Adapting offshore wind power foundations to local environment

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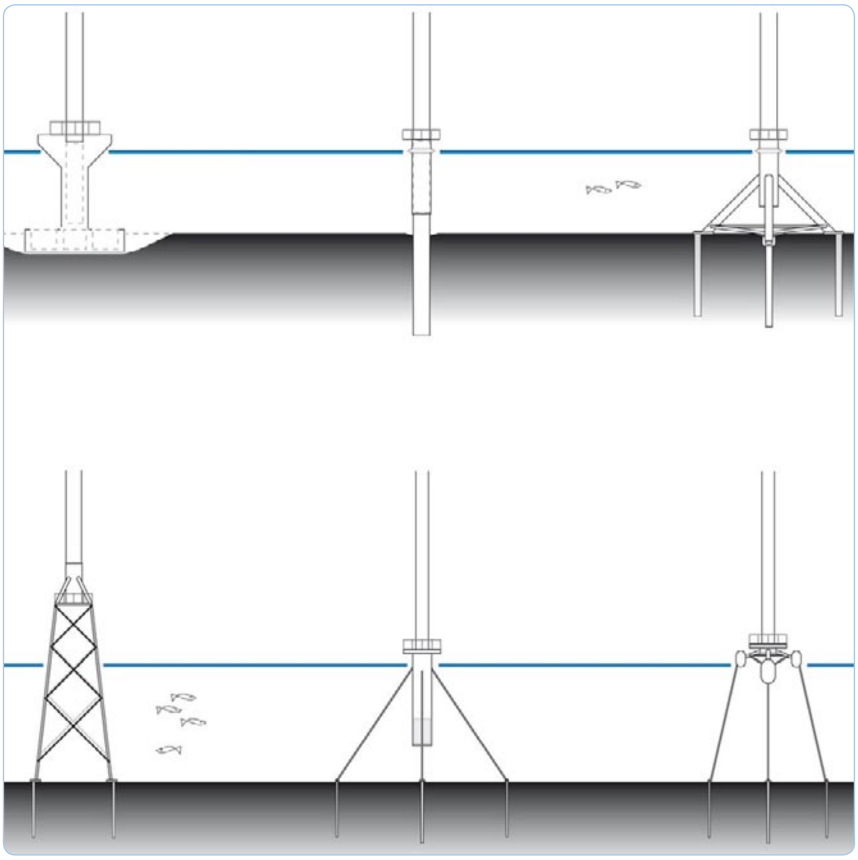

Adapting offshore wind power foundations to local environment

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Preface

There is a great need for knowledge concerning the impact of wind power on humans and landscapes, the marine environment, birds, bats and other mammals. Previous studies regarding the environmental impacts from wind farms have lacked an overall view of the effects. This has lead to deficiencies in the processes of establishing new wind farms.

Vindval is a program of knowledge and a cooperation between Energimyndigheten (Energy Authority) and Naturvårdsverket (Environmental Protection Agency). The purpose of the program is to collect and distribute scientific based facts regarding the impacts of wind power on human and nature. The commission of Vindval extends to 2012.

The program comprises about 30 individual projects and also three so-called works of syntheses. These syntheses consists of experts which compile and assess the collected results of research and experience regarding the effects of wind power within three different areas – humans, birds/bats and marine life. The results from the research projects and work of syntheses will provide a basis for environmental impact assessments and in the processes of planning and permitting associated with wind power establishments.

Vindval requires high standard in the work of reviewing and decision making regarding research applications in order to guarantee high quality reports. These high standard works are also carried out during the reporting approval and publication of research results in the projects.

This report was written by Marine Monitoring AB; Linus Hammar, Sandra Andersson and Rutger Rosenberg 2007 and translated by Anna Dimming 2010. The authors are responsible for the content.

Vindval in June2010

Contents

Summary

The aim of this study is to provide an environmental perspective regarding the choice of foundations for offshore windpower, suggesting that differences in environmental impact should be involved in decision-making and development concerning future offshore windpower foundations. The study concerns only the marine environment, excluding seabirds, and is based on the level of knowledge available in 2007.

The study focuses on three different types of foundations; gravity- monopile- and jacket foundations. Also tripod- bucket- and floating foundations are mentioned. The different characteristics of the foundations are discussed based on their environmental impact in five different areas; 1) epifouling and reef-effects, 2) operational noise, 3) changes in hydrographical conditions, 4) noise during construction, and 5) dissolved sediment during construction.

Regarding epifouling, it is noted that the surface texture of the foundation (i.e. steel, concrete) is of less importance in the long run since the initial substrate soon will be covered with organisms, creating a rugged surface for later colonising organisms. It is rather the level of salinity, distance to shore, exposure, depth and turbidity of the water that decide which organisms that will dominate the different foundations after a few years. Generally all foundations for offshore windpower are expected to be dominated by filtering animals, such as blue mussels. A possible exception is if concrete is coated with a silicone product that limits larger organisms to establish on the foundations. This kind of surface treatment has not yet been used by the windpower industry but occurs on other submarine concrete constructions.

The potential for an evident reef-effect (local increased occurrence of mobile animals such as fish and crustaceans) increases with the complexity of the foundation structure. Hence, tripod and especially jacket foundations have better possibility to contribute to the reef-effect than monopile- and gravity foundations.

Reef-effect, as well as epifouling, may be considered negative in some marine environments, such as possible valuable areas without any natural occurrence of hard substratum. In such areas new species may be introduced, changing the local ecological conditions. However, in many areas an increased level of biological diversity is viewed as a positive change, and here reef-effect and epifouling may be considered favourable. To amplify the reef-effect, scour protection devices may be designed to create more habitats.

Operational noise from offshore windfarms has been shown to initially affect some organisms (mussels, fish) during experimental studies in small containers. Whether corresponding operational noise in field and during natural circumstances can cause any environmental impacts is not yet fully understood. Available information indicates that there is a common sound level peak from wind turbines at frequencies of 100 – 200 Hz. In the same frequency range cargo ships emit higher sound than wind power even over several kilometres distance. Based on the present lack of certainty, it can be motivated to minimize the sound at these frequencies in areas with special

biological values, such as endangered organisms sensitive to stress. However, there are no indications that operational noise may significantly affect the environment beyond the vicinity of each foundation.

Based on a limited number of measurements it seems as if gravity and monopile foundations emit noise of similar amplitude, but the frequency range of the gravity foundation is generally lower. There are no measurements of jacket foundation but theoretically these should emit less noise, at least within the lower frequency range. Even if little is known about future turbines and foundations, it should be technically possible to decrease the emitted noise level.

The local conditions of the seabed have a large impact on the propagation of the noise, where shallow water and hard substratum allow the sound to propagate longer distances. The background noise is also of importance and in quiet areas there is theoretically a higher risk of environmental impacts than in areas with heavy ship traffic.

Changes in the hydrographical conditions around a foundation are small and are expected to be of importance only in very narrow water passages. The gravity foundation probably has the largest impact on the local hydrography. However, no direct comparisons between the different foundations have been made.

During the construction period extreme noise levels may occur, especially during pile-driving which is needed for most foundations except for gravity foundations. The noise level depends on the diameter of the piles that are driven into the sediment as well as the piling method. This means that the monopile foundation generally emits higher construction noise levels than jackets, while gravity foundations emit the least construction noise.

Since the extreme noise levels from pile-driving, covering large areas, can be harmful to fish and marine mammals it is very important to minimize this disturbance. This can be done by the choice of foundation, by precautionary measures and by adapted methods of pile-driving. It is of great importance not to perform pile-driving during spawning periods of commercially valuable fish species.

Gravity foundations need no pile-driving but require dredging, which disperses dissolved sediment in the water. High concentration of dispersed sediment can disturb or harm sensitive marine organisms such as juvenile fish. The highest risk of negative impact on the environment is dredging calcareous sediments, dredging in stagnant water and where the sediment contains toxic substances. The impact on the environment from dredging can be minimized by precautionary measures and good planning. However, the impact of dredging and sediment transport related to offshore windpower is small compared to other large dredging projects that have been carried out in Sweden without any documented any sustained environmental impacts.

The result of this study is to be applied on local conditions (e.g. hydrography, bottom substrate and ecological circumstances) at every specific site, hereby indicating what type of foundation to prefer from an environmental point of view, and also to state what technical as well as planning adaptations that ought to be applied.

1 Introduction

A major expansion of offshore wind power in northern Europe is to be expected in the near future. Today (2007) there are 25 offshore wind farms in operation, while more than 30 wind farms are planned of have permission to get started, see Table 1.

The projections of offshore wind power normally involve extensive environmental screening, which includes the anticipated effects on marine algae and animals. The environmental impact statements analysed in Swedish projections are often considering the marine environment thoroughly, but has not in detail dealt with wind mill foundations. There are major technical differences between foundations and the different models have their particular advantages depending on prevailing environmental conditions. There are also substantial differences of the environmental impacts from the various foundations, which is not clearly analyzed in environmental trials.

The choice of foundation has been made only after authorization and is mainly due to the required geotechnical investigation of the bottom which is costly. There is also an advantage taking a late decision regarding the rapid evolution of technology. So far the choice and design of the foundations have been exclusively based on technical and economical aspects. The purpose of this study is that marine biological and ecological aspects of the foundation are to be taken into consideration in the early stages of planning - thereby increasing precision of future environmental impact assessments and the promotion of an optimized planning of offshore wind mills.

This study intends to compare the fundamental works in relation to environmental impacts (such as reef-effects, sound, changes in hydrographical conditions)-regardless if this influence then presents a significant environmental impact or not.

Reading instructions

This study of foundation optimization is especially addressed to wind energy developers working with environmental impact assessment and planning, as well as to administrators and policy makers involved in the authorization process. Chapter 2 provides a technical overview of the various foundation models, and Chapter 3 deals with the different foundations in relation to environmental impacts. In Chapter 4, the results are summarised with suggestions how to use them. It is very important that this study is to be considered in its entirety for use, and not where Chapter 4 or Table 6 is used without knowledge of the other content. Conclusions concerning the foundations carrying a more or less environmental impact should be interpreted from the knowledge that this whole "more-or-less scale" in some cases may be within what is considered a moderate environmental impact.

The study does not intent to represent the whole state of knowledge regarding the potential environmental impacts (Chapter 3) and the study is based on current (2007) technologies and applications. Information and recommendations should therefore be corrected in line with increased knowledge and technological development.

Table 1a. A list of installed (2007) offshore wind power in Northern Europe.

WIND PARK In operation/ establised	AREA	NUMBER OF MILLS	FOUNDATION	BOTTOM SUBSTRATE	DEPTH (m)	DISTANCE FROM THE SHORE (km)
Breitling	Belt Sea	1			2	0.5
Nysted	Belt Sea	72	gravity foundation with score protection	sand with shell and gravel	5 - 9.5	10
Samsø	Belt Sea	10	monopile	soft substrate	20	3.5
Tunø knob	Belt Sea	10	monopile		20	3.5
Vindeby	Belt Sea	11	gravity foundation		3 - 5	1.5
Arklow Bank	Irish Sea	7	monopile		2 - 5	10
Barrow	Irish Sea	30	monopile	soft substrate	21 - 23	7
Burbo Bank	Irish Sea	25	monopile	hard bottom	3.7 - 7.5	6.4
North Hoyle	Irish Sea	30	monopile	sand	c:a 10	6
Blyth Offshore	North Sea	2	monopile		6 - 11	0.8
Egmond aan Zee	North Sea	36	monopile		19 - 22	10
Ems-Emden	North Sea	1			3	0.04
Horns rev	North Sea	80	monopile with score protection	sand	6.5 - 13.5	14 - 20
Irene Vorrink (Ijsselmeer)	North Sea	28			5	0.02
Kentish Flats	North Sea	30	monopile with heavy score protection	soft clay	6 - 8	8.5
Lely (Ijsselmeer)	North Sea	4	monopile		5 - 10	0.75
Roenland	North Sea	8			shallow	close to shore
Scroby Sands	North Sea	30	monopile with submerged score protection	clay	4 - 8	2.3
Beatrice	North Sea (Scottish east coast)	2	jacket foundation	sand	45	5.5 - 9.5
Fredrikshavn	Northern Kattegat	4	bucket foundation			
Lillgrund	Öresund (the Sound)	48	gravity foundation with score protection	sand & limestone		7
Middelgrunden	Öresund (the Sound)	20	gravity foundation with score protection	sand & stone	3 - 6	3
Bockstigen	Baltic Sea (Gotland)	5	monopile		6	3
Utgrunden I	Baltic Sea (Kalmarsund)	7	monopile	pebble mixed bottom	7 - 10	8
Yttre Stengrund	Baltic Sea (Kalmarsund)	5	monopile	pebble mixed bottom	6 - 10	5
Svante I (nedmonterat)	Baltic Sea (Nogersund)	1	concrete tripod		6	0.3

Table 1b. A list containing some of the offshore wind parks being planned, permitted or under construction in Northern Europe (2007).

WIND PARK planning phase / construction	AREA	NUMBER OF MILLS	FOUNDATION	BOTTOM SUBSTRATE	DEPTH (m)	DISTANCE FROM THE SHORE (km)
Finngrunden	Bothnia	100 - 200		stone &sand	down to 20	
Storgrundet	Bothnia	approx. 50		stone & sand	down to 20	
Klocktärnan	Gulf of Bothnia	approx. 100		sand & gravel		
Mecklenburg - Vorpommern	Belt Sea					
Rødsand II	Belt Sea		gravity foundation	hard clay	5 - 12	
Sky 2000	Belt Sea					
Rhyl Flats	Irish Sea	25	monopile			8
Robin Rigg	Irish Sea	60	monopile		3 - 21	9
Skottarevet	Kattegat	30		clay and smaller stones	20 - 30	7.5
Stora Middelgrund	Kattegat	108		gravel & stone	12 - 30	30
Alpha Ventus	North Sea	12	tripod & jacket foundation		30	43 - 50
Borkum Riffgrund	North Sea	157				34
Breedt/Mardyck Bench	North Sea					
Butendiek	North Sea	80			20	34
Cromer	North Sea	30				7
Gunfleet Sands	North Sea	22	monopile with score protection	sand		7
Horns rev II	North Sea	95	monopile			
Jade	North Sea	1			5	0.6
Lynn/Inner Dowsing	North Sea	54	monopile		6 - 13	5
Q7	North Sea	60			20 - 24	23
Solway Firth	North Sea					
Thornton Bank	North Sea	60	gravity foundation			27
Vlakte van Raan	North Sea					
Taggen/Hanöbukten Offshore	Baltic Sea	60-83		sand & stone	10 - 35	12
Trolleboda	Baltic Sea	50				
Klasådern	Baltic Sea (Gotland)	14	gravity foundation or monopile			
Utgrunden II	Baltic Sea (Kalmarsund)	24	monopile	pebble mixed bottom		
Kriegers flak	Baltic Sea	128			15 - 42	

2 Foundations

This chapter provides a description of various foundations used in order to anchor offshore wind mills. The models described includes; gravity, monopile, jacket, tripod, bucket and floating foundations. A feedback to the ecological impact is given in Chapter 3.

