.

The technical structure of a windmill enables the construction to absorb forces of impact in different ways, which affects the dimension and design of the foundation. In order to optimize the construction from an environmental, technical and economic perspective, it is therefore important that the characteristics of the windmill are determined before the foundation is constructed.

The impact of offshore wind projects can be divided into three main phases: installation phase, operation phase and decommissioning phase. The greatest impact on the marine life is during the installation phase, which gives rise to acoustic disturbance, sediment dispersal and introduction of a new habitat. These effects are considered in Chapter 4. This chapter discusses the impacts from a technical perspective.

The construction of a wind farm is always preceded by extensive planning and an approval process. For the wind farm Storgrundet outside Söderhamn, consultation and site investigations commenced in 2006. Permission was finally granted by the Land and Environmental Court in 2011, and construction is planned to take place no earlier than 2014. Several laws are involved in offshore wind farm installations: the Environmental Code, the Planning and Building Act, the Continental Shelf Act, Electricity Act and the Cultural Act. A web guide on how to accomplish and review an Environmental Impact Assessment (EIA) for a wind power project can be found at the Swedish EPA website (see references).

## 3.1 Installation

The installation of offshore wind turbines starts with detailed geotechnical investigations of the site where the plants will be placed, and where the cable pathways connecting the wind turbines and the electricity grid should be drawn (Hammar et al. 2008a). Before the placement of the foundation and electrical cables are set, the bottom has to be examined to ensure that no archaeological remains will be harmed.

There are primarily two types of foundations used in Sweden: gravity-based foundations (figure 1), and monopile foundations (figure 2). These two are in the current situation also the most commercially viable, but there are a number of other foundation technologies available for offshore windmills.

The rapid development of offshore wind power, and the great interest in technology driven by increased electricity prices and the need to reduce our impact on climate, has led to the utilization of greater depths. This in turn has accelerated the development of tripods and foundation with several poles. Outside the Norwegian coast, at very large depths, floating foundations have been tested. These are held in place with wires extending from the lowest point of the foundation, which is about 100 meters below the surface, and down to the bottom. In some places, such as off the coast of Portugal, floating foundations are tested in shallower waters. The following section describes methods for the construction of gravity-based foundation and monopile foundation. The techniques are similar to those used in the construction process of other commercial types of foundations.

### 3.1.1 Gravity-based foundations

A gravity-based foundation (GBF), is a structure that due to its own weight is stable enough to withstand the various loads caused by wind, waves and ice. To protect the foundation against damage from the pack ice during cold winters, GBFs are often hourglass-shaped so that the top angle can break away ice. For logistical reasons, GBFs are prefabricated on land. Production is generally in accordance with two principles: either in a dry dock or on shore. Casting of the foundation can also be made directly on a barge as an alternative to a site on land. The finished fundaments are then transported to the site, floating in separate parts, or on barges. Once put in place, the foundations are filled with ballast, for example olivine, which means that an entire foundation can weigh 3,000–7,000 tonnes. Usually all types of foundations require some form of protection against erosion in order to prevent water movement from undermining the anchoring (SGS 2005). Before the crushed masses of ballast are added, the bottom is prepared so that it is smooth and firm, which may require some digging. The foundation should preferably be 0,5 to 1 meter below the adjacent ground to get the right pressure on the structure.

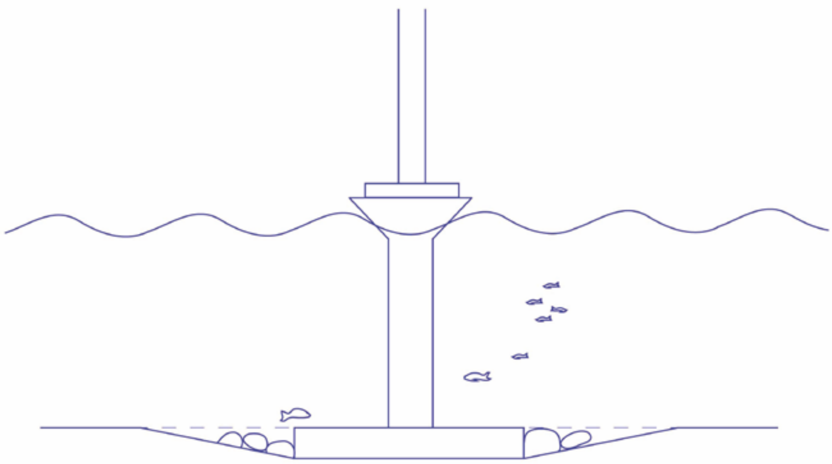


Figure 1. Schematic drawing of a gravity-based foundation made of concrete (scales and dimensions are not proportional).

WHEN ARE GRAVITY-BASED FOUNDATIONS USED?

Gravity-based foundations (GBF) that are made of concrete have a relatively large base resulting in a high load from water movements laterally, and the cost for traditional GBFs (manufacturing and installation) increase exponentially with depth. Therefore, concrete GBFs are mainly an option for shallow waters. Deeper installations are technically possible (SGS 2005) and there are prototypes designed for depths of 20–30m, which is planned for a Belgian wind power project in the Thornton Bank of North Sea (EWEA 2007). GBFs made of steel have been developed to be able to utilize deeper water (DWIA 2003).

Since this kind of foundation does not require a deeper recess in the bottom substrate, GBFs can be adapted to a variety of bottom substrates by adjusting the base diameter. This makes GBFs well suited for rocky bottoms and bottoms with boulders as well as stable (well packed) sediments. Bottoms of consistently loose sediment are however not appropriate for a GBF (SGS 2005).

The technology for this type of foundations is well proven today and GBFs are used for example at the wind parks of Nysted, Vindeby and Tunø Knob in the Bält Sea, Middelgrunden in Kattegat, Lillgrund in Öresund and at Thornton offshore in Belgium.

### 3.1.2 Monopile foundations

Monopile foundations can be used at most sites and they are the most commonly used foundation today. The foundation consists of a simple pile of steel that is plunged far down in the bottom by pile-driving or drilling. The latter is foremost used on stony bottoms and/or bottoms with a high density of boulders.

The diameter of the foundation and the depth of piling can be adjusted to the loading weight. Even if the water movements might dig out the sediment, the monopile foundations are not as dependent on wave score protection as gravity-based foundations. The technique is relatively simple and does not usually require any pre-processing of the bottom. However, during the installation pile equipment with large lifting capacity is required. A monopile foundation can be up to seven meters in diameter, while e.g. a tripod can consist of three smaller piles with a diameter of two metres each.

During piling, the surroundings are affected mostly by the noise generated by the hydraulic pile-driver. The construction starts when a ship or barge is fixed in position (for example with computerized operated anchorage ropes) over the planned attachment point. After that, the pile of the foundation is plunged in position by cranes and a hydraulic pile-driver. The piling is done by heavy beats, where the strength and the frequency of the beats are adjusted due to prevailing conditions, until the desired depth in the sediment is achieved. Where boulders or other impermeable substrate are present, the piling is interrupted and a drill head is lowered down in the hollow cylinder to get through the material. The number of beats, the strength of the beats and the need for drilling or blasting is strongly dependent upon the type of bottom substrate, the depth of anchorage and the diameter of the foundation.

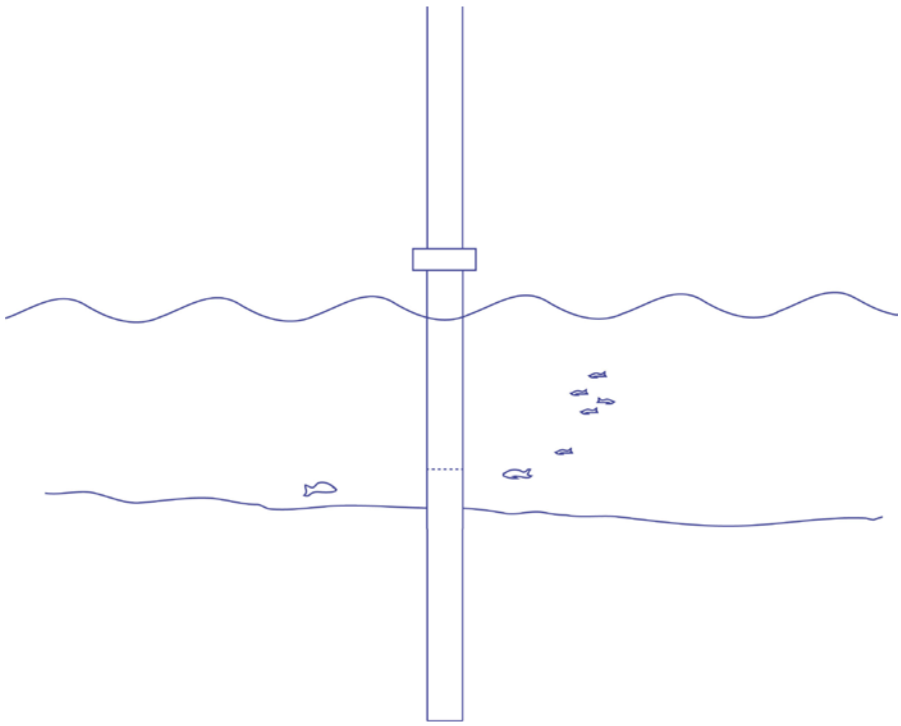


Figure 2. Schematic drawing of a monopile foundation made of steel (scales and dimensions are not proportional).

This leads to very large variations between different wind parks and between individual foundations (table 1). After completed piling, the transitions piece of the monopile foundation is put in place and the installation phase can be completed (Dahlén personal comment).

When drilling is used to construct monopile foundations, it is done using a casing (sometime the monopile acts as a casing). The casing is a metal structure slightly wider than the drill. Its function is to guide the drill and drill bit through the air, water and soft materials. It also prevents material from the drilling to spread uncontrollably, and hinders material from outside the insulation pipe to penetrate and interfere with the drilling. The casing is held in place by a frame mounted on the barge or vessel used.

The drill cuttings produced are sent up through the casing with a water and air mixture that is circulated during drilling. If necessary, the sediment dispersal can be reduced by various forms of "skirts", or captured on barges or with geotextiles. Once drilling is completed, the monopile foundation is installed and the space between the monopile foundation and the adjacent rock or other hard substrate is sealed with mortar.

### PILING NOISE DURING INSTALLATION OF MONOPILE FOUNDATIONS

In table 1 the measurements of piling noise during the construction of monopile foundations at Utgrunden in Sweden, North Hoyle in Scotland and Horns Rev in Denmark are presented. The noise levels can be measured as the sound exposure level (SEL): the level of sound for a moment standardized to a second, or peak pressure, which is the highest level of sound achieved in a pulse. Both measures are relevant in evaluating the effects of noise on the marine fauna. Measurements show that piling noise can have a varying source values for different construction methods. Read more about effects on marine fish, mammals and invertebrates in chapter 4 and on how the effects of noise can be reduced in chapter 5.