The descriptions are based on information from experts in the offshore industry as well as technical evaluations, detailed descriptions and design manuals. Specific technical information has been obtained from Vattenfall and E.on especially concerning the most common foundation models in the current situation; gravity- and monopile foundation. Dimensions and other details should only be considered as examples; since the design and dimensions of the foundations vary from case to case due to the current circumstances. The future foundations can be expected to be generally larger than the foundations used today (2007) due to the trend towards higher installed capacity (MW).

Section 2.6 provides a general description of score protection which is used especially for gravity foundation but in some cases also for other foundation models. Facts about anodes, which are used in connection with cathode protection, can be found in information box 1.

Information box 1. Cathode protection of anodes

Anodes with cathode protection are commonly used to prevent oxidation and corrosion of metals. The anodes are consisting of metal rods attached to the outside of the foundations, where it is in contact with the metallic parts of the foundation to be protected (for example; pile and transition piece on monopile foundations or reinforcement bar on concrete gravity foundations). The anodes used in Lillgrund wind park (gravity foundations) consist of 1.5 m long pieces of 64 kg anodic metal compound, containing mainly of zinc (Zn), and a small part of indium (In), copper (Cu), cadmium (Cd), silicon (Si), iron (Fe) and aluminum (Al) (Grahn personal comment).

Anodes are consumed and replaced within a 10 year time interval. Several of the active substances are toxic, but the emissions are relatively small per unit time. Cathode preventive anodes are not specific to wind power foundations but are used widely in the protection of steel structures in marine environments.

Definitions

SGS	Societe Generale de Surveillance SA
DWIA	Danish Wind Energy Association
WPD	Wind Power Development
EWEA	European Wind Energy Association
OES	Offshore Environmental Solutions
ØDS	Ødegaard & Danneskiold-Samsoe A/S

2.1 Gravity foundation

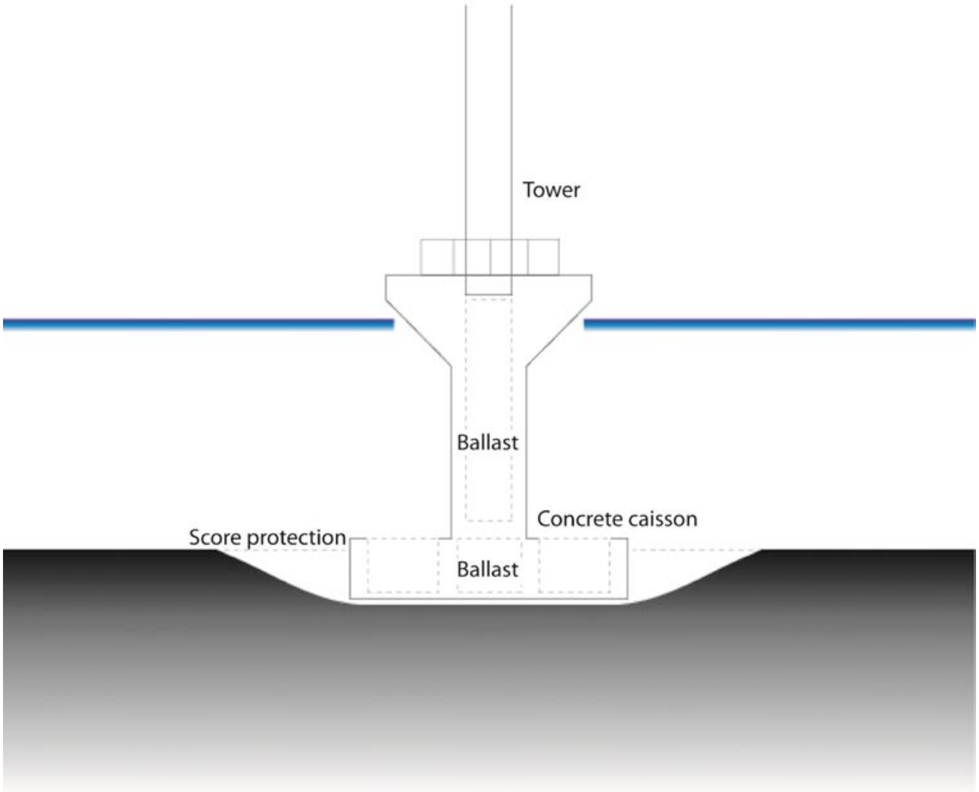


Figure 1. A schematic outline of a concrete gravity foundation. The scale is not proportional; for details and dimensions see section 2.1.3.

2.1.1 General information on gravity foundation

As the name indicates, a gravity foundation works by using its weight to keep the wind turbine in an upright position. A base consisting of a concrete caisson or a steel container is plunged into the bottom where it is filled up to and above the level of the surrounding seabed with ballast stones, concrete or other material of high density. Almost always, the gravity foundations require some kind of score control to prevent the water movement in undermining the anchorage. The foundation has a time glass design to prevent ice damage during cold winters which allows the upper angle to break ice away.

2.1.2 When is a gravity foundation used?

The concrete gravity foundations have a relatively large base resulting in a high load from water movements laterally, and the cost for traditional gravity foundations (manufacturing and installation) increase exponentially with depth. Therefore, the concrete gravity foundations (Fig.1) are mainly an option for shallow water. From an economic point of view, up to date (2007) tested versions of the concrete gravity foundations are suitable down to about 10m (DWIA 2003; WPD 2005). 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). Gravity foundations made of steel have been developed to be able to utilize deeper water with this kind of foundation (Fig 2; see section 2.1.3) (DWIA 2003).

Gravity foundations can be adapted to a variety of bottom substrates by adjusting the base diameter because this kind of foundation does not require a deeper recess in the bottom substrate. This implies that gravity foundations are well suited for rocky bottoms and bottoms with boulders as well as stable (well packed) sediments. Bottoms of consistently loose sediment are on the contrary not appropriate for the gravity foundations (SGS 2005).

The gravity foundations are used for example at the wind parks of Nysted (Bälthavet), Middelgrunden (Öresund), Vindeby (Bälthavet), TunØ Knob (Bälthavet) och Lillgrund (Öresund).

2.1.3 A detailed description of concrete gravity foundation

Depending on the water depth, exposure (waves and currents), drifting ice and the size of the tower, there is a variation in the proportions of every individual gravity foundation. The foundations at the wind parks of Middelgrund and Lillgrund are standing on bottoms with an interval of 4 - 9m in depth in the Öresund with rather strong currents. They have concrete caissons with a diameter of 16.7 – 17.6 respectively 16.5 – 19.0 meter (Grahn personel comment; Sorensen et al 2002). At the Middelgrund, the weight of the foundations is 1 800 tons including the ballast (Sorensen et al 2002). The ballast used with the gravity foundations may consist of sand, stones, concrete or iron ore (SGS 2005).

At Lillgrund, the hexagonal caisson of concrete is immersed 2.5 m and protrudes 0.6 m up from the bottom. The caisson is resting on a bed of stones and is filled with an underlying layer of gravel (Ø = 35 – 350 mm) and an overlay of larger boulders (200 – 1 200 kg per stone). From the caisson, the foundation rises up through an approximately 5m diameter concrete column filled with ballast, which extend conical (55^0 angle) towards the surface to a platform of 10 m in diameter. The reinforced concrete is smooth (cast in steel / wooden molds) and not painted.

To avoid corrosion, zinc anodes are mainly used since leading metals delay corrosion of reinforcement inside the concrete. Anodes are consumed and replaced within a 10 year time interval (Grahn personal comment).

At the Lillgrund wind park, the score protection extends 6 – 8 m around the recessed concrete caisson, which leads to a total diameter of 35 m. The score protection outermost consists of gravel (Ø = 35 – 350 mm) and further into the pillar boulders are used (30 – 350 kg per stone) (Grahn personal comment).

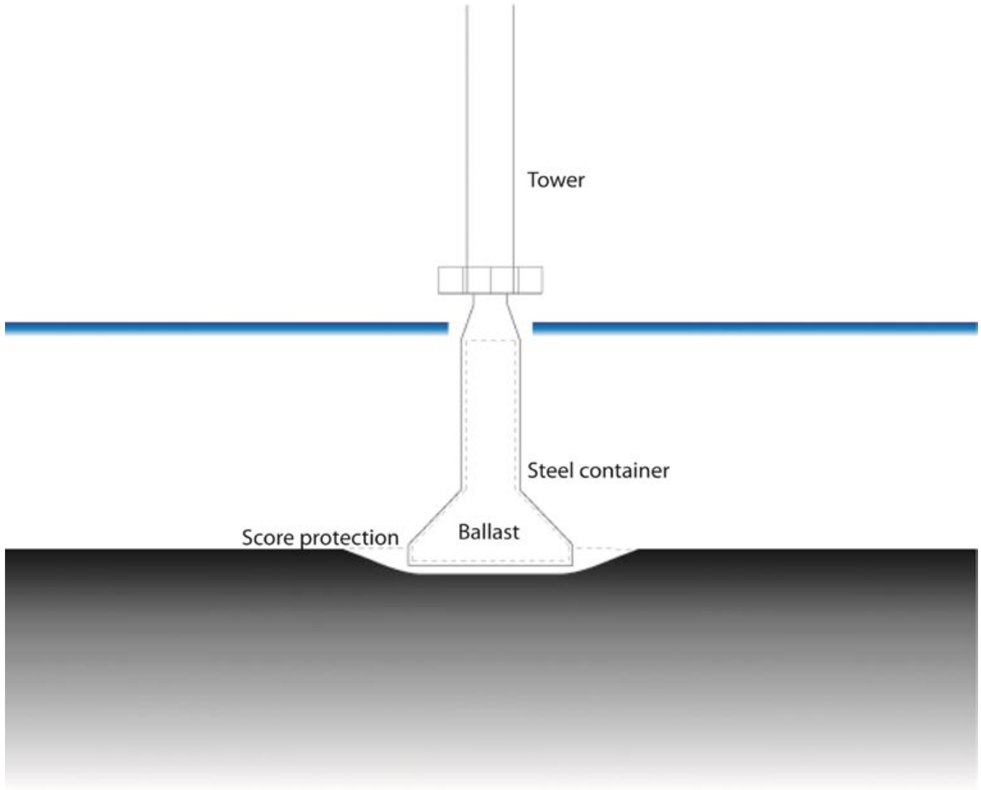


Figure 2. A schematic outline of a steel gravity foundation. The scale is not proportional; for details and dimensions see section 2.1.4.

2.1.4 Description of steel gravity foundations

An alternative to concrete gravity foundations with caisson is gravity foundation with a smaller and lighter base consisting of a steel container. The steel container, which is in the magnitude of Ø = 15 m for a water depth of 4 – 10 m, is filled with high density materials such as "olivine" (magnesium-iron-silicate) (DWIA 2003). The foundation is built on a preprocessed bed of gravel and is generally in need of score protection.

The great advantages with the steel gravity foundation, in comparison with the concrete foundation, are the lighter handling weight and also that the production and installation expenses do not increase exponentially with depth (DWIA 2003). At greater depths, where the expenses for installation usually are high, the steel foundation may be favorable.

2.1.5 Construction of gravity foundation

In the construction of gravity foundation the bottom is preprocessed in several stages; 1) dredging, 2) paving 3) attachment of the foundation, and 4) the filling of ballast.

The work of dredging from dredging vessels results in a recess in the sea bottom of specific measures. Where larger boulders are present, these are blasted into pieces. In those cases, a smaller explosive charge is set before, in order to scare away fishes (Peter Madsen Shipping 2006). At the wind park of

Lillgrund, the dredging was performed from vessels and was accomplished in two separate steps – rough dredging down to 0.5 m over the calculated depth and then a more precise dredging (Peter Madsen Shipping 2006). The sediment dredged and removed from Lillgrund was about 1 500 – 2 000 ton per foundation, with a spread distribution of various amount of days depending on local bottom conditions and weather. The dredged material was deposited on land.

After completed dredging there is a bed of crushed stones established for the foundation to rest upon. The stones are spread over the dredged area by a bar, maneuverable from a vessel, which results in a flat-bed of stones. In Lillgrund Wind Park this bed of stones was 0.3 m thick, containing about 130 m^3 of crushed stones for every foundation.

When the bed of stones is completed, the gravity foundation is placed by a vessel with a crane after which the ballast is filled (see section 2.1.2). The most sensitive parts of the foundation can be protected with wooden boards during the ballast filling (Grahn personal comment).

During the whole work of installation, the ship is fixed in position with spud legs, computerized operated propellers or computerized anchor ropes. Inspection with divers is made after every completed section.

2.1.6 Applied summary of gravity foundation

Gravity foundations require a greater bottom area than other foundations. The natural bottom is destroyed and replaced by an artificial substrate which gives new conditions for marine organisms. During the work of installation there is sediment spreading activity which may cause local effects. The list below is a summary of relevant biological impacts related to installation of gravity foundations. The information is mainly based on the conditions at Lillgrund. The details from Lillgrund are to be considered of general interest since the wind parks of both Nysted and Middelgrund have nearly identical foundations.

Structure (for every foundation)

- Foundation pillars: creates an artificial vertical bottom surface of smooth concrete
- Conical platform: creates an artificial overhang
- Eventual caisson of concrete: creates an artificial horizontal bottom surface (about 250 m^2) of stones, elevated 0.5 – 1 m above the bottom
- Container of steel: creates an artificial bottom surface of surface-treated steel, could be covered by horizontal score protection (stones)
- Score protection: creates an artificial horizontal bottom surface (about 650 m^2) of stones and gravel
- Anodes: outer rods containing zinc especially, which are consumed and replaced over time (see Information box 1)

Work of construction (for every foundation)

- Dredging in the range of 1 500 – 2 000 tons of dredging materials: sediment spreading, proceeding during several working days.
- Drilling and blasting: high sound levels.
- The spreading and equalization of crushed stones: noise, proceeding in one to a couple of working days.
- The filling of ballast: noise.
- The vessel activity including anchorage: noise and local disruption of the bottom

2.2 Monopile foundation

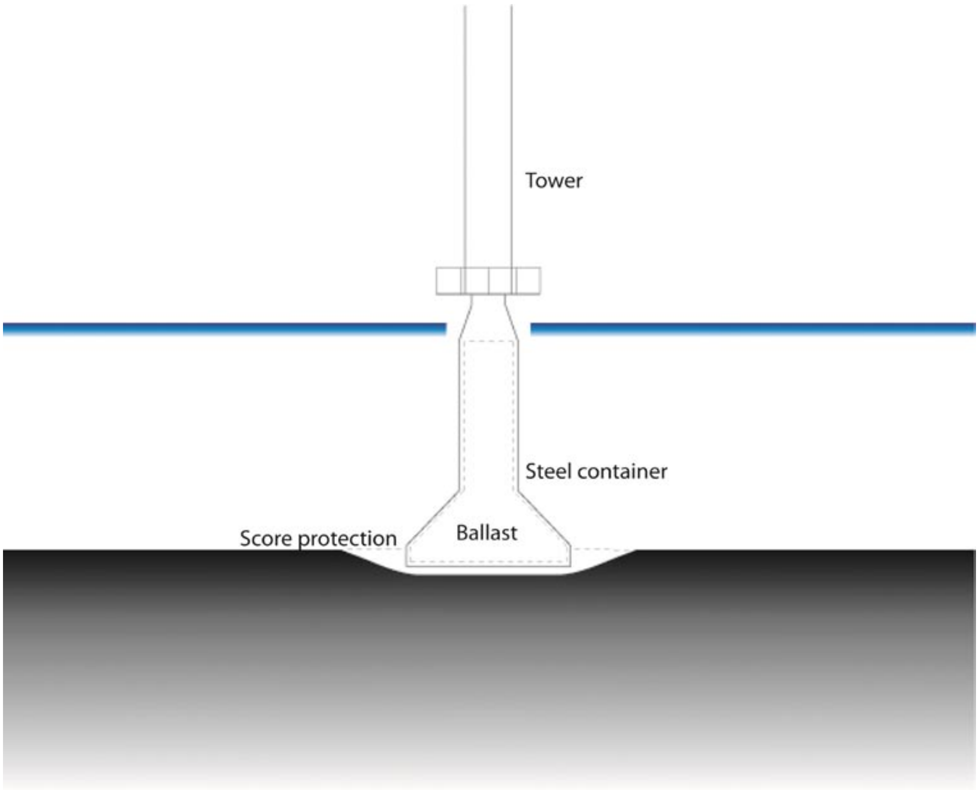


Figure 3. A schematic outline of a monopile foundation. The scale is not proportional; for details and dimensions see section 2.2.3.

2.2.1 General information on monopile foundation

The monopile foundation (Fig. 3) consists of a simple pile of steel that is plunged far down in the bottom by pile-driving or drilling. Due to the loading weight stress, the diameter of the foundation and the depth of piling can be adjusted. The technique is relatively simple and does not usually require any preprocess of the bottom. However, during the installation a pile equipment of big lifting capacity is required. Even if the water movements might dig out the sediment close to the bottom, the monopile foundations are not as dependent of score protection such as gravity foundations, since the depth of eventual calculated future erosion can be compensated with a greater plunging depth during the construction work (Dahlén personal comment).

2.2.2 When is a monopile foundation 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 the clay is predominant in all layers (SGS 2005). In the presence of stony bottoms or occasional boulders, drilling is used for the ongoing piling process. So far the monopile foundations have declared to be an economical alternative down to the depth of 20 – 25 m (SGS 2005; WPD 2005), although differences occur between different ocean areas and the conditions of the bottoms. 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 Horns rev (North Sea), Utgrunden l (Baltic Sea), Arklow Bank (Irish Sea), Scroby Sands (North Sea) and Kentish Flats (North Sea).

2.2.3 A detailed description of monopile foundation

The design of monopile foundation is relatively simple compared to other foundations. The foundation consists of one long hollow steel pile (cylinder) which is pressed down in the substrate and a similar transition piece is then attached as a sleeve which reaches up to about 10m above the water surface (Dahlén personal comment). To strengthen the connection between the pile and the transition piece a grout protection (concrete mix) is used.

The depth of the anchorage, the diameter of the foundation and the thickness of the steel is decided by the bottom substrate, the depth, the weight of the turbine, the height of the tower and the load (weight stress) from the currents, waves and ice. At the first establishments of large-scale offshore wind power, the monopile foundation have been 3 – 4 m in diameter (DWIA 2003), but the technological development increases the turbine sizes which leads to higher demands. This creates pressure on the foundation and its size in diameter which increases. The wind power of 3 MW planned to be stationed at Utgrunden (Baltic Sea) of 20 m depth have been calculated to a required diameter of 5.4 m and a anchorage depth of 23 m down in the substrate for monopile foundations (Dahlén personal comment). This generates a weight of

490 tons of steel for every foundation. Another calculation of monopile foundation diameter is found at the German Borkum Riffgrund (Nordsjön) where the calculations have lead to a diameter of 6 m for a 4.5 MW windmill in a water depth of 30 m, resulting in a weight of 700 tons of steel per foundation (WPD 2005). For the last version of offshore wind power one might assume that monopile foundation will have a diameter of 6 m (EWEA 2007).

The steel used for the monopile foundations has a thickness of 50 – 100 mm and is comparable to the steel of ships. Anodes are used to prevent corrosion (see Information box 1), and the whole foundation or parts of it, is painted with corrosion protective epoxy and paint without anti-fouling components (Dahlén personal comment). At the Kentish Flats only the upper part of the foundations (the transition piece) is treated with corrosion protection and paint, while the pile of steel is untreated and is protected by anodes (EWEA 2007). The monopile technique is well-tested in the offshore industry (for example; bridges, harbours and oil platforms) and the duration for the constructions is calculated to at least 50 years (DWIA 2003).

The energized cable from the generator is conducted inside the foundation down to the transition between the pile and the transition piece. Then the cable is headed out on to the seabed through an outer casing on the foundation. 33 kV three-phase alternating current (AC) cables are commonly used, which potentially can emit a smaller magnetic field and an induced electric field (Gill and others 2005).

Mitigation measures against eventual pack ice can be prevented by an ice collar mounted at the waterline of the foundation. At the Utgrunden II, a cone-shaped ice collar of steel (an angle of about 45^0) is suggested.

2.2.4 Construction of monopile foundation

The monopile construction does not in general require any preprocess of the bottom surface (DWIA 2003), but requires very strong pile-driving tools.

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 made 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 amount of beats, the strength of the beats and the need for drilling or bursting is strongly depended upon the substrate of the bottom, the depth of anchorage and the diameter of the foundation. This leads to a great variation between different wind parks and between individual foundations. After completed piling, the transitions piece of the monopile foundation is put in place and the construction phase can be completed (Dahlén personal comment).

During the construction of monopile foundation (Ø = 3 m) at the Utgrunden I (of the year 2000), the piling took about 1 – 4 hours for every individual foundation. Measurements were performed at one foundation which revealed that the frequency of the beats escalated from 2 – 30 beat per minute; a total of 1320 beats. During the piling, hydrophones were placed 30, 320, 490 and 760 meters from a foundation, showing a spectrum of sound with an elevated noise at the frequencies 4 to 20 000 Hz. The loudest noise was measured at 300 Hz where the SEL (Sound Exposure Level) was 184 dB re 1 µPa at the distance of 320 meters (ØDS 2000).

During the construction of monopile foundations (Ø = 4 m) at the North Hoyle wind park (Irish Sea, depth; 7 m) sound levels originated from a source level were measured up to 262 dB re 1 µPa at 1 m. The range of frequency was about 40 – 1 000 Hz. The corresponding source levels at Horns Rev wind Park (Nordsjön; depth 9 m) was 215 dB re 1 µPa at 1m (Nedwell & Howell 2004).

2.2.5 Applied summary of monopile foundation

The monopile foundation only needs a smaller part of the natural bottom environment, especially when no score protection is needed. Compared to other foundations, the simple structure (a cylinder of steel) of monopile foundation gives a minimal structural complexity for marine organisms. The construction work generates very powerful levels of noise which could be of direct harm for the marine organisms in the surrounding areas. The list below is a summary of the relevant biological information regarding monopile foundation. The information is based on several different sources from both established and planned offshore wind parks, why details and dimensions should be looked upon as examples.

Structure (for every foundation)

- Foundation pillars: creates an artificial vertical bottom surface of steel, painted with topcoat (without anti-fouling components).
- Ice collar: creates an artificial overhang by the water surface.
- Score protection: creates an artificial horizontal bottom surface of stone and gravel.
- Exterior cable in an exterior casing: can emit a smaller magnetic field and an induced electric field along the cable outside the foundation.
- Anodes: exterior rods, containing mainly zinc, which are consumed and replaced over time (see Information box 1).

Work of construction (for every foundation)

- Piling: generates very loud pulsating sounds/noise, for about 1+ hours.
- Eventual drilling: locally spreading of sediment.
- Activities from vessels including anchorage: noise and local bottom disruption.

2.3 Tripod foundation

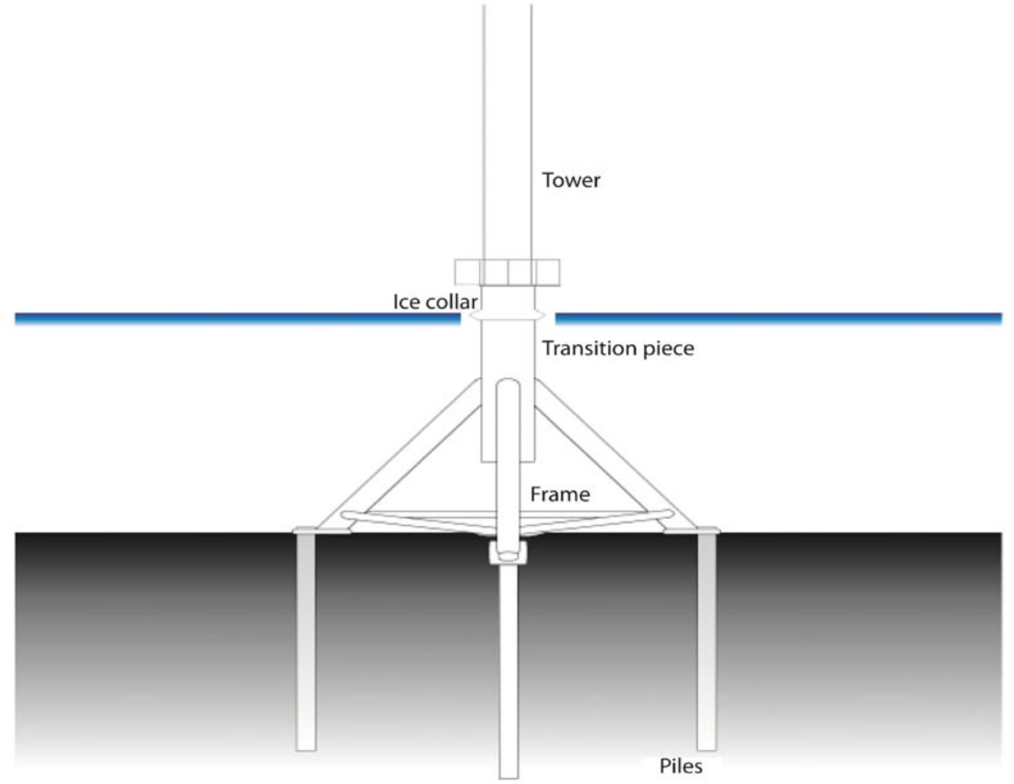


Figure 4. A schematic outline of a steel tripod foundation. The scale is not proportional; for details and dimensions see section 2.3.

2.3.1 General information of tripod foundation

The tripod foundation (Fig. 4) can be described as a monopile foundation in the water column, and eventually all the way to the bottom, where it is divided into a triangular frame of steel transition pieces. These are attached into the sediment with piles of smaller diameter compared to one simple monopile foundation. Due to this frame, the load is distributed across multiple attachment points and a greater bottom surface compared with a monopile foundation. The transition can also be placed over the water surface where three simple piles lead down in the water to their attachments.

The technical design of the tripod foundation may differ a lot between producers and due to the existing conditions such as depth, weight stress and bottom substrate. An estimation of weight for a tripod foundation (3 MW turbines) has been performed in a depth of 20 m and with a fairly hard sandy bottom substrate. 535 tons of steel were the calculated needed weight (SGS 2005). Another calculated weight with a depth of 40 m and a non-specified bottom substrate, gives a weight of about 1 500 tons of steel. This is not including the attachment piles but only the foundation (WPD 2005).

The tripod foundation is attached by piling. Due to the smaller dimensions of the piles, the piling can be done with lighter pile-drive equipments compared to the required piling work for the monopile foundation. The dimensions of the tripod piles depends on water depth, bottom substrate and the weight load, but generally they are in the size of Ø 3 – 4 meters (Achmus & Abdel-Rahman 2006; EWEA 2007). It is possible to replace the big piles by several smaller ones (about Ø = 1 m) (DWIA 2003). The construction work with tripod foundations requires several steps and might take considerably longer time than the attachment of a monopile foundation.

In locations where great water movements at the bottom are present, a score protection may be needed (WPD 2005).

2.3.2 When is a tripod foundation used?

The tripod foundation is best suited on undisturbed sediment, but is adjustable to most bottom substrates (Dahlén personal comment; SGS 2005). Due to the piling, a tripod foundation is not a good alternative in areas with a lot of boulders (DWIA 2003). One of the greatest advantages of a tripod foundation is its ability to be used on deeper bottoms compared to gravity and monopile foundation and also, in general, there is no need for preprocessing the bottom before a tripod establishment.

At a depth interval of 20 – 40 m, the tripod foundation could be of technical and economic advantage (SGS 2005; WPD 2005). The dimensions of a tripod foundation is, like a monopile foundation, dependent on the impact of waves at the Swedish west coast and by the pack ice in the Baltic, where there is a greater cost per depth (DWIA 2005).

The technique of tripod is well tested in the offshore business (DWIA 2003) but has not yet (2007) been applied in the offshore industry, except for a smaller one made of concrete in Nogersund. In Alpha Ventus wind park (North Sea), tripod foundation is now under construction and this kind of foundation is given much attention in the investigations of new projection plans. With a future trend for deeper offshore establishments, the tripod foundation as an alternative is to be expected.