**Table 1. Piling noise during installation of a few monopile foundations.**

| Offshore Wind Park | Diameter (m) | Distance (m) | Frequency interval with elevated sound level (Hz) | Energy density, SEL (dB re 1 μPa²s) | Sound intensity (dB re 1 μPa peak) | Reference |
|---|---|---|---|---|---|---|
| Utgrunden | 3 | 30 | 4–20,000 | 184 | 203 | ØDS 2000 |
| | | 320 | 4–20,000 | | 183 | ØDS 2000 |
| North Hoyle | 4 | 955 | 40–1,000 | | 192 | Nedwell & Howell 2004 |
| | | 1881 | 40–1,000 | | 185 | Nedwell & Howell 2004 |
| Horns Rev | 4 | 230 | <100–100,000 | | 185 | Tougaard et al. 2008 |
| | | 930 | <100–100,000 | | 178 | Tougaard et al. 2008 |

WHEN ARE MONOPILE FOUNDATIONS USED?

The monopile foundation can be used in bottom conditions such as stone mixed bottoms, sand or clay where there is an underlying solid bed. The technique is on the other hand less suitable in bottom conditions where there is a high density of boulders, rocky bottoms or where clay is predominant in all layers (SGS 2005). In the presence of stony bottoms or occasional boulders, drilling is used for the on-going piling process. So far the monopile foundations have been declared to be an economical alternative down to the depth of 20–25 m (SGS 2005; WPD 2005).

At the Swedish West Coast (Kattegat and Skagerrak) the dimensions of constructions for a certain depth are based upon the water movement effects, such as waves, whereas the heavy weight stress from ice is the main concern in the construction work of monopile foundation in parts of the Baltic Sea (DWIA 2003). The costs increase with depth and are therefore more expensive in the Baltic Sea than at the Swedish West Coast and similar ice free ocean areas. The monopile foundation has great advantages in areas with sediment movements, such as drifting sandy bottoms, since the foundation is plunged deep (10–40m) into the bottom substrate (SGS 2005).

Examples of wind parks with monopile foundations are Arklow Bank (Irish Sea), Horns rev, Scroby Sands and Kentish Flats (North Sea), and Utgrunden (Baltic Sea).

### 3.1.3 Electricity connections

The electricity produced by a wind farm is normally collected via a transformer station to one or more transmission cables. By converting to a higher voltage level at the wind farm, the number of transmission cables to shore and total losses can be reduced. The transmission cable, or cables, connects the wind farm to the public electricity grid. The number of cables and their voltage levels depends on the size of the wind farm and the distance to shore.


Picture 5. Installation of transformer station at Lillgrund (Photo: Hans Blomberg/Vattenfall).

The submarine cable is performed as a three conductor AC cable with fibre optic cable for communications. The conductors in the cable are made of copper or aluminium. The insulation material is plastic and the cable is mechanically protected by an outer reinforcement of steel.

Submarine cables are generally of such length and size that specialized vessels are required for transportation and establishment. The placing of the submarine cables requires a careful analysis of the bottom and identifying what risks are to be considered, such as ice, currents, shipping and trawling. The risks will determine which parts that should be protected by burying or covering. At the shore connection site, cables should be placed deeper into the bottom to withstand impact from ice and waves.

The techniques used to place the cable in the bottom substrate is ploughing, washing or digging. Ploughing causes less turbidity problems than digging or jet techniques such as washing. In both cases, the aim is to replace as much as possible of the bottom material over the cable. In places where it can be difficult to dig the cable may also be covered with concrete blocks.

SEDIMENT DISPERSAL DURING INSTALLATION

Dredging, drilling and the laying of cables during the installation phase of offshore wind farms causes sediment particles to spread and stay suspended in the water column for a shorter or longer time (Hammar et al. 2009). This can cause organic material, nutrients and possible toxins bound to sediment particles, to spread to the surrounding water. During the dredging of gravity-based foundations at the offshore wind park of Lillgrund (Öresund) the sediment concentration in water was measured to be <10 mg/l at a distance of 200 metres from the source (DHI 2006). The sediment spill from the dredged masses was estimated to 4,8 percent (DHI 2006). However, at most submerged constructions, such as harbours, bridges and tunnels, the bottom are dredged. A study by Bonsdorff et al. (1984) reported measurements of 10–40 mg/l of sediment in the surrounding waters at different dredge works in the Finnish archipelago. Occasionally, sediment levels of 100–200 mg/l, in extreme cases up to 400 mg/l, were found. Other human activities, such as shipping and bottom trawling also cause sediment dispersal.

One reason why many species survives sediment dispersal is that certain background turbidity is common in all waters. Sediment particles swirl up from the bottom of natural causes, such as during heavy wave action caused by strong winds or by bottom currents. In Öresund, values of 0–2 mg/l was measured during calm weather, increasing up to 40 mg/l at times of increased wind speed (Valeur 2001). From the Finnish side of the Gulf of Bothnia background values of 2–10 mg/l have been reported (Bonsdorff et al. 1984). On both erosion bottoms and transportation bottoms, dispersal of sediment particles is common, particularly in cases of strong wind.

Environmental effects of turbidity due to construction of wind power foundations and drawing of cables should be put into perspective to other work performed, as well as natural turbidity levels. Offshore wind farms are often built on the offshore banks where the bottom material is relatively coarse, since they are naturally exposed to strong water movement. This means that the organisms will not be exposed to settling particles to the same extent as in shallow coastal environments with finer sediment. For effects on marine organisms by sediment dispersal read Chapter 4, and for measures that can be taken to reduce the effects of dredging read Chapter 5.

### 3.1.4 Wind turbines

After the foundation is put in place and electrical cables are routed through the foundation, the installation of wind turbines begins. There are three common installation methods for the actual wind turbine. The rotor can be assembled on land, transported to site and assembled in the already built tower and machine house. The rotor, machine house and tower can be assembled onshore and then be transported as composite construction to the site for installation on the structure. The blades can also be mounted, one by one, on the engine house built on the site, which is more complicated out at sea than on land. Installation can be done either by using different solutions using barges or vessels that usually have to use supporting legs to be able to implement safe lifting. The main limiting factors for the assembly are changes in wind direction, and wave height.

Picture 6. Installation of wind turbine at Lillgrund (Photo: Hans Blomberg/Vattenfall).

## 3.2 Operation

Boat traffic in the wind park due to scheduled service work, maintenance and unscheduled repairs will be consistent throughout the operational phase. Operation of wind parks at sea differs from those on land because:

- Work at sea is limited by weather conditions that may prevent access to the turbines.
- Work at sea is expensive, so the importance of planning and design of components that can minimize the need for servicing increases.

TURBINE NOISE AND BOAT TRAFFIC

The turbines are equipped with advanced monitoring systems to enable maintenance in the most efficient manner possible and to reduce the need for transport. Transportation to and from the wind farm is typically carried out by smaller vessels, but helicopter might be an option in circumstances where it is difficult to put to at the wind turbine. Ship traffic results in a slight increase of the underwater noise. Sound strengths and frequencies will vary depending on the vessels used during maintenance. The use of hovercraft service vessels during periods of ice cover reduces the noise spread in the water (Blackwell 2005). Major repairs of wind turbines are usually done with the help of crane-equipped vessels with or without stabilizing legs.

The underwater noise in a wind farm in operation depends on the type of wind turbines and on the type of foundation. The sound originates from individual components of wind turbines, such as the gearbox, generator and blade rotation. If future studies show that the noise must be reduced to lessen the impact on biological life, it is a technical question that can be considered in the design.

All boat and ship traffic at sea generates underwater noise at the same frequencies as wind turbines during the operational phase, which may mask the operating noise at relatively long distances (Madsen et al. 2006, Andersson 2011). Of course it is difficult to compare the future of different energy supply systems with each other but to not expand the offshore wind power, could lead to other exploitations of energy sources, and therefore increased vessel traffic in Swedish waters, and possibly an increase in the use of fossil fuels. For the effects of noise from windmills in operation and boat traffic read Chapter 4, and for measures that can reduce the effects of noise read Chapter 5.

### ELECTROMAGNETIC FIELDS

Electric and magnetic fields arise for example where electricity is produced, transported or consumed and is therefore present in the marine environment as well as on land (Svenska Kraftnät 2010). Both magnetic and electric fields decrease in strength and size with distance from the cable.

Within an offshore wind farm a magnetic field is generated due to the current in the cable parts and electrical components. The magnetic field of the cables is no different from other cables that electrify the archipelago environment or connects Sweden with other countries. The largest magnetic field is the static magnetic field of the Earth, whose field strength reaches 50 µT in Sweden. Depending on which direction the current is led through a cable, the Earth's magnetic field is either amplified or attenuated. The magnetic field is strongest directly above the cable, becomes weaker laterally, and decreases with distance from the cable. The size of the magnetic field depends on how the leaders within the cable are located. By using three conductor electric cables to lead the AC, magnetic fields can be reduced to such low levels that no effects on marine life have been observed (Kling et al. 2001). Some short term effects where, for example eels temporarily changes direction has been demonstrated by studies on DC power cables and their possible effects on fish that navigate by making use of the geomagnetic field (Read more in section 4.1.5).

Electric fields arise when voltage is applied to a conductor. Underneath overhead lines on land, an electric field can generate between the ground and power lines, but it decreases rapidly in strength and is screened by vegetation and buildings. Within a cable the electric field is isolated inside the wire walls, and therefore do not spread to the surroundings (Kling et al. 2001). Cable connections are an important part of the licensing process when applying for permission to construct a wind farm. Also needed are approval of construction under the Environmental Protection Act, concession under the Electricity

Act, planning permission under the Planning and Building Act and the right to use the water sector. Submarine cables are buried in the ground in many places in the Swedish coastal areas. In assessing the environmental effects of electromagnetic fields, it should be taken into consideration that wind parks are not the only projects that places electric cables in Swedish waters.

## 3.3 Decommissioning

To decommission a wind farm out at sea is more complicated than on land. The methods used will depend on the type of foundation to be dismantled. Consideration must also be taken to the surrounding marine environment and the knowledge available at the time of decommissioning. The monopile foundation is usually cut one or a few meters below the ground surface. The column can then be lifted up as a whole on a transport barge. The disposal is expected to take 1,5 days per turbine.