2.3.3 Applied summary of tripod foundation

The tripod foundation creates an artificial structure of higher complexity than both gravity and monopile foundations, which is of importance for marine organisms. Construction work does not, in general, demand any activity involving spreading sediment but the piling results in powerful/heavy and potentially harmful levels of sound. The list below is a summary of the relevant biological information. The given dimensions are only to be looked upon as examples since the tripod design can be very variable.

Structure (for every foundation)

- Triangular frame with transverse ribs: creates a complex, artificial bottom surface consisting of steel girders which are painted (without anti-fouling components) and protected from corrosion with epoxy.
- Eventual ice collar: creates an artificial overhang by the water surface.
- Eventual score protection: creates an artificial horizontal bottom surface of stones or gravel.
- Eventual exterior cable in an exterior casing: can emit a smaller magnetic field and an induced electric field along the cable outside the foundation.
- Anodes: exterior rods, containing mainly zinc, which are consumed and replaced over time (see Information box 1).

Work of construction (for every foundation)

- Several pilings: creates very loud pulsating sound levels
- Activities from vessels including anchorage: noise and local bottom disruption

2.4 Jacket foundation

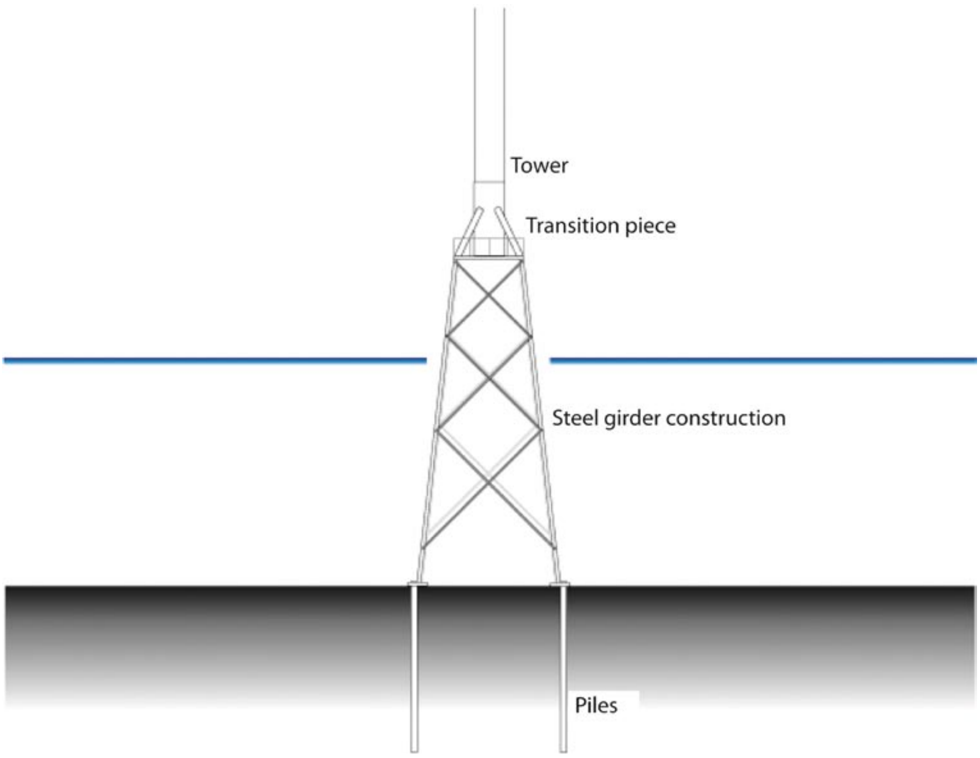


Figure 5. A schematic outline of a jacket foundation. The scale is not proportional; for details and dimensions see section 2.4.

2.4.1 General information of jacket foundation

The jacket foundation (Fig. 5) is composed by a squared network steel rods design, which is anchored in the bottom using piling activity. The technique is derived from oil platforms and is adapted for great depths. The rods of steel in the network are fixed together by welding or by the use of molded sleeves. Corrosion protection is achieved by using anodes, epoxy and/or galvanizing underneath the covering paint. The attachment of a jacket foundation takes place by piling 3 – 4 anchorage points in the bottom substrate, after which the whole steel construction can be mounted in one piece. A transition piece between the foundation and the tower is placed to distribute the weight (Dahlén personal comment).

In connection with the establishment of Utgrunden II (Baltic Sea), jacket foundation was developed to suit turbines of 3 MW and with a water depth of 20 m. The diameters of the steel pipes of these jacket foundations were calculated to 0.7 m for the outward bars and 0.5 m for the transverse bars (Dahlén personal comment). The anchorage piles to this jacket foundation were calculated to a diameter of 1.5 m.

In the year of 2006, the demonstration and research project Beatrice (Talisman Energy) was installed at a depth of 48 m in the North Sea, consisting of two 5 MW wind mills anchored on jacket foundations. Each foundation is 62 m high with 20 x 20 m at the base. Between the 4 corner beams is a network of transverse (45^0) smaller beams. The weight of each foundation is about 750 tons (plus the transition piece of 150 ton) and it is corrosion protected by epoxy and 72 smaller anodes (a total of 240 kg). In the splash zone (water surface area) all the steel is covered by sprayed aluminum. Both foundations are anchored each by four long piles (44 m) of the diameter 1.8 m (60 mm-thick steel) (Talisman 2006; EWEA 2007).

At the preliminary calculations for the wind park of Kriegers Flak (Baltic Sea), the weight of a jacket foundation at a depth of 40 m was roughly estimated as 700 tons of steel. As for the foundation at the project Beatrice, jacket foundations require a relatively low weight, which is favorable in an economical perspective in comparison with other foundations.

2.4.2 When is a jacket foundation used?

The jacket foundation is cost-efficient at greater depths (from 20 m) since they require less steel than for example the monopile and the tripod foundations (WPD 2005). When used in shallow water it becomes generally more expensive than other foundations (Dahlén personal comment). One advantage of jacket foundation is that the anchorage does not require such heavy piling work as the monopile foundation.

After extensive investigations and comparisons with tripod foundations at the Beatrice project (North Sea, 48 m) it was established that jacket foundations were a less expensive alternative than other foundations (Talisman 2006). Jacket foundations are widely used and in a variable way also in other sectors of the offshore industry. It is likely that jacket foundations will be a dominating alternative in the future offshore establishment in deep waters (Dahlén personal comment).

2.4.3 Applied summary of jacket foundation

The jacket foundation only occupies a smaller part of the natural bottom environment, limited just to the 3 – 4 anchorage points. But the structural complexity that is created by the multiform construction leads to a significant addition of habitats for many marine organisms and thus changes the natural environment. The aggregation of fish may also give a secondary impact on adjacent bottoms. The piling during the construction work creates heavy noise levels that might be harmful for the organisms in the surroundings.

The list below is a summary of the relevant biological information regarding jacket foundation. The given dimensions are only to be looked upon as examples since the jacket design can be very variable.

Structure (for every foundation)

- Steel construction: creates a multiform network of artificial bottom surface, consisting of steel rods (Ø 0.5 – 1m) which are galvanized and/or painted with covering paint of corrosion protection (for example glass flake epoxy).
- Exterior cable in a casing: can emit a smaller magnetic field and an induced electric field along the cable outside the foundation.
- Anodes: exterior rods, containing mainly zinc, which are consumed and replaced over time (see Information box 1).

Work of construction (for every foundation)

- Piling: creates very loud pulsating sound levels.
- Activities from vessels including anchorage: noise and local bottom disruption.

2.5 Other foundations

Besides the four basic models; gravity-, monopile-, tripod- and jacket foundations, suggestions of foundations based on a combination of these techniques have been developed. Examples of combinations are: gravity/pile, jacket/monopile and tripod/monopile (SGS 2005). The technical design, the construction procedure and the relevant details of marine biology can be estimated on the basis from the four basic models described in the previous chapters.

Two additional models, bucket foundation (Fig. 6) and floating foundation (Fig. 7) are under development but have so far not been in use. The bucket foundation, which is hollow and can be resembled as a suction cup, is plunged to the bottom and is fixed in position with vacuum. This technique have so far been tested without success (Dahlén personal comment), but could possibly be of importance in the future due to continuous research within this area. A bucket diameter of 12 m has been deemed calculated to be suitable at depths of 10 m (EWEA 2007). In a marine biology perspective, the bucket foundation is to be considered as a gravity foundation (see section 2.1).

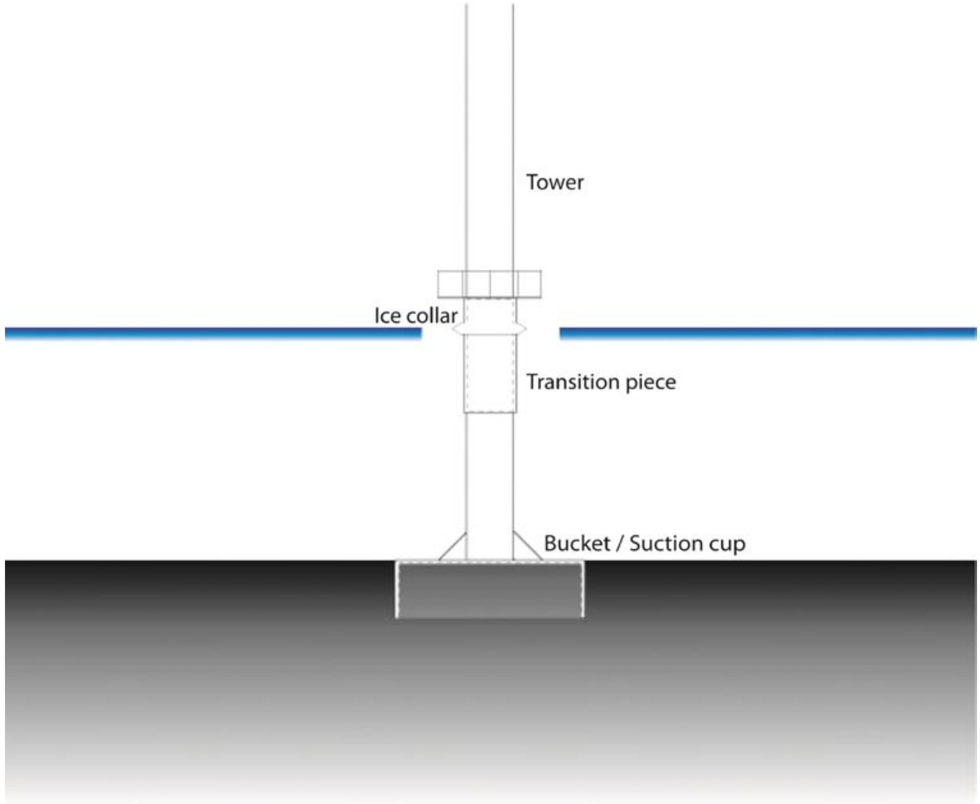


Figure 6. A schematic outline of a bucket foundation. The scale is not proportional; for details see section 2.5.

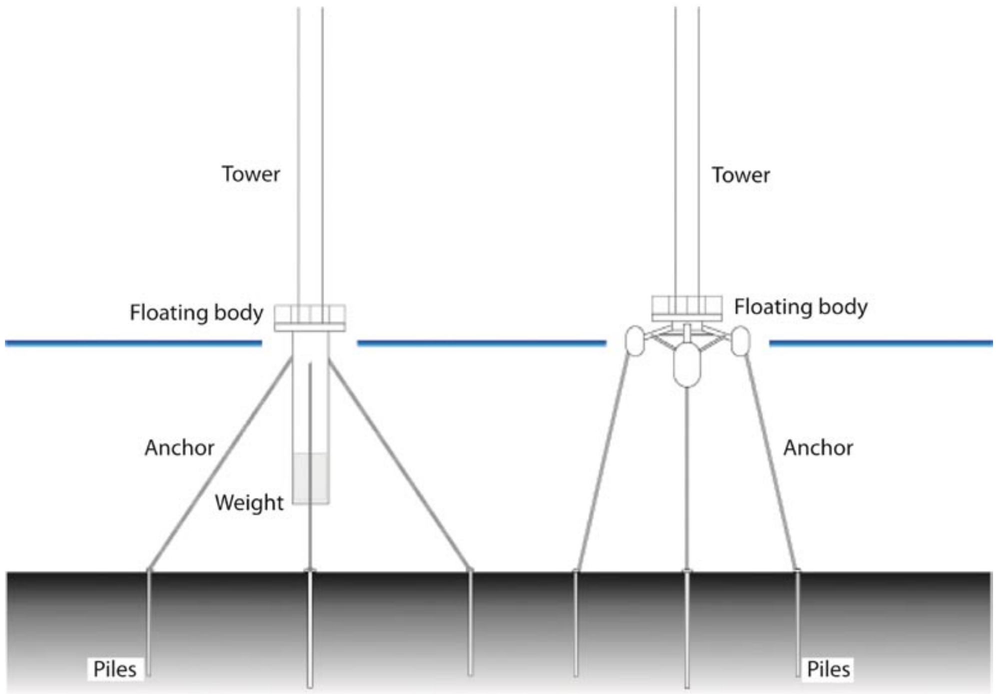


Figure 7. A schematic outline of floating foundations, two different versions. The scale is not proportional; for details see section 2.5.

The suggestion of floating foundations, designed with steel constructions which is fixed in position by wires anchored to the bottom, refer to future establishments in deep water and has so far been estimated to be too expensive as alternatives in commercial use (WPD 2005). The idée of using floating foundation in the future is not considered impossible. A concept with simple floating foundations for depths at 150 – 800 m is developed by the Norwegian Statoil Hydro. The part submerged is here made of 100 m deep concrete weights. Also another concept with three wind mills for every floating construction is under development thru FORCE technology (EWEA 2007).

In a marine biology perspective, the floating foundations may come to resemble either monopile foundations (see section 2.2) or jacket foundations (see section 2.4). Though with a significant difference since the only contact with the bottom for floating foundation is by anchored wires.

2.6 Score protection

Score protection is made to prevent the local hydrographical changes that might occur around the foundation from digging out and undermine the bottom. It is calculated that a current velocity of 0.5 – 1.0 m/s causes erosion of the magnitude 1.3 times the pile diameter if the wave currents reach the bottom. Correspondingly erosion without the waves is 0.5 – 1 times of the pile diameter. In bottoms with sandy substrates, this erosion might take place in a couple of hours while the same erosion could last for hundreds of years in muddy bottoms (Nielsen personal comment).

The erosion control used so far for the offshore wind mills generally consists of a lower layer of gravel and an upper layer of stone, which is placed out from the anchorage point of the foundation to a suitable distance (in the range of 5 – 10 m). The size of the score protected area is decided by the hydrographical conditions such as under surface currents and waves. An example of score protection of 5 – 10 m from the foundation is found at the wind park of Kentish Flats (North Sea) and has proved to be effective (OES 2007). However, at the wind park of Horns rev significant erosion has occurred despite using a similar technique. Reasons for this are under investigation (2007) (Nielsen personal comment).

A score protection is always required for gravity foundations since even a slight change would result in significant instability. The piling foundations (monopile, tripod and jacket foundation) do not require score protection since they can be adjusted for erosion. The adjustment is done by extending each pile with the same number of meters which erosion is expected to dig out (EWEA 2007).

Figure 8. Artificial score protection, GRIP, adjusted to increase the amount of habitat for fish and bottom living animals associated to hard bottom substrate –by the reef-effect. Each module consists of a perforated concrete pipe lined with protruding plastic pipes.

In addition to score protection of gravel and stones, specially designed protection has been produced. One example is “GRIP” by Reef Systems, which is a combination of score protection and artificial reef (see Fig. 8). The GRIP consists of concrete modules, equipped with protruding plastic tubes. Its capacity as score protection is not yet evaluated (Reef Systems 2007).

The impact on the marine environment from score protection is the extensive heterogeneous hard-bottom substrate, with many cavities, which is produced. The structure creates opportunities for the establishment of the organisms associated with hard bottom substrate and protective structures (see section 3.1).

3 Sources of influences

Offshore wind is an expanding business where marine resources are used and its environmental impact is now widely investigated by gathering experience and knowledge. This gathering of information is achieved by monitoring programs and through experimental studies. Extensive control programs have been carried out at the Danish wind parks of Nysted and Horns reef. The environmental impacts of the offshore wind parks in Sweden are studied at the wind park of Lillgrund (Öresund) and new control programs are planned for coming offshore wind parks. Targeted research with experimental studies and literature syntheses are in progress in several countries; for example in Sweden (Vindval), United Kingdom (COWRIE) and USA. A larger number of literary compilations have also been produced regarding environmental impacts from offshore wind; through authorities (Fiskeriverket/Swedish Board of Fisheries 2007; Jonasson 2002; Petersson 2000), through scientific papers (Gill 2005; Petersen & Malm 2006), through research programs (Michel et al 2007; Nedwell et al 2003; Nedwell & Howell 2004; Gill et al 2005; Thomsen et al 2006) and through the Environmental Impact Assessments for the different offshore wind projects.

Thus, the total current knowledge is increasing but instead of looking at the environmental impacts, this study focuses on comparing how the different designs of the foundations relate to environmental impacts; describing the technical factors that can increase or decrease the various sources of influences. The sources of influence discussed here are compared between the different models of foundations regardless of which of the sources that will appear to be significant in the future.

The following section deals with every source of influence by 1) a short summary of the mechanisms, 2) the difference between sea areas, 3) the difference between various foundations, and 4) any adjustments that may be taken to minimize negative impacts. The following sources of impacts are discussed:

- Fouling and reef-effect (3.1)
- Noise during operational phase (3.2)
- Hydrographic changes (3.3)
- Construction noise (3.4)
- The spread of sediment during the construction phase (3.5)

3.1 Fouling and reef-effect

3.1.1 Background

During the establishment of offshore wind parks, the foundations and the score protections are expected to create new habitats for the hard bottom living algae and animals. This in turn results in the increase of the biological biodiversity in the area. Artificial hard bottom habitats with the function similar to natural hard bottoms are called artificial reefs, and have been proven to be substrate for sessile algae and animals (Anderson & Underwood 1994; Conell & Glasby 1999; Jensen et al 2000; Glasby & Conell 2001; Svane & Petersen 2001; Bacchiocchi & Airoldi 2003; Knott et al 2004; Perkol-Finkel & Benayahu 2005; Boaventura et al 2006). Fouling on the reefs creates new habitats and an increasing access of food for fish and other mobile fauna. The new habitat does not only create a larger availability of food but also creates shelter against strong currents and predators. This will increase the number of mobile fauna concentration, such as fish, near the reefs and a so called reef-effect is created.

There is documentation of reef-effects on artificial reefs from both south and north Europe (Jensen et al 2000) and other parts of the world. This is now used, for example, in Japan and in USA in an attempt of increasing the catch of the commercial fish (Buckley 1982; Grove et al 1989; Milon 1989). The reason for the increased fish catch has been discussed. Whether it is only a gathering of fish or if it is an increase of fish production is hard to determine (Bohnsack 1989; Pickering & Whitmarsh 1997; Svane & Petersen 2001) but the reality most likely reflect a combination of both theories. The reason for the increase in fish abundance may also vary between different species.

The development of a hard bottom is created gradually when animals and plants are established at different times of the year and has a range of how competitive they are (Gaines et al 1985; Underwood & Anderson 1994; Qvarfordt 2006). A so called biofilm of microorganisms are created on a newly formed substrate, and this can make the establishment of larger organism's easier (Wieczorek & Todd 1998; Unabia & Hadfield 1999). During the initial phase, the opportunists are generally colonizing the substrate. These are characterized by; fast reproduction, fast growth and are widely dispersed geographically. The opportunists are in general not competitive regarding space and after some time species with longer life cycles, which also generally are more competitive, are established. This leads to a changing species composition with time until stabilized conditions are reached (Dean & Hurd 1980; Wennberg 1992; Qvarfordt 2006). It may take several years before a stabilization of a hard bottom community is reached and this is important to take into consideration before making any conclusions of diversity, abundance and biomass on a new established substrate.

Definitions
Fouling, a production of sessile plants and animals is here separated from the reef-effect which is defined as an increasing availability of mobile animals with a result of either an aggregation or an increased production. See Fig. 9

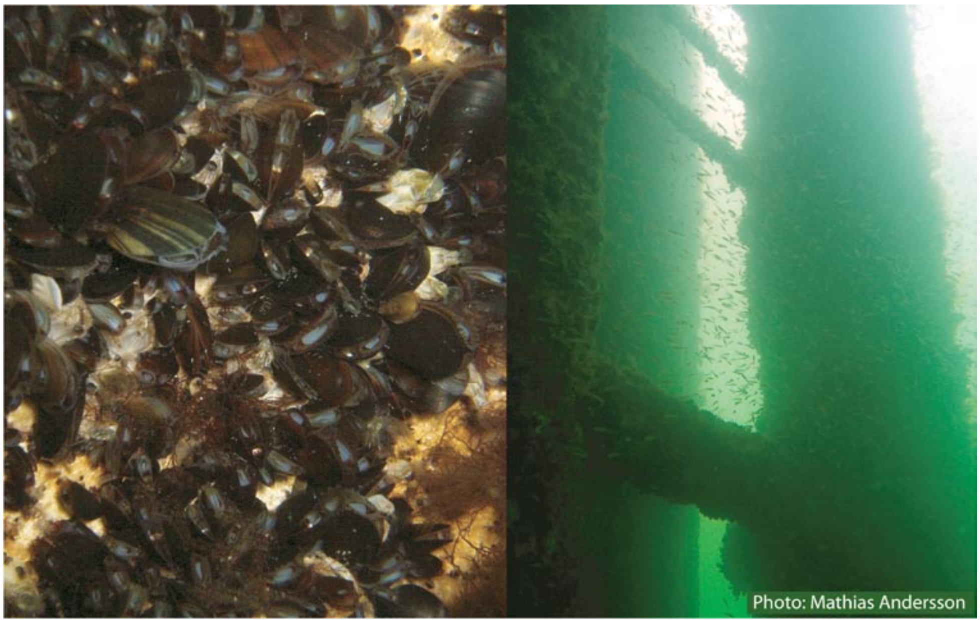


Figure 9. Fouling (left) and reef-effect (right) on a monopile foundation at the Utgrunden I. The structure to the right is the anchorage ladder on the transition piece of the foundation. The photos were taken on a depth of 5 – 6 m during August. They show a rich fouling of blue mussels and a high presence of two-spotted goby.

The main difference between a foundation of a wind mill and many other artificial reefs is the vertical structure that goes through the whole water column, from the surface to the bottom. A depth related zonation is created where both the deep living animals and the light demanding animals could be established. Other artificial reefs, that resemble foundations of wind mills, are bridge poles, piers, oil platforms and lighthouses.

The location of an offshore wind park is generally exposed and the plankton larvae and spores passing by with the water mass are more easily stuck on the vertical structure against the current and may colonize the free sites. This is especially good living conditions for filtrating animals, since the current contribute with planktonic food. The current is consequently an important factor in the development of a biological hard bottom community.

The design of the foundation with the adherent erosion protection (vertical, sloping and horizontal surfaces) and the structure of the surface (smooth or rough) are initially of importance regarding which kind of species that will establish on the foundation. The surfaces that are sloping or horizontal create different conditions than vertical ones, especially for light-dependent algae. Perennial macro-algae that are commonly found on shallow bottoms are limited when there is a sharp slope of the substrate. Studies in the Baltic Sea have shown that the algae dominate the substrate when the slope is less than 60^0 (degrees). Between 60^0 and 90^0 in angle inclination, the organism community gradually changes and is dominated by filtrating fauna. Some of the species are excluded already in the establishment phase, for example the important *Fucus vesiculosus* which has less than 1% successful settling when the angle is steeper than 60^0 (Qvarfordt 2006). The distance to the bottom is also of importance for the presence of some macro-algae since their heavy propagules easily sinks to the bottom in calm water after leaving the mother plant. One might see a result of this on large boulders where there is less recruitment of *Fucus vesiculosus* (Qvarfordt 2006). Some macro-algae are also limited by a high exposure due to waves and currents (Kautsky & van der Maarel 1990; Kautsky and others 1992; Nielsen 2001).

The structure of the erosion protection may contribute with small and large cavities, which enlarge the given conditions for fish and crayfish around the foundations. These various cavities can be utilized by different species and different life stages (sizes) of the same species. For example; lobsters and crabs can utilize both small and large cavities depending on which life stage they are in.

The surface structure of a foundation, originally, differs from natural hard bottoms in their lack of microhabitats such as indentations, crevices, cracks and bumps, which provide habitats for many species and create shelter against predators (Mc Guiness & Underwood 1986; Chapman 2003). Steel and treated concrete give the foundation a smooth surface, which makes it more difficult for many animals and plants to settle, while a rougher surface like the untreated concrete has a more resemblance to a natural bottom and so it is a more attractive habitat for many organisms (Harlin & Lindbergh 1977; Lubchenco 1983). Concrete may also leak calcium hydroxide, which may benefit the establishment of some organisms (Anderson 1996). Even if the biological community development may proceed quicker on a rough surface initially, the structure of the surface and by that also the species composition will level out when the species begin to grow over each other. Some species like the barnacles (which produce glue in order to attach themselves to the substrate) and the calcareous worms are more easily established directly on a smooth homogeneous surface than other organisms and are therefore creating a coarser structure. These organisms may later be overgrown by other species (Öhman & Wilhelmsson 2005). The initial differences can thus be explained by different surface structures, but if the differences remain after a longer period of time it might have other physiological and biological factors that are of importance.

Species colonization on offshore wind park foundations are dependent on the location of the park; east or west coast, exposed or sheltered, prevailing bottom substrate, depth and also closeness to natural hard bottoms.

There is a great salinity variation between the Swedish east and west coast, and it is important to pay attention to this while comparing the offshore wind parks in Sweden since salinity has a significant role for marine organisms and thus for the colonization of the algae and fauna. Whether the foundation is placed in open water or in a sound may be of importance, since some species benefit from water currents, some prefer high exposure and other benefit from high levels of nutrients which are found closer to the shore. Comparative studies in Kalmarsund, Öresund and at Gotland and Öland show that filter feeding animals dominated in areas with strong currents and that filamentous algae, which benefit from eutrophication, were more common close to shore (Naturvårdsverket, Environmental Protection Agency, 2006a). The ecological changes of an offshore wind park are more apparent when placed on a soft bottom (clay, sand, gravel) than placing the wind park where there is an existing hard bottom. The new habitat on the soft bottom attracts new species for the area, and so it changes the ecological conditions (Jensen et al 2000; Bulleri 2005). But it takes several years before a new hard bottom community is stabilized. How rapid the development of a hard bottom community is, also depends on the distance to a natural hard bottom.

Planktonic life stages of animals have different length of life in the free water mass depending on species and they are spread to new areas with the currents. When a new hard bottom substrate is created in soft bottom areas, hard bottom species can use this new substrate as a "stepping stone" and it will be easier to cross soft bottoms and deeper areas for establishment on new hard bottoms which then can be within reach (Glasby & Connell 1999). The effects of this may be both positive and negative depending on the species and the area. Alien (introduced) species can be spread to new areas in this way and can affect the local ecology. The success of the species establishment depends on the survival in the planktonic phase before it reaches the free space and their ability to establish on the substrate and in the area. An example of an introduced species is the amphipod *Jassa marmorata* which invaded the foundations of Horns rev on the Danish west coast where it was previously unknown (Leonard & Birklund 2006). This amphipod depends on hard bottom substrate, which is naturally scarce along the west coast of Jylland (Denmark).

The reef effects in terms of increased fish abundance have been found at the foundations of Utgrunden I and Yttre Stengrund in the Baltic Sea. Some species, especially smaller fish species, were concentrated nearby the foundations. This was also observed at the bridge of Öresund (Öhman & Wilhelmsson 2005). During the investigation close to the foundations of Horns rev and Nysted, larger fishes were observed, including cod (Leonard & Birklund 2006). Other studies have been looking at the fish abundance on a larger scale, with no focus close to the foundations but between the foundations within the whole wind park area. Comparative studies at the Horns reef and Nysted have not so far shown any significant effects and increased abundance or species richness of fish among the foundations in these wind parks (Klaustrup 2006). The Kentish Flats control program results (North Sea) indicate general increased fish abundance within the park. This result has not been analyzed statistically and there are no studies done close to the foundations (Emu 2006). All in all, it is difficult with the present knowledge (2007) to state to what extent reef-effects occur in a wind park. However, an increase in fish abundance at artificial constructions it is a common occurrence and is to be expected also in the wind parks.

A more detailed presentation of different studies that have been done with foundations, bridge poles, oil platforms and other artificial reefs is given in Information box 2. This gives an indication on how the organism communities may develop in various areas and on different types of foundations. The conclusions in the section below, dealing with the differences between ocean areas and foundations are mainly based on the information and the references presented above and in Information box 2.