For gravity-based foundations the weight is of great importance. There are three possible methods of decommissioning. One alternative is to use underwater cutting tools to divide the construction into more manageable parts and then move them from the site. They can be processed by hydraulic hammers or concrete-scissors. Another alternative is to blast the construction into smaller parts, thereby making it easier to transport. A third option is to remove the ballast and then using a pump to replace the water inside the base by air. The foundation can then be towed to shore. The cost of this phase is primarily due to which type of boat is required and the duration of the operation. Usually, the same vessel used during the installation will be used in this stage.

# 4. Effects on marine organisms and communities

Offshore wind farms along the northwestern coasts of Europe are built in the depth range 5–40 meters, but the construction depth will, with emerging technologies likely be able to be deeper than that. Today, however, the establishment is limited to coastal areas and offshore banks (4COffshore 2011). The wind power industry prefers to build on sandy bottoms with moderate elements of rock and boulders. Such bottoms are suitable for the construction of both gravity-based foundations and monopile foundations.

Establishment of offshore wind power obviously means changes that may affect the natural environment. In this chapter, we address the factors of influence that according to found literature have effects on fish communities, marine mammals and benthic flora and fauna. These groups are affected in one way or another by the construction, operation or decommissioning of offshore wind power.

Based on current knowledge, each effect has been assessed based on if it is noticeable at 10, 100, 1000 or more than 1000 meters from a turbine tower, and whether the effect takes place during installation phase, operation phase or if it is permanent. The assessment relates to each effect separately, and does not take into account the combination of multiple effects simultaneously, or the influence of other environmental disturbances such as shipping or trawling.

All studies performed within the Vindval research programme suggest that local environmental conditions are of great importance for what the effects on marine life will be. This makes it difficult to generalize results from one area to another, especially for benthic communities and reef effects (Malm 2006), but also on fish communities (Hansson 2006). Investigation results show the great importance of well-conducted studies and the importance of finding a comparable control area in order to determine the impact of wind power and study the environmental impact in the short and long term. When site-specific studies have been undertaken, these considerations can be adapted. For example, it may require special protection of an endangered species or prohibition of construction during certain times of the year. Also, detailed investigations minimize the risk that unnecessary measures to reduce effects from wind power are taken.

**Box 3. Criteria for assessing the impact of windmills on marine life.**

**ASSESSMENT CRITERIA**
The following criteria have been used to assess the impacts of windmills on marine life in Swedish waters:

**STRENGHT OF ASSESSMENT**
**1:** The literature is very limited and knowledge is lacking for a scientifically based assessment.
**2:** The literature provides a possible basis for a scientifically based assessment, but results from different studies may partly be contradictory.
**3:** The literature provides a good basis for a scientifically based assessment.
**4:** The knowledge base is very good and gives a reliable assessment

**SPATIAL DISTRIBUTION**
**Very local:** The effects are noticeable less than 10 meters from each turbine foundation.
**Local:** The effects are noticeable up to 100 meters from each turbine foundation.
**Large:** The effects are noticeable up to 1000 meters from each turbine foundation.
The effects are noticeable throughout the park area.
**Very large:** The effects are noticeable more than 1000 meters from each turbine foundation. The effects are noticeable even outside the wind farm.

**TEMPORAL SCOPE**
**Short:** The effect lasts only during the installation phase.
**Long:** The effect lasts throughout the operational phase.
**Permanent:** The effect persists after the turbines are decommissioned.

**SWEDISH SEA AREA IN WHICH ASSESSMENT IS RELEVANT**
**A:** West Coast
**B:** Baltic Proper
**C:** Gulf of Bothnia

**DEGREE OF INFLUENCE ON POPULATIONS AND COMMUNITIES**
**Small:** Small or negligible effects on communities and populations.
**Moderate:** Changes in the proportion of different species, but no changes in the functioning of the community.
**Large:** Changes in community structure, such as exclusion of important species or introduction of new species that affects the original environment and its function.
(The criteria are based on the IUCN-report, see Wilhelmsson et al. 2010).

**Table 2. The effects of wind power on fish, marine mammals and benthic flora and fauna.**

| | Effects on marine organisms and communities (page reference) | Strenght of assessment (1 = low, 4 = high) | Assessment of the effect | | | |
|---|---|---|---|---|---|---|
| | | | Spatial distribution | Temporal scope | Swedish sea area in which assessment is relevant | Degree of influence on populations and communities |
| Fish | Acoustic disturbances during the installation (47) | 3 | Large | Short | All | Moderate - Large |
| | Sediment dispersal during the installation (48) | 3 | Large | Short | All | Small |
| | Introduction of new habitat (49) | 3 | Local | Long | All | Small - Moderate |
| | Turbine noise and boat traffic (51) | 2 | Large | Long | All | Small - Moderate |
| | Electromagnetic fields (52) | 2 | Local | Long | All | Small - Moderate |
| | Attraction of predators (54) | 1 | Large - Very large | Long | All | Moderate |
| | Altered fishing (54) | 2 | Large - Very large | Long | All | Moderate - Large |
| Marine mammals | Acoustic disturbances during the installation (55) | 2 | Very large | Short | All | Large |
| | Turbine noise and boat traffic (56) | 2 | Very large | Long | All | Small |
| | Electromagnetic fields (57) | 1 | Local | Long | All | Small |
| Benthic flora and fauna | Acoustic disturbances during the installation (57) | 2 | Large | Short | All | Small |
| | Sediment dispersal during the installation (57) | 3 | Large | Short | All | Small |
| | Introduction of new habitat (59) | 4 | Very local | Long | AB | Moderate |
| | Electromagnetic fields (61) | 3 | Very local | Long | All | Small |
| | Exclusion of birds (64) | 3 | Large | Long | AB | Moderate - Large |
| | Organic enrichment of the bottom (66) | 3 | Very local | Long | AB | Moderate |

## 4.1 Effects on fish

### 4.1.1 Acoustic disturbances during the installation

In order to calculate the distances at which fish can be affected by noise, models of sound propagation under water have been combined with knowledge of how fish hear and how they react to sound. Thomsen et al. (2006) considered that for example herring and cod are likely to perceive noise caused by piling more than 80 kilometres away, and that salmon and flatfish hear noises up to a few kilometres from the source.

There are, however, few direct studies on how fish perceive or react to loud noise levels in the water. Excessive noise levels would likely lead to flight reactions so that the fish move away from the area if they are able to (Nedwell and Howell 2003, Mueller-Blenkle et al. 2010, Andersson 2011). Larvae and early life stages of fish have limited flight ability and are probably at least as sensitive as adults to acoustic noise (Wahlberg and Westerberg 2005).

In areas of increased noise levels, the ability of fish to perceive natural sounds in the environment may be limited. It can affect their orientation, location of prey and peer communication negatively. The effect is probably greatest if it occurs during the fish's spawning period, or if their foraging is prevented during growth periods of early life stages. At very high noise levels, the fish is directly affected by the rapid pressure changes in the water, which can lead to physical injury or death (Nedwell and Howell 2003). The auditory organ could be damaged and the swim bladder and blood vessels may also burst by sudden pressure changes (McCauley et al. 2003). The effect of rapid changes in pressure in the water is well known from dynamite fishing which is based on that fish dies or is paralyzed by excessive noise.

In experiments where fish were exposed to the noise of air guns that resembles the sounds produced by pile driving, there was direct damage to the inner ear of the fish. These injuries were in some cases chronic and in other cases temporary (Popper and Hastings 2009). In direct observations in connection to piling, damage to fish was discovered at a distance of few meters from the sound source (Popper and Hastings 2009). Experiments with fish in net cages showed that some species of fish change their behaviour when subjected to the recorded noise of pile driving (Mueller-Blenkle et al. 2010, Andersson 2011). The results also suggested that piling could affect fish distribution within the range of some 100 meters up to several kilometres.

The risk of damage to fish populations is particularly high if the area of the construction overlaps with important recruitment habitats for endangered species or weak populations. Noise disturbance could then pose a risk to the population, since even a single year of unsuccessful recruitment may have implications for the species' ability to survive in the area.

ASSESSMENT SUMMARY:

The effects of acoustic disturbances on fish during the installation phase depend on the type of work performed. The greatest risk is associated with pile driving, in which direct damage in the form of tissue damage and death may occur. Such effects are likely to occur within distances of less than 100 meters from the source of noise. For all types of work, flight reactions can be expected within distance of one or a few kilometres.

STRENGTH OF ASSESSMENT: 3

**Box 4. Fish hearing.**

**HOW DOES FISH HEAR?**

Based on the type of swim bladder, fish species are usually divided into three groups: non-specialists who have no swim bladder, generalists with swim bladder but with no special connection to the inner ear, and specialists who have a bone between the swim bladder and inner ear or extra air bags in the inner ear. This grouping, however, is too simplistic (Popper and Fay 2011). There are over 30 000 species of fish, and only a dozen of these have been studied in detail with respect to the hearing. Both the inner ear and swim bladder anatomy varies considerably between different fish. Therefore, there is probably more specializations and variation among species. The hearing ability of the same individual fish can vary between different times, for example, depending on how much air there is in the swim bladder, and possibly on the age of the fish (Popper et al. 2003, Popper and Fay 2011).

All fish species have ears. The ears are inside the cranium consisting of a labyrinth system (the vestibular system) and a number of otolith organs. The vestibular system detects the rotational acceleration, and the otolith organs detect linear accelerations. When the fish is vibrated in a sound field, there is a relative movement between the heavier limestone, the otolith, and the hair cells that it is resting on. The fish species studied to date perceive the acceleration of a sound field down to very low frequencies (below 1 Hz), and up to 50–100 Hz. The sensitivity is fairly similar in different species, with thresholds about $10^{-4}$–$10^{-5}$ m/s$^2$.

Many species also use the swim bladder in hearing. When the fish is exposed to sound the swim bladder starts to vibrate because of the pressure changes in the sound field. The vibration is propagated to the otolith organ that detects the movements. In this way, a fish with swim bladder not only detect the acceleration in the sound field, but also the sound pressure. The appearance and behaviour of the swim bladder differs considerably between fish species, and some species lack swim bladder completely (Popper et al. 2003). Cyprinid and sheatfish have a special bone connection between the swim bladder and inner ear, which makes them especially efficient at detecting the sound pressure. Other species, such as herring have gas bubbles at the inner ear, which enables vibrations to be conducted effectively to the inner ear. In general, these so-called hearing specialists are better at detecting sound pressure, and they can also hear sounds with higher frequencies than other fish species.

### 4.1.2 Sediment dispersal during the installation

Experiences on how fish is affected by sediment dispersed in the water mass are from marine constructions sites and from experimental studies. The main risk is that suspended sediment clogs the gills of the fish and thus reduces or cuts off the oxygen intake (Lake and Hinch 1999). Larval stages are particularly vulnerable because of their larger gills and higher oxygen consumption in proportion to their body weight (Auld and Schubel 1978, Partridge and Michael 2010). High levels of sediment can potentially reduce the survival of the fish roe by affecting its density or by covering it and thereby hinder the uptake of oxygen (Rönnbäck and Westerberg 1996).