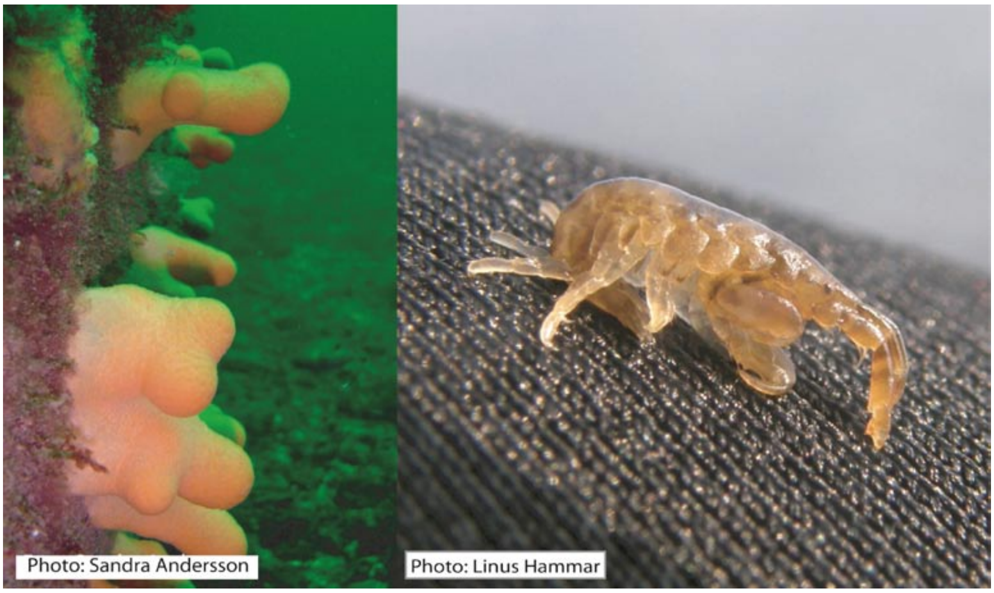


Figure 10. The soft coral (left) is a common marine fouling deeper down on the foundation or score protection. Tube building amphipods of the *Jassidae* family (right) often creates dense mats on exposed foundations.

3.1.2 Differences between sea areas

When a wind park is located in an exposed area, regardless if it is on the Swedish east or west coast, the dominating animal group is filter feeders. The lower salinity in the Baltic Proper does, however, result in fewer filtering species, and the absence of certain predators means that a monoculture of the common blue mussel is to be expected over time. If there is a high abundance of seabirds, which can consume large amounts of blue mussels, the mussels will have a limited distribution and other species may become established. In the areas where the low salinity limits the blue mussels, for example in the Gulf of Bothnia, it is rather the filamentous algae that are expected to dominate on the foundations. The limiting factor for the distribution of blue mussels on the west coast could be the depth. This may lead to a hard bottom community with higher species richness and a zonation in depth. Potential filtering organisms on the west coast and in the North Sea are among others; blue mussels, barnacles, ascidians, calcareous worms, sponges, bryozoans, hydroids and various kinds of corals. Tube building amphipods have been shown in the North Sea to be competitive on exposed foundations. This is consistent with the authors' personal observations at the wave power park at Islandsberg in the Skagerrak, where the tube building amphipods (*Jassa pusilla* and *J. falcate*) dominated the fouling of the plastic covered wires (see Fig 10). In the upper meters of the foundations, blue mussels can be abundant, probably because low predation pressure from seabirds and also because other predators like sea stars and crabs cannot establish in high exposure areas.

Exposure resistant algae may occur on foundations in both the Baltic Sea and on the Swedish west coast, with a variation in species composition depending on nutrient load and level of exposure. In places where the light penetrates deeper down, like on offshore banks, and if the erosion protections are not exposed to high exposure, even larger algae as bladder wrack and other kelp species may become established. The reef-effects, i.e. an increased concentration of mobile animals around the foundations, are expected to occur irrespective of sea area, with higher species richness in the North Sea as a result of higher salinities.

If a wind park is located in stagnant water or on a depth where the foundation reaches below the halocline, an increased deposition of organic matter may result in oxygen-deficient bottom water and hydrogen sulfide could, in the worse case, form at the base of the foundation. This may then have a negative impact on the local benthic fauna. The likely occurrence of oxygen-deficient bottoms around the foundations is thus dependent on local conditions, such as depth and level of exposure.

3.1.3 Differences between various foundations

Whether the surface structure consists of concrete or steel, studies have demonstrated that different adhering organisms can establish on the vertical foundations. Concrete gravity foundation at Nysted Wind Park has proved to be an excellent substrate for filtering animal groups. This has also been found on steel monopile foundations at Utgrunden I, Yttre Stengrund, Horns reef and at the wind park of North Hoyle outside the west coast of England. Establishments of filamentous algae have also been successful closest to the surface of the foundations.

Differences between various structures may arise initially and this is determined by the availability of larvae and their availability to establish ("settle"). But gradually, as the biological community is built up, the species composition changes and more competitive species grow over other species and may be dominant until a relatively steady state finally arises. After a number of years, regardless of the initial surface structure of the foundation, the expected attached algae and fauna will be similar on the different foundations located in areas with the same level of exposure and salinity.

Different design of the foundations, with both vertical and more horizontal surfaces, may result in varying development of the biological community, mainly because of the algae which more easily establish on angled surfaces where the light exposure is higher.

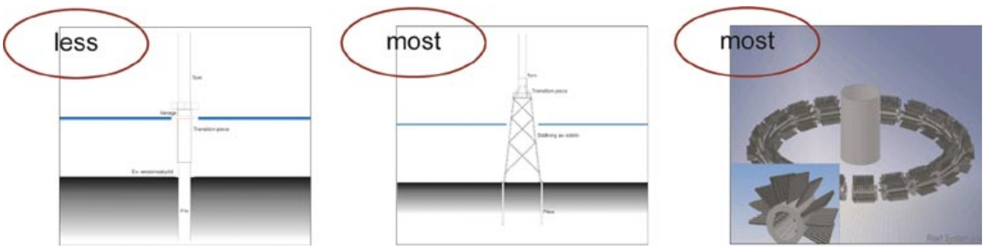
Jacket foundations, in particular, and partly tripod foundations have a more complex structure with far more sloping surfaces which is suitable for light dependent algae. In a study of a jacket foundation the research flat form FINO 1, the only jacket foundation studied so far (2007), it was observed that attached filter feeders and tube building amphipods dominated due to the exposed location despite potential suitable sites for the algae. In areas with weak currents, where the conditions for the filter feeders are less suitable, other species may establish. In this case, if the light availability is sufficient, the algae are expected to establish on the sloping and horiozontal (score protection) surfaces of the foundation.

The top meters on the gravity foundation consists of a so called overhang. The light is limited here and the exposure is high, which is a disadvantage for the algae but creates an attractive site for filter feeders. Regarding the gravity foundation, an immersion of the sea bed is made which may result in covering parts of the erosion protection with sand. This was shown to be a disadvantage for the otherwise dominant blue mussel at the Nysted wind mill park, thus benefiting other species.

The conclusion is that the salinity, level of exposure, depth, distance to land and light availability primarily determines which attached species will dominate at the established wind park. The effects of the design and the structure of the foundation are only secondarily factors that determine the species composition; the filtering animals are in general benefited but shallow horizontal structures and low level of exposure might benefit macro algae.

As a habitat becomes more complex, the more attractive it will be for the mobile fauna such as fish and crustaceans, since there is plenty of cavities and sites to settle. Jacket foundations and tripod foundations is thus a more attractive reef than a more compact and homogeneous structure like the one of monopile foundations. Abundant reef-effects have been observed on oil platforms around the world and the structures of these are similar to jacket foundations. Even more deep living species might exploit the food availability and the various habitats of the artificial reef of jacket and tripod foundation since they are planned to be placed at greater depths.

Associated erosion protections can be designed to benefit the reef-effects, and this may compensate for the plane surface of monopiles and gravity foundations. A multiform score protection with both large and small cavities creates habitats for several species and for different life stages within the same species. This may create favorable conditions for crustaceans and fish among others.



Extract from Table 6. Summary of different foundations relative influence on an eventual reef effect. Knowledge: moderate

3.1.4 Adjustments to minimize or maximize the impact

In a perspective of preservation of the natural existing environment, fouling and reef-effects may be considered as negative environmental impacts in areas without the presence of, or proximity to natural hard bottom (because of the risk of introduction of alien species which can change the ecological conditions). An increased production and diversity of fish and invertebrates may however, in most cases, be regarded as a positive environmental effect, especially if hard bottom substrate with associated organisms already may be found naturally in the area. The wind mills will then be a protected environment for, especially, stationary fish and crustaceans since efficient fishing most probably will be suspended close to the foundations.

Regardless of which model of foundation that is used, it is impossible to avoid fouling. Silica based surface treatment of the foundation, sometimes used on concrete constructions such as bridge-pillars, may be a disadvantage for the establishment of some organisms since it may be difficult to settle on the smooth surface. Regarding the reef-effect, the complex structure of a jacket foundation is expected to generate habitats for more species (e.g. fish) then a more homogenous model of foundation like monopile. To increase the reef-effect one may advocate jacket foundations.

To further reinforce a desired reef-effect the erosion protection may be designed to support a greater diversity. By building structures of high heterogeneity, the amount of habitats will increase and create space for more species and more life stages. One possibility is to use erosion protection blocks of mixed-size. There is also artificial erosion protections specially developed for this purpose. One example is the GRIP by Reef Systems a/s (se Fig. 8). Similar artificial structures may also be used as protection for the buried cables, and thereby increase the possibilities for the reef-effect. Suitable constructions may also become a base of recruitment to surrounding sea areas regarding the dispersion of larvae and fish fry associated to the hard bottom.

Information box 2. Studies and experiences regarding fouling and reef-effects

The low salinity in the Baltic Sea is a limiting factor for many species and leads to a reduction in predation pressure especially on the common blue mussel (*Mytilus edulis*) (Saier 2001; Enderlein & Wahl 2004). This is one of the reasons why the blue mussel dominates the vertical surfaces in the Baltic Sea. The blue mussels compete for food and space and are very competitive as a filter feeder when the water flow is high (Kautsky 1982; Littorin & Gilek 1999; Westerbom et al 2002; Qvarfordt 2006). Another common filter feeder in the Baltic Sea is the acorn barnacle (*Balanus improvisus*). Barnacles can initially be rapid colonizers, especially on smooth surfaces where the blue mussels are less capable to settle. But they are poor competitors and are easily overgrown by blue mussels (Dean & Hurd 1980; Öhman & Wilhelmsson 2005; Zettler & Pollehne 2006).

The macro algae *Fucus vesiculosus* dominate on the shallow hard bottoms of the Baltic Sea where the angle and level of exposure are not too high. At high exposure, the alga community is instead dominated by filamentous algae (Kautsky 1989; Kautsky et al 1992). The filamentous algae are commonly found at the shoreline since they require a great amount of light, while the red algae who does not require as much light, can establish much deeper. Unlike seaweed species, the filamentous algae may also establish on more homogenous structures (Lubchenco 1983).

During an inventory at the offshore banks in the Baltic Proper the common blue mussel dominated at all depths. The exposure at the offshore banks is high and other species have difficulties to settle or they are not as competitive as the blue mussels. In one of the stations the blue mussel was less distributed, which can be linked to the predation from seabirds. As a result, the occurrence of annual filamentous algae and perennial red algae became greater. In the north and south parts of the Gulf of Bothnia, where the blue mussel is limited by the low salinity, the offshore banks are mainly dominated by filamentous algae. At the offshore banks in the southern part of the Gulf of Bothnia the occurrence of *Fucus vesiculosus* and *Fucus radicans* was observed (in one of the stations) as well-developed belts and lived deeper down than by the coast. This is due to the fewer particles in the water and so the light penetrates further down, and also because of the level of exposure which decreases with depth (Naturvårdsverket, Swedish Environmental Protection Agency, 2006 b).

Studies of existing wind farms in the Baltic Sea, such as Utgrunden I and Yttre Stengrund (Kalmarsund) (Öhman & Wilhelmsson 2005) and also Nysted outside Denmark (Leonard & Birklund 2006) showed a clear dominance of blue mussels. This has also been observed on bridge piles at the Öresund Bridge (Öresundsbro consortium 2004), Öland Bridge (Qvarfordt et al 2006) and on vertical steel constructions in Germany which are placed in the water for the purpose of research (Zettler & Pollehne 2006). In the studied areas, the observed algal communities had few species and the filamentous algae dominated.

On the concrete piles of the Öresund Bridge, the estimated densities of the blue mussel could be up to 40 000 individuals/m^2. But no blue mussels were found on the top meter. That space was colonized by filamentous algae. Red algae were observed somewhat deeper between and on the mussels. Other fauna on the bridge piles included barnacles and small crustaceans (Öresundsbro consortium 2004).

Barnacles and blue mussels dominated on the piers of the Ölands Bridge but were smaller in size than the same species on surrounding bottoms. The presence of algae was sparse and was dominated by annual filamentous algae. The concrete had a smooth surface due to the silica treatment which probably was one of the reasons why the larger mussels had difficulties to establish (Qvarfordt et al 2006) Silica based surface treatments are used on concrete constructions to reduce penetration of water and salt, and may have a limiting effect on the establishment of organisms (Petersen & Malm 2006). This effect may be more obvious in the Baltic Sea where the low salinity reduces the ability of the blue mussels to produce strong byssus threads that attach them to the surface (Young 1985).

Studies on the foundations of the wind parks of Utgrunden I and Yttre Stengrund showed that it was a two-layer covering on the foundations. The first layer consisted of barnacles overgrown by blue mussels. The dominating blue mussels were also both more abundant and larger compared to the areas of reference. This is interpreted as a result of the good current conditions at the foundations. Another observation was that mussels older than the wind parks had successfully moved to the foundations from the surroundings. Filamentous algae were also observed, mainly on the top meters, but the density was lower on the foundation compared to in the surroundings (Öhman & Wilhelmsson 2005).

At the Nysted wind park foundations, there was nearly a monoculture created by blue mussels, and they had a larger biomass on the foundations compared to the score protections. The reason for the lower recruitment of the blue mussels on the score protections was due to the sediment covering of partly the boulders as a result of the immersion in the seabed when the gravity foundation was established. This reduced the filtering ability of the blue mussels, giving other species such as tube building crustaceans and filamentous algae the opportunity to establish. The barnacles were observed at the waterline. The shore crab (*Carcinus maenas*), which is a potential predator on blue mussels, was also observed in the area, but the predation pressure was not high enough to limit the distribution of the blue mussels (Leonhard & Birklund 2006).

Outside Germany in the south western part of the Baltic Sea, a cylinder of steel resembling a foundation, was placed on a depth of 20 m for the purpose of investigate its environmental impact. The salinity at these depths and in this area of the Baltic Sea is high enough for the benthic starfishes and crabs to live in. Plates made of steel were placed in the open water mass from 3 to 20 m depth in the same study. On the cylinder of steel, connected to the bottom the barnacles and the polychaetes dominated while the blue mussels dominated on the steel plates, located in the open water. The differences between the two constructions were considered to be their different locations. The cylinder was in contact with the seabed where sea stars and crabs limited the distribution of the blue mussels. During this study, oxygen deficiency and the formation of hydrogen sulfide was observed on the seabed underneath the plates and on the steel cylinder, which supposedly was a result from deposition of organic matter due to the increased production. The accumulation of the mobile animals around the foundations decreased in connection with the formation of hydrogen sulfide. (Zettler & Pollehne 2006). When the load of organic material is too high, all the oxygen could be consumed during the process of decomposition, and may lead to the formation of hydrogen sulfide which is harmful for plants and animals.

The higher salinity on the west coast and in the North Sea gives a hard bottom community with high species richness where the distribution in depth for most algae and sessile animals has a clear zonation. The zonation depends of the light, salinity, temperature, level of exposure, site/space competition, grazing and predation. Potential attached fauna in exposed areas are different sessile filter feeders such as blue mussels, barnacles, ascidians, calcareous polychaetes, sponges, bryozoans, hydroids and corals (Öhman & Wilhelmsson 2005; Naturvårdsverket 2006 b; Svensson 2007; Länsstyrelsen 2007). Small tube building polychaetes and filtering crustaceans (like the family Jassidae) seems to be very competitive in exposed areas, and the colonization of these may become widespread on the foundations on the west coast. The distribution of the algae on hard bottoms follows the same pattern on the west coast as in the Baltic Sea, thus with larger perennial species of seaweed (*Fucus*) and kelp seaweed (*Laminaria*) in more sheltered areas and mainly red algae where the level of exposure is higher.

The depth distribution of blue mussels on the west coast is limited by predators such as crabs and sea stars which require a higher salinity compared to in the Baltic. On the artificial constructions that are placed on the seabed and do not reach the surface, there is only a sparse distribution of blue mussels. High densities of blue mussels are however found on the uppermost meters of the constructions which go through the whole water column, like in the Horns Rev outside Denmark and the research platform FINO 1 outside Germany.

There was a massive colonization of blue mussels on Horns Rev after establishing the wind park. But with time there was a control of the distribution by the common sea star (*Asterias rubens*). The result was that adult blue mussels only were found on the upper part of the foundation and a depth zonation appeared. Different species of green, brown and red algae were found at the splash zone. The foundation on the other hand was dominated by the tube building crustacean *Jassa marmorata* (with a density of 1 million individuals per m^2), most likely a good food resource for e.g. fish. Down by the score protection there was instead an increase in distribution of sea anemones and soft corals such as *Metridium senile* and *Alcyonium digitatum*. (Leonhard & Birklund 2006).

The research platform FINO 1 outside Germany is similar to a jacket foundation and is placed on a 28 meters deep sandy bottom. One year after the establishment the upper five meters were covered by blue mussels. Like on the Horns Rev, the distribution in depth was limited by the predation pressure of crabs and sea stars. Initially, before the colonization of the blue mussels, the hydroids dominated (*Ectopleura larynx*). The hydroids are easily adapted to various types of substrate and have a short lifecycle (Gili & Hughes 1995), and are thereby a group of animals capable of establishing in an early stage. The hydroids decreased with time when the predation pressure from the nudibranchs increased. Instead there was an invasion of the tube building crustaceans (*Jassa herdmani*) on the foundation and these created dense and thick mats underneath the blue mussel belt after a year. Some hydroids and sea anemones (*Metridium senile* and *Sargatiogeton undatus*) could even be found between the tubes. The total biomass decreased with depth, as a result of the dense mat of blue mussels (Schröder et al 2006).

At the inventory of the offshore banks in the Kattegat, diverse algal community occurred with, among others, well developed kelp forests (*Laminaria*), calcareous algae and other leaf formed red algae. The boulders were often covered with algae in depths shallower than 15 meters and when the light was reduced the algae were replaced by the sea anemones *Metridium senile*, the leather coral *Alcyonium digitatum* and hydroids. The mobile fauna was diverse with different crustaceans, sea stars and fish species, among others. On a wave exposed offshore bank in the Skagerrak, Persgrunden, big kelp forests and loads of sea anemones and leather corals were also found (Naturvårdsverket 2006 b).

On an artificial vertical and horizontal substrate that have been placed on the Swedish west coast, species from the groups barnacles, calcareous polychaetes, hydroids and ascidians (*Ciona intestinalis*) established in an early stage (Wilhelmsson et al 2006 b; Svensson et al 2007). The biological community succession has not been studied for a longer period of time and a stabilized community was not reached.

On a more horizontal reef consisting of boulders outside Gothenburg, the succession of fauna has been studied in a five years period of time (Länsstyrelsen 2007). The initial colonization was also here calcareous polychaetes, barnacles, hydroids, ascidians and various bryozoans. Two years after the stones were put out in the sea, the corals (such as sea anemones and leather corals) also occurred. With time, there were also macro algae colonizing the artificial reefs. The succession is expected to precede a couple of years more before a stabilized community is reached. The concentration of both benthic fauna and pelagic fish may increase in an area and also the hard substrate with associated colonizing flora and fauna. Most studies which are made today, related to offshore wind power and increased fish abundance, are based on short-time studies. But together with studies made on constructions similar to foundations, such as oil platforms, it is possible to have an indication if the abundance of fish and other mobile fauna will increase at the foundations, i.e. if a reef-effect will appear.

A reef-effect in the Baltic Sea, in terms of increased abundance of fish, was observed at Utgrunden I, Yttre Stengrund, Svante 1 outside Nogersund and at the bridge of Öresund. At Utgrunden I and Yttre Stengrund (Wilhelmsson et al 2006 a), the densities of adult fishes (two-spotted, black and sand goby) was twice as high next to the foundations (out to a distance of 5 m) than at a distance of 20 m and in the areas of references. When the juveniles of two-spotted goby (*Gobiusculus flavescens*) were included, the fish density was instead a 100 times higher close to the foundations. The foundations seemed to favor some of the species when the biomass increased, but not the species richness. In connection to the study of Utgrunden I och Yttre Stengrund, a comparative study was made by the Öresund Bridge (Öhman & Wilhelmsson 2005). The fish density observed here was also higher close to the foundations compared to the surrounding bottoms. At the solitary wind mill Svante 1, the fish density was studied at various distances to the mill. The results showed that there was an attraction of fish to the area closer than 400 meters from the wind mill, which was most obvious when the mill was shut off (Westerberg 1994).

At the Swedish west coast and in the North Sea, reef-effects have been observed at vertical structures of various heights. These structures are placed outside Tjärnö in Skagerrak (in the northern part of the Swedish west coast archipelago), the research platform FINO 1 outside Germany in the North Sea, on the more horizontal artificial reef (of shattered stones) deposited outside Gothenburg (in the so called “lobster project”) and in the wind park of Kentish Flats outside the east coast of England. The vertical structures at Tjärnö were observed to have a positive effect on the fish density and benefited some of the species, independent of the height of the constructions (Wilhelmsson et al 2006 b). At the research platform FINO 1, an aggregation of horse mackerel (*Trachurus trachurus*) was observed and there was an increase in abundance of the sea stars and different life stages of crabs around the platform (Schröder et al 2006). Thus, these were only observations. The highest occurrence of lobsters has been observed at the artificial reefs (of deposited stones) outside Gothenburg –which has increased over the years. There are also significantly larger and more fish at the reefs (Länsstyrelsen 2007). At the Horns Reef and the Nysted, it has only been observed that fish are staying around the foundations, but there is no confirmation of increased density or increased species richness of fish in these wind parks (Leonhard & Birklund 2006; Klaustrup 2006). The control program (Emu 2006) of the wind park of Kentish Flats (in the North Sea) showed, in many cases, a higher density of fish in the wind park area compared to the studied areas of reference. Some of these fish species were Common sole (*Solea solea*), Common dab (*Limanda limanda*), Plaice (*Pleuronectes platessa),* Thornback ray (*Raja clavata*) and Starry smooth-hound (*Mustelus asterias*). However, the natural variations were large and no statistical analysis was made. As a result, the reef effect could not be proved or rejected. It should be noted that this control program did not study the presence of fish close to the foundation, but in the quite large distances between the foundations.

Reef-effects have also been observed at oil platforms, which complex structure is similar to the jacket foundations. It has been documented that the fish densities increase at oil rigs; i.e. in the Mexican Gulf, (Stanley & Wilson 1996; Lindqvist et al 2005), in the Adriatic Sea (Fabi et al 2004) and in the Norht Sea (Bell & Smith 1999; Lokkeborg et al 2002; Soldal et al 2002). During a long-term study outside the coast of California it was also observed that platforms provide substrate for a variety of invertebrates (Love et al 2003).

3.2 Noise during the operational stage

3.2.1 Background

An offshore wind mill in operation emits a low frequency noise, which mainly arise from the gearbox and apparently is transmitted to the water body through the foundation (Ingemansson 2002). The underwater sound has been measured in field at i.e. Nogersund (Baltic Sea), Vindeby (Belt Sea), Bockstigen (Baltic Sea) and Utgrunden I (Baltic Sea) – all of them relatively small wind mills (power up to 1.5 MW). Measurements of the sounds have been the basis for several estimations where the hearing capability of different organisms has been put in relation to sound from the wind power; such as these made by Wahlberg & Westerberg (2005) and Thomsen et al (2006).

A description of used units and the physical properties of the sound are found in Information Box 3, see below.

The overall sound (beneath the sea surface) from offshore wind power extends over a frequency range of 1 to 1000 Hz with particularly high peaks at certain frequencies, which vary between the different wind mills. So far, the highest peaks have been observed to have a range of intervals of 15 to 30 Hz and 100 to 200 Hz, with an increase in the level of sound up to 60 dB on top of the ambient noise at the distance of 1 meter (Ingemansson 2005; Betke 2006; ÅF-Ingemansson 2007). Regarding the biological impact from the low frequent sound of the wind power, the properties of sound such as particle motions are in many cases of more importance than the level of sound (dB). At distances exceeding about 10 to 100 m, the particle motion is in direct relation to the level of sound and may be calculated on the basis of this, but within a shorter distance it is not possible to calculate the particle motions. This means that an eventual impact on the organisms in close vicinity to the foundations may be difficult to estimate without site-specific measurements in the field.

The ocean is a habitat with plenty of ambient noises such as wind, wave motions, animals and not least the anthropogenic sources. Due to the traffic of ships, the variation in the circadian rhythm of the low frequency sound may be very high, especially in the coastal waters (Westerberg 1996; Nedwell et al 2003). The vessels, such as ferries, ro-ro´s (roll on-roll off ships) and trawlers emit submerged sound in the same interval of frequencies and higher sound levels than from the wind mills (Ingemansson 2002; Ingemansson 2003; Madsen et al 2006; Thomsen et al 2006). Also the bridges used for railway traffic emit equivalent noise in the same range of frequencies as the wind power plants (Westerberg 1996). The difference is that the noise from the wind power may emit a longer lasting noise compared to passing ships and trains, at least in less busy ocean areas.

As an example, modern ships of today emit a low frequency sound (30 to 300 Hz) with a volume of 175 dB re 1 µPa (RMS) at the source, which is 30 dB (30 times) more than the loudest sound calculated from measurements at the wind power parks (Madsen et al 2006). The sound from the wind mill is consequently over shadowed over great distances by the sounds of the vessels, and so the question of a far away disturbance from the wind mills is only relevant theoretically in ocean areas with low vessel traffic (Madsen et al 2006).

Despite the fact that the ocean organisms live with a high ambient noise it cannot be excluded that the sound arising from offshore wind power might be of importance in specific cases within short distances from the foundations.

Many marine animal species use sound in their communication, orientation, foraging or detection of approaching danger. Most fish have especially good hearing at low frequencies, where the fish may perceive the particle motions of the sound (Westerberg 1996). The fishes perceive the particle motions by the internal ear, to frequencies up to about 150 Hz. Moreover, they have an organ of a lateral line which registers small, low frequent (<150 Hz) changes in pressure along the body. The lateral line is used over very short distances to be able to detect water movements in relation to the body of the fish, for example in the orientation in the water body or in a school. The lateral line organ only detects sound from extremely short distances from the source.

At higher frequencies, the audible sound consists of pressure waves and the capability to detect these waves varies among different species. These waves of pressure are only detected by the fishes with a swim bladder, and for those species where the bladder is in connection with the internal ear is the hearing especially developed. Generally, the fishes hearing organs are assumed to be sensitive at frequencies from about 1 Hz up to a few hundred of Hz for the fishes without swim bladder, up to about 500 Hz for the fishes with swim bladder and up to a couple of kHz for the hearing specialists. Even invertebrates may detect and in some cases communicate by low frequent sound (Popper et al 2001). Marine mammals, such as whales, dolphins and seals, have a very well developed hearing, but are especially adapted for the high frequencies (well above 1000 Hz) (Nedwell et al 2007). In a comprehensive literature synthesis, by Madsen et al (2006), it has been concluded that the offshore wind power poses no risk for the marine mammals regarding hearing disorders.

SOUND LEVEL dB ht*	EFFECT ON FISH (Nedwell et al. 2007)
0 - 50	*Mild reaction in a minority of the individuals; likely temporary*
50 - 90	*Clear, eventual temporary reaction in a majority of the individuals*
90 +	*Strongly evasive reaction by almost all individuals*
130 +	*Possible damages even from indivdual sound pulses*

* dBht is the number of dB which exceeds each fish species' hearing threshold at the current frequency

Table 2. Estimated effects on fish at different sound levels above each species-specific hearing threshold (dBht) for a given frequency.

Impact on fish

It is not yet (2007) evaluated how fish react on sound generated from wind mills in operation. Experimental studies where fishes were exposed to sound stress have shown different results, both avoidance and acceptance. In a pilot study within Vindval (Wikström & Granmo 2008), it was shown that juvenile plaice had an increased rate of respiratory movement when exposed to 178 Hz about 100 dB re 1 μPa. Since the exposure time of the pilot study was short, only 15 minutes, it could not be determined if there was any eventual habituation to the disturbance. In the same study it was shown that affected mussels were habituated after about a 24-hour period of time. The results should be interpreted with caution since the experiment was carried out in small tanks where the sound characteristic of the particle velocity was implemented as a much closer distance from the wind turbines than the indicated sound pressure measured of the sound (which means that it was in fact a louder sound tested than the corresponding 100 dB re 1 μPa).