Fish larval stages are also vulnerable because of their severely limited ability to move from, or avoid areas with high sediment content (Knudsen et al. 1992, Wahlberg and Westerberg 2005), something that adult fish have little problem with (Westerberg et al. 1996). In the monitoring of fish in connection with the construction of gravity-based foundations at Lillgrund wind farm in Öresund, however, no effect on fish distribution was noted, although sediment concentrations were measured at 10 mg/l (Hammar et al. 2008b). Neither measurement after 1 day nor after 1 month showed any significant impact on the occurrence of juveniles or single species.

The effect of sediment dispersal in relation to the establishment of wind farms are usually short-lived, as the construction takes place primarily on the bottoms dominated by heavier substrates such as gravel and sand, which does not spread so easily in the water column. Wind farms are often placed in areas with relatively good water flow, allowing sediment particles to be spread relatively far away, while they are diluted in the water column. A modelled distribution of particles from a calcareous sediment, which stays a long time in the water column, suggests relatively local (0.09 percent of the park area), and temporary effects (60 hours) in this type of environment (Didrikas and Wijkmark 2009). Read more about what can cause sediment dispersal in the water mass in section 3.1.5.

ASSESSMENT SUMMARY:
An increased concentration of sediment in the water column associated with dredging and drilling may primarily affect juvenile fish and larval stages, especially after prolonged exposure. Sediment material is usually only spread over a short period of time, but the distances of spreading in the water column varies depending on the type of sediment and water currents.

STRENGTH OF ASSESSMENT: 3

### 4.1.3 Introduction of a new habitat

Fish are 0attracted to fixed structures in the water. Most likely, they benefit from the protection provided by the structure. Fish can more easily escape predator detection, and some predators may have an increased opportunity to hunt undisturbed. The fish may also be attracted to the structures in search of food, if the abundance of its prey is higher there than in surrounding areas. In many areas, items such as scrap vessels or other artificial structures are placed on the seabed in order to attract fish. This increases the value of an area for both recreational diving and fishing (Wilhelmsson et al. 1998, Claudet and Pelletier 2004, Seaman 2007, Egriell et al. 2007).

Similar reef effects have also been found on structures such as oil platforms, jetties, bridge piles and pontoons, as well as on wind turbine foundations (Wilhelmsson et al. 2006a, 2006b, 2010, Maar et al. 2009). A unique feature of the reef effect around wind power foundations is that they extend from the ocean floor and all the way up to the surface. Such Fish Attracting Devices (FAD) can be a further attraction of fish to the area (Fayram and de Risi 2007).

Hammar et al. (2008b) evaluated experiences from different types of wind turbine foundations and found that the probability of fish accumulation in wind parks were higher if the foundations had a complex structure, and for example were surrounded by erosion protection. The effects are probably greatest in areas with a low initial complexity, such as sand and mudflats. For pelagic fish, the effect is also more important with increasing water depth (Schroeder et al. 2006).

Inventories by SCUBA diving near wind turbines in the Baltic Proper showed an increased occurrence of small fish near the foundations, especially of *Gobiusculus flavescens*. Similarly, survey fishing at the currently largest wind farm in Sweden, Lillgrund, showed an accumulation of fish in the near surroundings of the wind park. In contrast, survey fishing in the wind farm as a whole, did not show any general changes in fish abundance during the first three years of operation compared to the period prior to the construction and the reference areas. There were, however, some differences between species (see Bergström et al. 2012a for further details).

In studies from the wind farm at Horns Rev at the coast of Jutland, signs of change also at the population level have been observed. Species such as *Ammodytes tobianus*, cod, *Merlangius merlangus* and *Pleuronectes platessa* showed not only an increased accumulation near the wind turbines, but also an increase in the wind farm area as a whole (Hvidt et al. 2005, Dong Energy et al. 2006).

When a new structure is placed in the ocean the fish redistributes, which means they swim to the structure from nearby areas, where the number of fish will be correspondingly reduced. If access to protection and food is good and the development continues for a long time, the survival of juvenile fish and growth rate can increase. This in turn could lead to an increased amount of fish in the area as a whole. The probability that such a productivity increase occurs depends on local conditions (Bohnsack 1989), i.e. mainly if the habitat at the wind park is more favourable for the species than the surrounding environments. Two other important factors are that the area needs to be of a sufficient size, and that the development of the fish population can continue without any other outside interference. An increased accumulation of fish might, for example, make the fish easier to catch if fishing near the structures is permitted. The amount of fish may correspondingly also be affected by piscivorous birds or mammals, if these increase in the area.

The location and environment of the wind park is therefore important in order to assess the expected effect on the fish populations. Introduction of new structures in the ocean can result in increased productivity and species richness in an area that has been depleted or otherwise exposed to negative human interference. Conversely, the change in the environment can also pose some risks in unaffected areas, particularly in sensitive or naturally species-poor environments. In such environments, a reef effect might cause a disturbance, since the ecosystem to a greater extent differs from its natural structure. Another effect occurs if the structures attract new species that have a negative impact on other species. They can also facilitate the spread of species further into new areas. *Neogobius melanostomus*, for example, has become more common in Sweden in recent years, particularly in harbour areas, and could thrive in environments of the type created by wind parks. Read more about invasive species in section 4.3.5.

ASSESSMENT SUMMARY:
The foundations of wind turbines can act as artificial reefs and attract many fish species, especially if they are surrounded by erosion protection or otherwise have a high structural complexity. Usually there is a redistribution of fish from nearby areas, where the amount of fish will be reduced correspondingly. An increased production is eventually possible under certain conditions. If the long-term effects are positive or negative, depends largely on the location of the wind park and the environmental conditions in its surroundings.

STRENGTH OF ASSESSMENT: 3

### 4.1.4 Turbine noise and boat traffic

The sound perception of fish differs in many ways from humans and other mammals, and different fish species perceive sounds in different ways (box 4). Even the way that fish respond to sound varies, depending partly on the species, partly on the individual's hormonal and behavioural status. For example, the same individual can react in one way during the spawning period and in a different manner during foraging, or depending on the season of the year, and so on. It also cannot be excluded that some learning can occur. It is therefore difficult to draw generalized conclusions of how fish reacts to the on going noise in a wind park in operation. Also the sound's specific characteristics, such as sound frequency, intensity, and how long it lasts will affect the reaction.

The sound from operating wind turbines is not so strong that it can cause immediate hearing damage in fish, even when the fish are present very close to the foundations (Wahlberg and Westerberg 2005, Mueller-Blenkle et al. 2010, Andersson 2011). Some studies show that certain fish species, for example young salmonids (Sand et al. 2001) can stay away from strong low-frequency noise of high intensity (Wahlberg and Westerberg 2005, Mueller-Blenkle et al. 2010, Andersson 2011). Such an effect is most likely within a few meters away from the sound source.

Within the Swedish Vindval program, a few studies have examined the influence of sound on fish. According to Sigray et al. (2009) the component of sound that is characterized by particle motion, is inaudible to the studied fish species beyond 10 meters from the foundation. In a laboratory experiment, neither roach nor *Perca fluviatilis* or trout was affected by sounds with the same strength as that measured at a distance of 80 meters from a wind turbine (Båmstedt et al. 2009). The three fishes represent species with different hearing anatomy (box 4).

At present, there are no studies of adequate quality that can show that fish are adversely affected by noise from wind turbines in operation, although it is difficult to show that they never would be adversely affected. The overall picture of current knowledge indicate only minor effects on fish by noise from wind turbines in operation, especially in relation to other potential effects, such as reef effects and other physical changes in habitat. This is described in an article by Ehrich et al. (2006) for German waters in the North Sea and the Baltic Sea.

The question of how fish are affected by the noise environment around wind farms is often recurring in planning matters, especially if the area overlaps with particularly important habitats for fish. For example, in the Kattegat, the local cod populations are greatly reduced and in some places have completely disappeared (Fiskeriverket 2011). Cods communicate by sound both to locate each other as well as using specific sounds during the spawning period (Nordeide and Kjellsby 1999). It is currently unknown whether noise from wind turbines can affect cod spawning negatively inside the park. The question is of lower relevance to the Baltic Sea, where cod spawn in deeper waters that are not relevant for wind power establishment and uses the shallower areas primarily for foraging. Results from survey fishing at Lillgrund wind farm in Öresund showed that cod does not avoid the area during their foraging (Bergström et al. 2011). A two-year monitoring study of a Dutch wind farm, Egmond aan Zee, established that cod even sought shelter within the park (Lindeboom 2011).

A common species in the Baltic Sea that could potentially be disturbed by noise from an operating wind farm is herring, which also has a good hearing ability. Especially during the herring spawning season when it accumulates in large schools, will communication between fish be important. Also, herring often spawn on shallow bottoms that can be of interest for wind power establishment. There are currently no studies showing whether the spawning of herring would be affected by the proximity to a wind farm. In connection with the survey fishing at Utgrunden wind farm in Kalmar Sound individuals with running roe were captured in the surroundings of the wind farm. (T. Didrikas, personal communication).

ASSESSMENT SUMMARY:
The disturbance of operational noise and boat traffic varies between fish species. The overall picture today indicates that the effect on most species is low. Effects of chronic stress due to an increased noise level and the effects of noise disturbance on fish breeding behaviour have not been studied.

STRENGTH OF ASSESSMENT: 2

### 4.1.5 Electromagnetic fields

The magnetic field generated within a wind farm could potentially affect fish if it distorts their sense of direction, while the electric fields could theoretically affect their ability to locate prey and/or conspecifics. The eel is considered to be the species most susceptible to electromagnetic fields in Swedish waters. As it navigates through the geomagnetic field during its migration to spawning grounds in the ocean, it can probably detect electric cables under the water and react to them. Studies suggest that interference from power cables in the earth's magnetic field actually leads to some misalignment of migratory eel and elvers. Eels passing a DC power cable (single conductor with return path through the water) deviated from its course by up to a few hundred meters (Westerberg and Begout-Anras 2000). However no clear effects were noticed on a cable with parallel metallic return cable, neither in the migration of eel nor in the swimming activity of salmon and trout (Westerberg et al. 2006). A delaying effect on the eel migration was also detected near an AC power cable in the Baltic (Westerberg and the Law Felt 2008). Studies of the eel migration behaviour carried out near Lillgrund wind farm in Öresund, showed that eels can modify their migratory behaviour in the vicinity of the wind farm. The studies focused, however, on the effects of the wind farm as a whole, i.e. it was not possible to separate the effects of electromagnetic fields, noise and changes in topography from one another, and the individual variation between eels were large (Westerberg and the Law Felt 2008, Bergstrom et al. 2012b).

Picture 7. In studies of migratory eel near Lillgrund wind farm some eels were found to avoid the area. However, it was not possible to discern what effect of the wind farm that caused the behaviour (Photo: Inge Lennmark).

Cartilaginous fish can potentially be affected by the induced electric fields from power cables, because they use an electric sense in foraging and localization of other fish. Experimental studies have shown that cartilaginous fish may confuse signals from electrical cables with signals from their prey, which could adversely affect the fish if the wind farm is established in an important foraging area. According to Gill et al. (2005) cartilaginous fish are attracted to lower field strengths of induced electric fields, but avoids higher field strengths. Learn more about electromagnetic fields in section 3.2.

ASSESSMENT SUMMARY:
The expected effect of electromagnetic fields on most fish species is low, but the impact will continue throughout the operational phase and the knowledge base is relatively weak. Due to the increased use of electric cables in the marine environment, the risk of cumulative effects should be taken into account.

STRENGTH OF ASSESSMENT: 2

### 4.1.6 Attraction of predators

In the same way as the reef effect can attract fish to the vicinity of a wind farm, so can piscivorous mammals and birds be attracted to the area in search for food, provided they are not deterred from the area for other reasons. They may then have much easier to find fish near the wind farm compared to the surrounding areas. An increased accumulation of piscivorous mammals and birds can affect the amount of fish in the area negatively, but have a positive effect on the predators themselves. Since both birds and marine mammals may have vast feeding grounds, the effect can be quite extensive.

ASSESSMENT SUMMARY
Attraction of fish-eating birds and mammals could have an effect on fish populations and the local ecosystem through effects on food webs.

STRENGTH OF ASSESSMENT: 1

### 4.1.7 Altered fishing

In some cases, changes in fishing patterns within an area where a wind farm is being built may have effects on the fish stocks. What type of fishing that will be permitted is governed in each case, and primarily by the owner of the business. It is therefore not possible to make a generally valid assessment of what changes might be expected. It may sometimes be justified to restrict fishing within a wind farm in order to prevent damage to the wind power plant, in particular on the power cables. Such limitations are primarily concerned with fisheries that touch the seabed, such as bottom trawling, and in some cases, fishing with bottom-set fixed gear. Within the larger wind farms where the distance between the turbines are large, it may be possible to trawl within the park without compromising plant reliability.

The expected effect of fishing restrictions are relatively low on species subject to quota, since the fisheries for those species is likely to be moved to other areas instead. The stocks can potentially benefit in the long run, if they can grow in strength locally and then spread to adjacent areas (Dayton et al. 1995, Jennings and Kaiser 1998, Kaiser et al. 2006). A prerequisite for this to occur is that the area not fished is large enough. Fishes should be able to spend much of their time there, which means that the effect is most likely on the local species (Palumbi 2004).

Within wind parks where fishing is allowed, the interest to fish close to fundaments might increase. This can lead to increased mortality in fish, by increasing the probability of an individual fish to be caught. The effect would primarily affect the species of interest by the recreational fishery, and species in commercial fishing that are not subject to quota. If a trawl ban is established in an area that has previously been exposed to trawling, other benthic species, which are heavily exposed to bottom trawling side effects, are favoured (Thrush and Dayton 2002). However, areas that are subject to bottom trawling today are often of no interest for the establishment of wind farms, since they are primarily established in areas inside the trawling limit and on shallower bottoms.

ASSESSMENT SUMMARY:
It is not possible to make a generally valid assessment of what changes might be expected due to changes in fisheries in the wind park. If fishing restrictions are introduced it is likely that the number of fish in the wind park and potentially also in its neighbourhood will increase, especially if there also is a reef effect. An increase in fishing effort is likely to affect the amount of fish adversely in the same way.

STRENGTH OF ASSESSMENT: 2

## 4.2 Effects on marine mammals

### 4.2.1 Acoustic disturbances during the installation

Porpoises and to some extent seals are sensitive to noise disturbance (Richardson et al. 1995). During the installation phase various forms of noise arise, both from increased boat traffic and the underwater work with pumps and sluice equipment. The piling of monopile foundations generates extremely strong pulses of sound that can be harmful and disruptive to seals and porpoises under water and at relatively long distances (Carstensen et al. 2006, Tougaard et al. 2009, Brandt et al. 2011). Porpoises in particular have shown both behavioural changes and hearing loss at the type of noise generated by the establishment of some wind turbines. By studying the distribution of porpoises using transects done by airplane and acoustic loggers, Carstensen et al. (2006), examined whether the establishment of offshore wind farms had an effect on the distribution of porpoises in an area. It was shown that porpoises could be intimidated by the piling noise at distances of tens of kilometres from the source (Tougaard et al. 2008, Brandt et al. 2011). In addition, experiments with porpoises indicate that they can get temporary hearing loss of sound, similar to pile driving noise at levels far below those seen to give similar effects on other marine mammals or fish (Lucke et al. 2009).

Seals appear to be less sensitive to underwater noise than porpoises. Despite careful studies of harbour seals behaviour during the installation of wind farms in Nysted, Horns Rev and further down in the German Bight, no significant long-term effects on either the harbour seal or grey seal has been found (Tougaard et al. 2003 Edren et al. 2004, Avelung et al. 2006). During the installation phase, boat traffic and air and water borne noise disturb the seals, but it is unclear whether this has any great significance on the seal population, except possibly during the birth and suckling period in June. The mating ritual that takes place under the water contains a lot of audio communication (Van Parijs et al. 2000), so there is some risk that underwater noise may scare the seals and mask their own communication.

ASSESSMENT SUMMARY:
Porpoises have demonstrated both hearing impairments and behavioural changes due to pile driving noise during construction of wind power foundations. There are no studies of seals that show that the noise would result in any long-lasting or significant effects.

STRENGTH OF ASSESSMENT: 2

### 4.2.2 Turbine noise and boat traffic

During the operational phase the turbine rotation particularly, generates a low frequency noise that is led through the tower into the water (Lindell and Rudolphi 2003, Brandt et al. 2011). At Nysted wind farm in Denmark controlled measurements of porpoise activity was monitored in the area before, during and after construction of wind turbine foundations in comparison to a control area. The study showed that even after the establishment of the wind farm, porpoise activity was reduced compared to the control area (Carstensen et al. 2006). It remains unclear if this effect is real or if it is due to some problems with the study methodology. One uncertainty is whether the areas used as controls were representative of porpoise distribution (Carstensen et al. 2006). The results are surprising because the sounds during the operational phase are relatively low and probably only faintly audible to the porpoises that swim through the area (Madsen et al. 2006, Tougaard et al. 2009). Similar studies at Horns Rev on the Danish west coast showed that porpoises re-established in the area as soon as the installation phase was over (Tougaard et al. 2004), although the construction process was more noise-generating there (piled monopile foundations) than at Nysted (submerged gravity-based foundations). In a study from the Netherlands, the number of porpoises in the area increased after construction of a wind farm (Scheidat et al. 2011). The authors of the study believe that this effect might be explained by that the area now has a lower noise level than the surrounding waters, as the boat traffic in the area of the wind farm is prohibited (Scheidat et al. 2011). This shows that the effects on marine mammals of the establishment of wind farms can be far more complex than can be summarized by analysing the direct impact of different influencing factors such as noise.

ASSESSMENT SUMMARY:
Noise from the increased boat traffic at a wind farm in operation may have some negative impact on marine mammals. However, there is still little or no evidence that porpoises and seals are significantly affected adversely by noise from boats or operational noise. The effect of increased boat traffic in a wind may be negligible in comparison with the overall increase of boat traffic in Swedish waters.

STRENGTH OF ASSESSMENT: 2

### 4.2.3 Electromagnetic fields

There is very little data on whether seals and porpoises can detect electric and magnetic fields. Recent results indicate that at least one dolphin specie is aware of electric fields (Czech-Damal, 2011). Whether this also applies to porpoises, harbour seals and grey seals, have not jet been studied.

STRENGTH OF ASSESSMENT: 1

## 4.3 Effects on benthic flora and fauna

### 4.3.1 Acoustic disturbances during the installation

Knowledge about the effects of loud noises on invertebrates is limited and based largely on the American grey literature compiled by Moriyasu et al. (2004). The group of invertebrate animals is so great and multiform that it is impossible to generalize the effects of loud noises. Even within a single class of crustaceans such as large crabs (Malacostraca), significant differences in tolerance to loud noises have been observed. For example the crab species *Metacarcinus master*, was not affected by seismic explosions while the blue swimmer crab, *Callinectes sapidus*, was very sensitive to noise of the same strength (Moriyasu et al. 2004). The shell of the scallop *Chlamys islandica* cracked by the explosions, while the survival of oysters and mussels, two common species in shallow waters along the Swedish coast, in most studies were not significantly affected. However, there are less extensive studies that show some effects on oysters (Moriyasu et al. 2004). Within Vindval, the effects of low frequency sound (similar to what is generated during the operational phase) on e.g. brittle stars, shrimps and Limfjord mussels were studied (Wikström and Granmo 2008). No significant effects on either species were established, but the burrowing activity of the mussel was higher during the first measures but returned to normal levels after 48 hours.

STRENGTH OF ASSESSMENT: 2

### 4.3.2 Sediment dispersal during the installation

During the construction of offshore wind farms and also in connection with the decommissioning, there is a risk of a short-term re-suspension of sediment and other particles from the bottom. How large area that may be affected depends on the type of sediment, water exchange and currents in the area, and the type of foundation (Hammar et al. 2009). In an area with good water exchange, sediment particles will be dispersed far while also being diluted, while the particles in a more enclosed area will remain in the water for a longer time. In order to construct gravity-based foundations the bottom often needs to be dredged, which causes more sediment re-suspension than the establishment of monopile foundations. When large numbers of particles sink to the bottom it affects sessile filter feeding species and macroalgae. A thin sediment layer on a hard bottom surface can prevent spores and larvae from attaching to the bottom substrate (Berger et al. 2003). Infauna, animals that live buried in the sediment, and sea grass that grows on soft bottoms, are generally more resistant to particle re-suspension than species living on hard bottoms (Vermaat et al. 1997). Seagrass species, such as *Zostera marina*, tolerate relatively large amounts of sediment material without being affected negatively, compared to, for example seaweed and kelp species (Vaselli et al. 2008). The *Zostera marina* meadows of the northern Baltic Proper should be protected. They consist of one or a few clones, indicating that the genetic diversity of the meadows is low which in turn implies that the *Zostera marina* is poorly equipped to adjust to environmental changes. One example is the *Zostera marina* plant that forms a meadow of over 6000 $m^2$ near Åland, which is estimated to be about 1000 years old (Reusch et al. 1999). A disturbance in the environment could, at worst, knock out much of the stand.

Picture 8. Eelgrass, *Zostera marina,* can withstand being covered by relatively high amounts of sediment, but some meadows composed of old individuals of the same clone may be particularly sensitive to disturbance (Photo: Inge Lennmark).

At Lillgrund wind farm in Öresund only local, short-term effects of sedimentation on benthic fauna were observed (Dong Energy et al. 2006). The expected impacts of sedimentation on benthic organisms are often relatively low, because wind farms are often built on bottoms which have a high natural mixing of sediment or where the majority of the sediment consists of sand and gravel. These sediment fractions sink back down to the bottom rapidly and are therefore not spread very far. Even a dispersal model of a calcareous sediment, which is the most potentially problematic sediment since those particles stay longer in the water column, suggest relatively local (0.09 percent of the park area) and short-term effects (60 hours) (Didrikas and Wijkmark 2009).

The routing of power cables from the wind farm to the mainland is another risk of re-suspending bottom sediment which disturbs the benthic communities (Austin et al. 2004). Studies of deep soft bottoms with abundant fauna, however, show that long-term changes are very small (Andrulewicz et al. 2001). However, the recovery of shallow seagrass beds after digging and dredging at such cable routing can take longer (Di Carlo and Kenworthy 2008), and in environments with very strong water movements, an opening in the vegetation can cause erosion of the substrate around the cable (Whitfield et al. 2002).

ASSESSMENT SUMMARY:
Sediment in the water column can temporally affect benthic marine organisms. Existing studies show that the effect is usually local, but the extent depends on the type of sediment and the local water current conditions. Effects on organisms living buried in the sediment are less studied, but appear to be limited and local. Many animals are adapted to the re-suspension of sediment, because it is a natural part of their habitats on the erosion and transport bottoms. When laying cables in shallow bays with soft sediment, stonewort meadows and in certain sea areas protection of *Zostera marina* meadows should be given particular consideration.

STRENGTH OF ASSESSMENT: 3

### 4.3.3 Introduction of new habitat

Establishment of wind farms in areas with predominantly sandy and muddy soft bottoms increases the area of hard substrate since the foundations are made of concrete or steel. According to estimates, the turbine tower foundations cover only a small part of a park's overall bottom area (Hammar et al. 2008a). For example at Lillgrund wind farm in South Öresund which covers approximately 4,5 $km^2$, the total increase of new hard substrate was approximately 0,1 percent of the park area (Malm and Engkvist 2011).

Although the biomass of filtering organisms is often significantly higher on the foundations compared to the surrounding natural bottoms (Wilhelmsson and Malm, 2008, Ore and Engkvist 2011), the total contribution of filtering organisms in a wind farm is small. Persson (1983) estimated that filtering animals on a shallow soft bottom in the southern part of the Baltic Sea had a biomass of about 90 grams per square meter. If a similar amount of sessile animals occurs on soft bottoms in Lillgrund wind farm, the total biomass of filtering animals would increase with about 3 percent after construction. The species composition also varies depending on what material the foundation is made of. The local faunal community has been shown to be more species-poor on steel foundations (Wilhelmsson and Malm 2008) compared to concrete foundations (Qvarfordt et al. 2006), although the biomass is not necessarily lower.

What species and how many individuals that can settle on the foundations is mainly dependent on what marine area the wind park is placed in. In the northern Gulf of Bothnia the sessile marine organisms lack importance, and freshwater species such as hydroids and bryozoans occur only in low biomasses (Kautsky and Foberg 2001). Wind turbine foundations in these areas are therefore unlikely to alter the species number, composition and production of the benthic communities. Further south and in the Baltic Proper mostly mussels and *Balanus improvisus* and a few species of filamentous algae, bryozoans and hydroids, establishes on hard surfaces. At the Swedish West Coast the number of attached species on hard substrates is very high. Mussels will be larger than in the Baltic Sea due the higher salinity, but competition with sea squirts (Khalaman and Komendantov 2007) and predatory starfish (Saier 2001, Zettler and Pollehne 2006) restricts the population sizes. Due to lack of data it is difficult to generally define how faunal communities develop on wind power foundations on the Swedish West Coast. Most likely, significant local and regional differences occur as a result of differences in wave action, depth and local salinity conditions.

In the marine environment, the macro-and microstructure of surfaces is of great importance to determine what organisms will settle on the foundations. The larval stages of most species prefer to settle on ribbed surfaces, but some organisms such as *Balanus improvisus* settles on smooth surfaces (Berntsson et al. 2004). The surfaces chemical properties, on the other hand, do not seem to be relevant for which organisms that settle on the surface (Guarnieri et al. 2009). In the coastal zone, where there is enough sunlight for photosynthesis, large algae grow on horizontal surfaces while vertical surfaces are dominated by sessile animals (Southgate et al. 1984). The time of year when the foundations are placed in the ocean may initially affect the community composition, but the differences are levelled off after a few years when the most common species have reached their maximum biomasses (Qvarfordt et al. 2006, Lang Hamer et al. 2009).

Erosion protection around a foundation often consists of stones and boulders of various sizes. It thus becomes structurally more complex than the foundation itself and provide habitat for numerous species (Charton and Ruzafa 1998). Mobile, free swimming species such as various crustaceans, uses the cavities between the blocks for protection and for foraging (Steneck 2006, Moore et al. 2010). It has also been shown experimentally that the diversity of species among the mobile fauna increases with the number of layers of blocks and thereby the increasing supply of protective features (Takada 1999). On the Swedish West Coast, the effects of erosion protection are likely to be greatest for species such as lobsters and crabs which are often limited by the availability of space and especially cavities in their natural environment, i.e. lobster (Jensen et al. 1994) and crab (Sheehan et al. 2008).

A Swedish experience of reef-effects is from the artificial reefs of Vinga. During an expansion of the port of Gothenburg between 2002 and 2005, rubble was tipped at depths of 20–37 meters in the Göta Älv estuary area. Stone rubble formed ridges similar to artificial reefs or rocky parts of an offshore bank. A monitoring of the marine life that developed in the area showed that during the first five years the reefs were colonized by 159 different taxa (Länsstyrelsen 2007). Crustaceans such as lobsters were attracted to the reefs and occurred in greater numbers than in the reference areas. Lobsters showed a rapid colonization rate and were present on reefs already four months after construction was completed. Fishing restrictions on the reefs may also have contributed to differences in species composition and species numbers in comparison to the reference areas where fishing was allowed.

Other artificial reefs that have been studied in regard to establishment of fauna are the wave energy plants which for some years have been setup in an experimental facility outside Lysekil. The concrete foundations are three meters in diameter and one meter high, and fitted with rectangular holes. The results show that crabs were attracted to cavities and that the number of fish and fish species were higher at the foundations than in the reference area (Langhamer and Wilhelmsson 2009).

ASSESSMENT SUMMARY:
Establishment of wind farms, which mostly occurs on sandy or muddy bottoms, leads on the Swedish west coast and in the Baltic Proper to a highly localized increase of sessile invertebrates on the turbine towers and erosion protections. Which species that will dominate depends primarily on the salinity of the sea area. The total addition of hard substrate is small and the impact and increased biomass is assessed to be mainly local, around foundations and erosion protections.

STRENGTH OF ASSESSMENT: 4

### 4.3.4 Electromagnetic fields

The numbers of studies on the tolerance in invertebrates to electromagnetic fields are few. Bochert and Zettler (2004) studied survival, size and quantity of offspring in *Crangon crangon*, *Rhithropanopeus harrisii*, *Sarduria entomon* and mussels in a magnetic field with a strength of 3,5 mT. After three months, no significant effects were observed in any of these species. The magnetic intensity used in the experiment corresponds to the level on the surface of the most common DC power cable used in the Baltic Sea (Bochert and Zettler 2004). At an even higher magnetic intensity, 40 mT, the production of zooids i.e. reproductive parts, was affected in *Clava multicornis* (Karlsen and Aristharkhov 1985). Such high levels are however, not produced around cables from offshore wind farms.

ASSESSMENT SUMMARY:
The few studies that have been made suggest that electromagnetic fields do not have any long term impact on common crustaceans or mussels. Based on the results, impact on the benthic fauna is considered to be very small or non-existent at the levels that exist around the cables.

STRENGTH OF ASSESSMENT: 3

Picture 9. Crustaceans such as *Sarduria entomon,* were according to a study not affected by a magnetic field with the same strength as that which occurs around an ordinary submarine cable (Photo: Inge Lennmark).

### 4.3.5 Introduced species

A possible effect of the introduction of new habitats such as offshore wind farms is a greater spread of newly introduced species. The on going urbanization of the coastal landscape, with many types of artificial structures (Glasby and Connell 1999), is often considered to contribute to foreign organisms associated with hard bottoms becoming more easily established (e.g. Bulleri and Airoldi 2005).

Examples of sessile species that have established themselves on hard bottoms in Swedish coastal waters during the last 150 years are *Balanus improvisus, Dressenia polymorpha* and *Cordylophora caspia* (Leppäkoski et al. 2002). Because many introduced species arrive with ballast water, they often spread primarily to the artificial surfaces in the vicinity of harbours and shipping routes (Tyrrell and Byers 2007). In coastal areas where the availability of natural hard bottom substrate is limited, it is conceivable that wind farms could favour a wider distribution of introduced hard bottom species with planktonic life stages. Meanwhile, the percentage increase of hard bottom surfaces is very small.

How far a species can be distributed depends largely on how long the larvae, spores and other propagules live in the open water, and how the ocean currents transports them. Investigations of oil platforms show a clear correlation between the distance between the platforms and the species present (Page et al. 2008).

The wind farms in Denmark and in Kalmar Sound have large quantities of larvae and pupae from the centimeter-sized *Telmatogeton japonicus* found in the swash zone, where it feeds on filamentous algae (Brodin and Andersson 2009). Any ecological effects of *Telmatogeton japonicus* have not been documented.

Picture 10. The barnacle, *Balanus improvisus,* is one of the first known introduced species in the Baltic Sea. Today it is present in almost the whole sea area (Photo: Inge Lennmark).

ASSESSMENT SUMMARY:

It is difficult to predict a new species' impact on the ecosystem because each species has its own distribution pattern and form specific interactions with other established species. In the current situation is not likely that the wind power foundations entails an increased risk of new species being introduced in Swedish marine waters since the addition of hard substrate is very small. If several parks are built close together, the risk may increase.

STRENGTH OF ASSESSMENT: 3

**Box 5. Introduced species.**

**INTRODUCED SPECIES IN SWEDISH WATERS**

Gulf of Bothnia

Because of the low salinity few marine species can establish themselves in the Gulf of Bothnia. Balanus improvisus is the only non-native species found on the foundation structures here.

Baltic Proper

Baltic Proper is naturally species poor with a low stable salinity. It is also a young sea to which nearly all species have migrated at some time during the past 10 000 years. This migration is still underway. More than 30 marine species have entered the central and northern Baltic Proper by human activities, such as in the ballast water of boat transports. Some of the species living on hard bottoms belong to the problematic fouling species, such as Cordylophora caspia and Dressenia polymorpha. So far only one recently introduced species has been found on foundations: Telematogeton japonicus. Another species which now exists in almost the whole Baltic Sea is Balanus improvisus which came to Baltic Sea during the 1800s. The barnacles mainly create problems as they settle on boat hulls.

Swedish West Coast

Most new species that over the past 100–150 years have established themselves in the coastal zone on the Swedish west coast are sessile hard bottom species. Among the seaweeds, Sargassum muticum is commonly found in ports but also in the algal belt all along the Bohuslän coast. Other species are Fucus evanescens, Colpomenia peregrina and multiple species of red algae such as Gracilaria vermiculophylla and green algal species such as Codium fragile. These are marine species that are unable to establish themselves in the Baltic Proper and Gulf of Bothnia. Among the invertebrates that have established themselves on the Swedish west coast are Crassostrea gigas and Crepidula fornicata. It is likely that these species originate from France, where they are used in different types of aquaculture.

### 4.3.6 Exclusion of birds

As the offshore wind farms are increasing in number and size, so does the fragmentation of the habitats of sea birds, which has become an increasingly important issue for research and environmental management (West and Caldow 2005). Impact on birds could also lead to other effects on food webs in the park area (Polis and Sears et al. 2000).

Studies show for example that diving ducks consume a significant portion of the filtering animals in many areas, mainly mussels of different species (Baird and Milne 1981, Hilgerloh 1997). Dense flocks of diving ducks can therefore be structuring the benthic fauna communities by influencing the amount and size of mussels on both hard (Guillemette et al. 1996, Hamilton 2000, Vaitkus and Bubinas 2001) and soft bottoms (Lewis et al. 2007).

The most important food-source for diving ducks in the Baltic Proper are blue mussels, Mytilus edulis (Nyström and Pehrsson et al. 1991). Blue mussels dominate the Baltic Sea near-shore communities, and being small and with thin shells (Kautsky 1982), they are probably easier for the birds to eat than the larger blue mussels in the North Sea.

The geographical distribution of bird flocks is determined by the availability and accessibility of food, such as diving depths and currents (Smaal et al. 2001, Kaiser et al. 2002). Large populations of diving ducks overwinter and forage along the coasts and on offshore banks (Livezey 1995), which are areas that are often of interest to the establishment of offshore wind power (Kaiser et al. 2002). The most numerous species in these areas are eider, long-tailed duck, common scoter and velvet scoter (Brager et al. 1995). In addition, waterfowl such as loons overwinters in the same marine areas as diving ducks (Garthe and Huppop 2004).

It has long been known that diving ducks are sensitive to human activities, mainly shipping traffic, and that they avoid areas with high disturbance frequency (Kaiser et al. 2002, Kenow and Korschgen et al. 2003) even though the availability of food is good (Guillemette et al. 1996). Velvet scooter, who is regarded as being the most sensitive species, has been shown to keep a safety distance of approximately 1,5 kilometres to ships (Kaiser et al. 2002). The birds behaviour can be affected by human disturbance especially when the opportunity to flee the area is limited, for example during moulting. The period of time that the birds forage may be shortened or changed to times of the day when foraging is less advantageous (Merkel et al. 2009).

Studies of existing wind farms, primarily in Denmark, show that diving ducks avoid wind parks, both during migration and during winter break (Guillemette and Larsen 2002, Larsen and Guillemette 2007, Masden et al. 2009). In the Nysted wind farm in southern Denmark the number of eiders decreased by more than 80 percent right after the park was constructed (Kahlert et al. 2004, Desholm and Kahlert 2005). The numbers of birds within the park area were further reduced after the turbines were taken into in use (Stewart et al. 2005).

Although several studies show the ecological importance of diving ducks in littoral communities, there are no studies to show whether, and if so how, disturbance of bird flocks affects the benthic community. In the wind farms that have been studied it has however been noted that the amounts of sessile animals, mainly blue mussels and barnacles, have increased since the construction of the park compared to reference areas, while the biomasses of macroalgae, mainly various species of red algae, have decreased (Wilhelmsson and Malm 2008, Maar et al. 2009, Ore and Engkvist 2011). The increase in the biomass and number of sessile fauna is not restricted to the foundation structures and their immediate vicinity. Changes in the benthic community structure have been observed throughout the park at Lillgrund in the South Öresund, also on boulders and rock several hundred meters from the nearest power plant (Malm and Engkvist 2011). It is not clear whether these changes are a result of reduced consumption of birds in the park or have some other explanation.

ASSESSMENT SUMMARY:

The areas in the Swedish economic zone, where a large-scale wind power development could have the greatest impact on benthic communities through effects on bird populations and the food web, are the offshore banks in the Baltic Proper, mainly Hoburgs Bank and Northern Midsjöbanken where two thirds of Europe's long-tailed duck populations, approximately one million animals, overwinters (Brager et al. 1995). The effect will depend on how large an area that is built upon, and also on the distance between the towers.

STRENGTH OF ASSESSMENT: 3

### 4.3.7 Organic enrichment of the bottom substrate

On the Swedish west coast and in the Baltic Proper dislodged mussels and other organic material can accumulate at the base of the turbine towers, which can affect the species composition of organisms in the sediment (Zettler and Pollehne 2006, Wilhelmsson and Malm 2008). Banks of dead mussels covered with hydrogen sulphide bacteria was noted around the foundations when diving at Utgrunden in southern Kalmar Sound (Wilhelmsson and Malm 2003). The amount of deposition of organic matter is however small relative to the entire park area.

ASSESSMENT SUMMARY:

Dead material falling off the wind power foundation can provide a very local concentration of organic material on the bottom. Under certain circumstances, for example, if the wind turbine stands on a bottom with small water mixing there is some risk of local oxygen deficiency.

STRENGTH OF ASSESSMENT: 3

# 5. Measures to reduce effects

There are various ways to minimize the effects of offshore wind power on marine life. Both by technical means, and through good knowledge of the marine environment in the area concerned, and of the organisms that live there. To supervise and monitor the impact of interventions in the natural environment, different types of environmental monitoring programs are conducted. An application for permission for the establishment of an offshore wind park should include a proposal for monitoring the operation, proposed safeguard measures and an environmental impact statement. Environmental control programs usually mean that environmental studies are conducted before and after impact in an area, and the results are compared with at least two similar but unaffected areas (reference areas). Any changes that are detected in the affected area can be identified and quantified in relation to the performance of reference areas, and facilitate the development of measures to mitigate effects on the environment.

## 5.1 Fish

The risk of damage to fish and fish stocks in connection to the construction should be limited by avoiding harmful noise levels, and adapting the construction of the wind farm in time and space to not affect important recruitment periods or habitats of particularly sensitive species. Before planned work with intense noise is begun, measures can be taken to scare away the fish from the local area e.g. with acoustic warning signals. To minimize the risk of injury, measures to limit the scope of noise propagation is motivated during both construction and operation phases. Ramp-up procedures can be used during piling. This means that the first pile drives are carried out with lighter blows that gradually increase to full strength. This way, the noise is controlled so that fish in the vicinity are able to get used to it, or flee the area, before it reaches dangerous levels.

Sediment dispersal should be avoided in important recruitment habitats for fish and during times of reproduction. The planning should take into account the potential impact of electromagnetic fields from the cable net, both within the park and at the connection to the mainland. Technical options to minimize impacts should be applied. The risk of adverse development in fish stocks due to increased fishing within the park should be monitored continuously during the wind park's operational phase so that measures can be taken if fishing pressure is expected to be too high.

**Box 6**

**REDUCTION OF NOISE DURING THE INSTALLATION**

- Animals can be scared off before construction work begins. Through a so-called "ramp-up" procedure, i.e. the first hammer blows at the piles are lighter, to give animals a chance to move away from the area before the work amounts to full impact strength and maximum noise disturbance.
- The facility can be planned so that noisy activities will be as short as possible, for example, by minimizing the number of transports.
- Boat transports passing sensitive areas can be minimized and the speed limited.
- Timing for construction work is planned so that the noise effect on wildlife is minimized, with special reference to the reproductive periods of fish and seals.
- To reduce noise impacts during the installation phase, if necessary, foundations can be surrounded by bubble curtains, or other structures that attenuate the noise.

## 5.2 Marine mammals

One measure to reduce impacts from construction, operation and decommissioning of offshore wind turbines on marine mammals would be to show consideration when building near dwelling areas for small and vulnerable populations and during reproductive periods. Special consideration should be taken foremost for the harbour porpoise in the Baltic Sea, the harbour seals in Kalmar Sound and the few grey seals that live on the Swedish West Coast.

As for fish, effects of acoustic disturbance on marine mammals are reduced by taking different measures. By gradually increasing the power in the blows during piling, the animals are given time to flee the area before damaging noise levels are achieved. There are also acoustic scares which can be used to warn the porpoises and seals. Another method, which efficiency varies between different technical configurations, is to screen off the pile-sound using air bubbles.

It is more difficult to reduce the low but continuous noise throughout the operating phase of the wind farm. Possibly, future generators will be developed so that they emit less noise and so that the amount of noise that spreads into the water decreases. Another solution that has been discussed is to cover the foundations with sound absorbing material. To invest in one of the solutions, however, seems unjustified before we know with certainty that, and if so how, noise impacts during the operational phase damages marine wildlife. The effect of electromagnetic fields is considered so small on marine mammals that no action to reduce the impact is needed.

## 5.3 Benthic flora and fauna

Special consideration in establishment of wind power should be taken in the northern parts of the Baltic Proper, where *Zostera marina* grows. The reason for this is that they consist of one or a few clones, are very old and may have difficulty recovering from disturbance. The laying of cables should if possible be done so that the impact on stonewort meadows is minimized, since the group contains species considered vulnerable. Measures to reduce the spread of sediments associated with dredging will reduce the risks to the superposition of benthic animals. For the benthic community there are no specific time periods when the influence of sediment dispersion is less.

**Box 7**

**REDUCTION OF SEDIMENT DISPERSAL DURING THE INSTALLATION**

- Carry out detailed analyzes of the bottom substrate character and content of toxic substances to minimize the spread of dangerous substances and sediment in connection with dredging.
- If there is a risk of significant environmental effects, methods for collecting suspended material should be used.
- Plan the work after the winds and currents that prevail at the time of construction, to minimize accumulation effects from work at other locations in the area.

# 6. Gaps of knowledge

The rapid development of offshore wind power contributes to the increased industrialization of the marine landscape. Although the Swedish effort so far has been modest, there is a need to consider the development of wind power in a broader European perspective. It is expected in the relatively near future that a very large number of wind farms with thousands of stations will be established along the north western coasts of Europe, from Normandy in France to far into the Gulf of Bothnia, and also on offshore banks in the North Sea and the Baltic Sea. It is also highly likely that future technology will enable deeper areas than today to be utilized for wind power. Such technology may lead to further geographical expansion of the parks. Possible impact on those deeper habitats has not been addressed in this report.

How the marine resources are being exploited has received considerable attention in recent years. This is partly due to the ever-increasing human use and interest in the goods and services that the ocean offers. The attention was first on the coastal waters but now includes to an increasing extent also offshore areas. Sweden has been preparing a law on marine planning that will come into force in 2012. For such planning a well-developed biological background material is required, including areas of interest for wind power.

### LARGE SCALE IMPACTS

The understanding of how large-scale construction would affect the marine ecosystems on a regional scale cannot be extrapolated from knowledge developed for a single windmill or a wind farm. This calls for new knowledge about potential impacts on the larger scales, how a large-scale establishment affects the marine plant and animal communities and the changes that occur in larger wind parks over long time.

### CUMULATIVE EFFECTS

The effects on the environment should also be balanced against other human activities, so that benefits and costs of different measures may be included as part of the planning documents. A wind turbine with a capacity of 3 MW can in good wind conditions produce 7500 MWh of electricity per year. This enables a reduction in electricity production from coal and achieves:

- reduced carbon dioxide emissions by about 7500 tonnes,
- reduced emissions of sulphur dioxide by about 5 tonnes,
- reduced emissions of nitrogen oxides by about 3 tonnes (Energimyndigheten, 2012)

The environmental impact of wind power should also be seen from a climate perspective, where the expansion of wind power could save environmental resources and reduce environmental impact. According to the government's final report in Vindkraftsutredningen (SOU 1999:75), some environmental goals would be more easily achieved if Sweden replaced parts of the nonrenewable electricity with wind power.

COLLABORATIONS

Since a large-scale establishment of wind power is expected in many countries around the Baltic and North Sea there is a need to work internationally with questions concerning the impacts of wind farms on marine ecosystems. A logical way would be to initiate a multidisciplinary international research program, for example within the framework of the Marine Commissions, HELCOM and OSPAR. To achieve a good overall picture it is useful to further develop the work with an overall assessment of potential effects on marine systems initiated through this and other similar projects internationally (e.g. Wilhelmsson et al. 2010). Below are some of the gaps of knowledge that have been identified for fish, marine mammals and benthic flora and fauna.

## 6.1 Fish

Based on current knowledge, the general picture is that offshore wind farms are compatible with sustainable fishing, provided that certain conditions are met. One area that needs to be developed is the long-term planning of the marine environment, to ensure appropriate siting of wind farms, and to avoid the risk of negative cumulative effects. Follow-up studies of long-term development of wind farms in operation is needed to understand better how reef effects can affect fish populations, and to identify appropriate measures to ensure a positive development. Another important issue is for further studies on how fish react to different types of underwater noise, preferably from a comprehensive perspective in which the effects on fish of noise from wind farms is related to noise from other human sources, such as boat traffic near the shipping lanes.

## 6.2 Marine mammals

The largest impact on marine mammals occurs during the installation phase of offshore wind farms, and particularly during piling of monopile foundations as it entails sound propagation under water. Information on how marine mammals, especially porpoises, react to different types of noise is lacking. The few studies carried out show that porpoises may be frightened by the piling noise at very long distances (Tougaard et al. 2009), but if it has a significant impact on porpoise survival, and how fast porpoises get used to these kinds of sounds, has not been studied. Porpoises are possibly affected by noise in different ways during different seasons, and perhaps at different times of day. This knowledge would be useful in order to develop measures to minimize impacts and ensure viable populations of marine mammals in Swedish waters.

## 6.3 Benthic flora and fauna

To increase awareness on the influence of wind power on benthic organisms, it would be useful with further studies on reef effects and especially the changes that occur during longer periods of time. This is true both for species that benefit from complex structures in and around foundations and the relationships between benthic sessile animals and the animals that feed on them, and for interactions between species that evolve only when the wind turbine has been present a number of years. This knowledge would be useful for developing foundations that benefit species such as crab and lobster and may also provide a favourable environment for various fish and their food organisms.

# Species and groups of organisms

Species and groups of organisms mentioned in the report are listed both by their scientific and English names. If a species has become established in Sweden from a foreign source, it is marked as introduced. Red listed species are classified as; critically endangered (CR), endangered (EN), vulnerable (VU) or near threatened (NT) (Gärdenfors 2010).

**Fish**

| | |
|---|---|
| *Ammodytes tobianus* | Lesser sand eel |
| *Anarhichas lupus* | Atlantic wolffish (EN) |
| *Anguilla anguilla* | Eel (CR) |
| *Belone belone* | Garfish (Sea needle) |
| *Chelidonichthys lucernus* | Tub gurnard |
| *Clupea harengus* | Atlantic herring |
| *Coregonus albula* | Vendace (European cisco) |
| *Coregonus spp.* | Common whitefish |
| *Ctenolabrus rupestris* | Goldsinny wrasse |
| *Cyclopterus lumpus* | Lumpermillecker (NT) |
| *Cyprinus carpio* | Common carp |
| *Enchelyopus cimbrius* | Fourbeard rockling |
| *Gadus morhua* | Cod (EN) |
| *Gobiusculus flavescens* | Two-spotted goby |
| *Gymnocephalus cernuus* | Ruffe |
| *Limanda limanda* | Common dab |
| *Melanogrammus aeglefinus* | Haddock (EN) |
| *Merlangius merlangus* | Whiting (VU) |
| *Molva molva* | Ling (EN) |
| *Neogobius melanostomus* | Round goby (Introduced) |
| *Osmerus eperlanus* | Smelt |
| *Perca fluviatilis* | Perch |
| *Platichthys flesus* | European flounder |
| *Pleuronectes platessa* | European plaice |
| *Pollachius pollachius* | Pollock (CR) |
| *Psetta maxima* | Turbot |
| *Salmo salar* | Salmon |
| *Salmo trutta* | Trout |
| *Scomber scombrus* | Mackerel |
| *Solea solea* | Common sole |
| *Sprattus sprattus* | European sprat (bristling) |
| *Squalus acanthias* | Spiny dogfish (CR) |
| *Trachinus draco* | Greater weever |
| *Triglopsis quadricornis* | Fourhorn sculpin |
| *Trisopterus minutus* | Poor cod |
| *Zoarces viviparus* | Viviparous eelpout (NT) |

## Marine mammals

| | |
|---|---|
| *Halichoerus grypus* | Grey seal |
| *Phoca vitulina* | Harbour seal (Baltic Sea stock, VU) |
| *Phocoena phocoena* | Harbour porpoise (VU) |
| *Pusa hispida* | Ringed seal (NT) |

## Benthic animals and plants

**Invertebrates**

| | |
|---|---|
| *Abra nitida* | |
| *Actiniaria* | Sea anemone |
| *Amphipoda* | |
| *Amphiura filiformis* | Brittle star |
| *Anthozoa* | Anthozoans (Coral animals) |
| *Ascidiacea* | Sea squirt |
| *Asterias rubens* | Starfish |
| *Balanus improvisus* | Smooth barnacle (Introduced) |
| *Callinectes sapidus* | Blue swimming crab |
| *Cancer pagurus* | Crab |
| *Chlamys islandica* | Scallop |
| *Clava multicornis* | Club hydroid |
| *Cordylophora caspia* | Club polyp (Introduced) |
| *Crangon crangon* | Sand prawn |
| *Crassostrea gigas* | Giant oyster (Introduced) |
| *Crepidula fornicata* | Oyster thief (Introduced) |
| *Dressenia polymorpha* | Zebra mussel (Introduced) |
| *Ephydatia fluviatilis* | Freshwater sponge |
| *Homarus gammarus* | Lobster |
| *Malacostraca* | |
| *Metacarcinus magister* | |
| *Mytilus edulis/trossulus* | Blue mussel |
| *Nephrops norvegicus* | Norwegian lobster |
| *Ostrea edulis* | Oyster |
| *Pandalus borealis* | North Sea prawn |
| *Rhithropanopeus harrisii* | |
| *Saduria entomon* | |
| *Semibalanus balanoides* | Ribbed barnacle |
| *Telmatogeton japonicus* | Japanese feather mosqito (Introduced) |

### Algae

| | |
|---|---|
| *Bacillariophyta* | Diatoms |
| *Ceramium virgatum* | Banded pincer weed |
| *Cladophora* | Common green branched weed |
| *Codium fragile* | Codium (Introduced) |
| *Fucus evanescens* | Two headed wrack (Introduced) |
| *Fucus radicans* | Narrow wrack |
| *Fucus serratus* | Serrated wrack |
| *Fucus vesiculosus* | Bladderwrack |
| *Furcellaria lumbricalis* | Clawed fork weed |
| *Gracilaria vermiculophylla* | Wart weed (Introduced) |
| *Laminaria digitata* | Oar weed |
| *Laminaria hyperborea* | Forest kelp |
| *Polysiphonia fucoides* | Black siphon weed |
| *Rhodomela confervoides* | Struggly bush weed |
| *Sargassum muticum* | Japanese wireweed (Introduced) |
| *Sphacelaria arctica* | |

### Water plants

| | |
|---|---|
| *Characeae* | Stoneworts |
| *Fontinalis antipyretica* | Common water moss |
| *Myriophyllum spicatum* | Eurasian watermilfoil |
| *Potamogeton* | Pondweed |
| *Ranunculus aquatilis* | Common water-crowfoot |
| *Zostera marina* | Eelgrass |

### Other species

| | |
|---|---|
| *Beggiatoa* | Sulphur bacteria |

### Birds

| | |
|---|---|
| *Clangula hyemalis* | Long-Tailed Duck |
| *Gavia spp.* | Divers |
| *Melanitta fusca* | Velvet Scoter (NT) |
| *Melanitta nigra* | Common Scoter |
| *Somateria mollissima* | Eider (NT) |

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# The effects of wind power on marine life

## A Synthesis

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The synthesis report gather existing knowledge of the effects of wind power on marine organisms and contains suggestions of how possible negative effects can be minimized. The main effects are seen when monopole foundations are being driven into the sea floor, and during the dredging work.

**Vindval is a research programme aimed at mobilizing and provide scientific knowledge about the effects of wind power impacts on humans and nature. CWE2013 is managed by the Swedish Energy Agency and the Swedish EPA.**

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