Aggregation of fish species near by the foundations of the wind mills has been shown in field work (see section 3.1). Within the control program at the Kentish Flats wind park, the presence of fish was studied in the wind park area between the foundations. Despite the poor layout and the lack of statistical analysis, the studies showed a similar or higher presence of fish within the wind park compared to the reference areas outside the wind park. Most of the reported species occurred in higher numbers within the wind park, including common dab, plaice and thornback ray (Emu 2006).

The fish habituation for sound is generally rapid; however their sensitivity for very low frequent sound (particle motions) may be high with a very slow habituation (Westerberg 1996). It is most certain that fish may be disturbed by particularly high sound within their audible frequencies, but it is not clear in what levels of sound that is required for the disturbance for various species. Nedwell et al (2007) investigated a system in order to identify the guidelines of sound disturbance on fish, see Table 2. According to these results, the levels of sound required to cause an "possible temporary clear response" is 50 dB re 1 μPa above the hearing threshold of the individual fish species (50 dBht) and to cause a "strongly evasive response" the sound level should be 90 dB re 1 μPa above the hearing threshold (90 dBht).

The threshold of hearing varies over different frequencies, and so does also the sensitivity for sound. The lowest level of hearing threshold for fish species investigated by Nedwell et al (2007) was 97 – 101 dB re 1 μPa at 200 Hz, which means that for the first mentioned level of disturbance it would require a sound level of 150 dB re 1 μPa at 200 Hz for these fish species. This high level of sound has not been measured close to the wind mills in any of the wind parks studied; Nogersund (at 6 m/s), Vindeby (at 13 m/s), Bockstigen (at 8 m/s), Lelystad (at 7 m/s), Middelgrund (at 6 and 13 m/s), Utgrunden I (at 14 m/s), Horns Reef (at 16 m/s) and Nysted. The measured levels of sound from the wind parks above were recalculated to a distance of 1 m from the foundations with an assumption of an audio loss on 4 dB per every doubled distance, based on measurements by Ingemansson (2003) at the Utgrunden I in the Baltic Sea.

The argument above, regarding stress related levels of sound above the hearing threshold (dBht), is based on a sound disturbing system (Nedwell et al 2007) which have been developed from the limited knowledge of the individual species´ hearing and their stress behavior. Therefore, all values and assessments based on this system should be considered with great caution.

Overall, it seems most likely evident that eventual disturbance on fish is limited to high wind speed at short distances (the metric system) from the foundation.

The presence of fish has been observed around and close to wind mills in operation. Thus, since indicated symptoms of stress have been shown in experimental studies it cannot however be excluded that the sound may be a source of disturbance for specific species or life stages.

Impact on invertebrates

Experiments in laboratory have been performed by Marine Monitoring AB within Vindval a program of knowledge (Vindval1 2008). The experimental trials, proceeding for 4 days, showed an initial increase of burrowing activity of the bivalve *Abra nitida* when exposed to low frequency sound (178 Hz) about 100 dB re 1 μPa (RMS). The effect declined thereafter and no signs of differences in the burrowing activity could be noticed, after the 4 days, between the mussels exposed for sound and the mussels acting as controls. The same experiment showed no corresponding effects on the behavior of the brittle star *Amphiura filiformis* or in the feeding behavior of common brown shrimp *Crangon crangon*. The tested level of sound is to be equivalent to a distance of several hundreds of meters from Utgrunden I at 14 m/s (Vindval 2008).

The results above should be interpreted with caution since the experiment have been performed in small water tanks where the particle velocity actually was equivalent to a shorter distance from the wind mills than what the level of sound pressure (100 dB) indicated (meaning that it was in fact a louder sound tested than corresponding 100 dB re 1 μPa). In this context it should also be mentioned that the background noise at 13 m/s have been showed to exceed 100 dB re 1 μPa, both at Vindeby and Middelgrund wind parks, in the same frequency range as for the above mentioned experiment (178 Hz) (Å F Ingemansson 2007). So, sound pressure with the same strength does also arise from natural sources during wind force.

In an earlier study by Donsky & Ludyanski (1995), it has been shown that the establishment ("settling") of the zebra mussel Dreissena polymorpha may be prevented by vibrations and low frequency (<200 Hz) sound. However, the same low frequency sound did not give any effects on the already established zebra mussels or the other organisms tested in the study; cyano bacteria, plankton crustaceans (Daphnia galeata merzdotae, D. pulicuria), juvenile yellow perch (Perca flavescens).

Consequently, there are indications showing that some species may be affected by particle motions of loud noise at specific sound frequencies within the measured range from the wind power. One may assume that most invertebrates become accustomed with sound; habituation in experimental studies have been observed, an abundant fauna of invertebrates have been found at all the existing offshore foundations and no significant changes of the fauna in the surrounding bottoms have been detected (Leonhard & Birklund 2006; OES 2007; see also section 3.1). According to the principle of precaution a consideration is still motivated when choosing and designing the foundations in particularly sensitive areas of establishment.

3.2.2 Differences between ocean areas

The background noise from the ocean is partly a factor that determines how far away an organism may be able to perceive the sound from a wind mill, and the background noise may vary greatly between different ocean areas. Generally, the background noise is considerably higher in the North Sea than in the Baltic

Sea (Thomsen et al 2006). In areas with dense traffic such as Öresund and the Belt Sea, the background sound should be nearly constantly high since the low frequency noises have a very long range. Thus, in ocean areas with low background sound, the sound from the wind mills in operation may have a greater impact on the current sound and hence a larger potential disturbance.

The efficiency of the sound, when traveling through the water column, is affected by physical properties like depth and the substrate of the bottom. In shallow waters (<30 m) and of hard bottom substrates, the wavelength of sound is transmitted further than in soft bottom substrates (muddy bottoms) and deep waters (Ingemansson 2005). The layers that are formed between water masses of different salinity and temperature (halocline and thermocline) differ between the ocean areas and may affect the the transmission of high frequency sound. In deep water, a minimum in the speed of a sound profile may give a good sound distribution over very large distances. The impact of the halocline and the thermocline are however marginal for low frequencies, like for wind power, since their wavelengths in relation to depth are great.

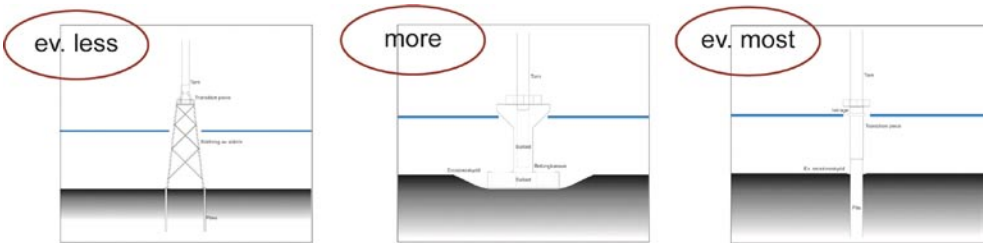
3.2.3 Differences between the various foundations

The choice of foundation is of importance for the sound radiation, i.e how efficient the sound from the gearbox is transmitted to the surrounding marine environment (Ingemansson 2002). The mass and the sound-transmitting surface of the foundation is of great importance, where a higher mass have a dampening effect while a large sound-transmitting surface leads to a greater radiation efficiency. Objects which is larger in comparison to the wavelength of the sound, also give greater radiation efficiency than smaller objects (ÅF – Ingemansson 2007). For example, the piles of monopile foundation are larger than the piles of jacket foundation and may therefore be expected to transmit sound more efficient. The materials are also of importance, where low frequencies theoretically radiate more efficiently in large concrete foundations than in steel foundations. Thus, the gravity foundations is expected to emit sound within a lower interval of frequency than the monopile foundations (Ingemansson 2002), which broadly complies to the study made by Betke (2006) where the gravity foundation at Nysted and the monopile foundation of Horns Reef where compared. Based on Ingemansson (2003), Betke (2006) and ÅF-Ingemansson (2007), it seems like both the gravity and the monopile foundations have their highest peaks of sound level within the frequency interval of 100 to 200 Hz. A significant factor in the sound radiation/transmission is the welded seams and joints, which seems to have a dampening effect and will primarily entail a reduction in sound in the jacket foundations (ÅF-Ingemansson 2007).

ÅF-Ingemansson (2007) did a theoretical study comparing gravity, monopile and jacket foundations regarding the operating noise, provided the same depth and bottom conditions. Since there are several opposing correlating factors, and at the same time the access of measured data is limited, there have been no general conclusions stated. The comparison indicates that gravity and monopile foundations radiates sound in the same magnitude, with the difference that gravity foundations radiate sound in a lower range of frequency than monopile. The jacket foundation, with its complicated structure, is difficult to compare with the other foundations since there is no measured data available. Nevertheless, the jacket foundations most likely emit sound from a higher range of frequency than the others (ÅF-Ingemansson 2007).

The reasoning above may give an indication regarding noise during the operation phase, but should be interpreted with caution until there are measured data available in comparison between a greater numbers of different foundations.

With reference to the size of the foundations, all measurement data of submerged sound is so far based on relatively small wind mills (up to 1.5 MW). Since a larger wind mill means that larger masses are set in motion, the output noise is expected to increase. At the same time a heavier foundation gives a more efficient dampening. Calculations of sound from two turbines of 500 kW on gravity and monopile foundations, where they had an enlarged scale of up to 2 MW (using data from a land based wind mill of 2 MW), indicates that large gravity foundations might emit a higher sound than the corresponding large monopile foundations (Ingemansson 2002). It is widely accepted, within the offshore industry, that the offshore adapted turbines emits more noise than turbines on land. The offshore industry is however expecting the technical development to generate more silent wind mill turbines in the future (EWEA 2007). Most of the sound is derived from the gearbox, but there are suppliers of turbines producing direct driven generators without a gearbox. These kinds of turbines have so far not been used in offshore establishments. Taken together, it is today not possible to predict if the future offshore wind power mills will emit more or less sound than the current (2007) wind power mills.



Extract from Table 6. Summary of the different foundations relative influence on eventual environmental impacts from sound transmission. Knowledge: moderate / poor

3.2.4 Adjustments in order to reduce negative impacts

The differences between the various foundations are highlighted in this study regarding the sound from the operational phase. The knowledge of both the kind of sound that originates and the effects of the sound on marine organisms are today (2007) limited. The frequency range of 100 – 200 Hz has been shown to be especially prominent in the sound spectra from both gravity and monopile foundations (the sound spectra for jacket foundations have not been investigated by measurements).

It may be motivated to advocate a less noisy model of foundation or turbine during special circumstances, where the risk for biological impacts from the sound is estimated to be particularly severe. This should preferably be preceded by a site-specific audio technical investigation. Theoretically, the model of foundation that most likely emits low frequent sound the least is the jacket foundation, but this should be ascertained by sound recordings during fieldwork.

The distinct frequency stop at 100 to 200 Hz of the studied wind mills may most likely be dampened by technical modified gearboxes. An alternative is to develop exterior noise dampening isolation on the foundation.

Information box 3. Sound in the ocean

The sound waves spread through a denser medium (water) in the ocean than on shore (air) which has consequences for the characteristics. In the ocean the sound energy are spread gradually over a greater area as the sound wave is spreading. In a free field sound it is spread over the area of a sphere. Trapped between two layers it is spread on the mantle surface of a cylinder. In reality the spreading of sound is often something in between. The sound can be spread in all directions - thus spherical- in a deep open sea and the power of the sound is then decreasing with about 6 dB per doubling the distance. In shallow waters (<30 m) where the sound is trapped between the surface and the bottom the sound is limited to two dimensions cylindrical spreading. The power of the sound is then reduced with about 3 dB per doubling distance at ideal conditions. As an example: a sound of 100 dB in a distance of 10 m from the source is decreased to 88 dB when the distance is 40 m from the source (two doubling distances) provided it is a spherical spreading. The same distance (40m) with a cylindrical spreading would be 94 dB. The loss of sound with increased distance also depends on other conditions such as the surface characteristics where for example the breaking waves increase the loss of sound. Bottom substrate is of particular importance in shallow waters. A smooth hard bottom (e.g. flat rock) causes smaller loss of sound while soft substrate (e.g. sand and clay) may cause greater sound loss. Standing waves between the water surface and the bottom arises in shallow waters. The surface is perceived as soft for the sound and the pressure of sound become very weak at the surface. If the bottom is hard the standing wave will get its maximum of sound pressure at the bottom and the minimum of sound pressure at the surface. (The lowest frequency standing wave appears when the depth is equal to a quarter of a wave length. At a bottom depth of 20 m this occur at about 19 Hz. Standing waves of higher sequences occurs when the depth of the bottom is equal to a number of odd quarters of wavelengths. The standing waves are of importance for the pressure of sound level in the distribution in depth.)

An example is the difference in the distribution of powerful sound pulses which were generated by the piling works at Utgrunden I (Baltic Sea; monopile Ø = 3 m) and Burbo Bank (Irish Sea; monopile Ø = 4.7 m). A sound loss of about 4.8 dB per doubling distance were measured at Utgrunden I (ØDS 2000) while the measurements at Burbo Bank was a sound loss of 6 dB per doubling distance (Parvin & Nedwell 2006). The wind parks are both located on shallow water but the bottom substrate differ with stone bottom at Utgrunden I and sand at Burbo Bank. Also the condition of the ocean sea surface was different between the both measurement occasions. The sea was relatively calm (wave height <2 m) at Utgrunden I while Burbo Bank had heavy wind and breaking waves (ØDS 2000; Parvin & Nedwell 2006). The differences in sound loss are of great importance regarding the activities at an offshore wind park and at what distances it may have an impact on the marine organisms.

The power of sound is usually described by decibel (dB) on a logarithmic scale which is related to how much the sound exceeds the pressure of reference. This reference is set to 1 μPa for the underwater environment (for air the pressure of reference is 20 μPa). The scale of logarithm is used due to the very wide spectra of measured sound. The logarithmic values compress the scale and make it more comprehensible. The way that the animals in the ocean perceive levels of sound of this dimension cannot be directly translated to how terrestrial animals and humans perceive sound of corresponding power dB (A). Sound perception is instead determined based on the hearing threshold of different organisms, i.e. lowest level of sound that can be detected at every sound frequency.

The physical sound phenomenon is characterized by both the pressure of sound and the particle motion. In a sound wave on a distance from a source the ratio of sound pressure and particle velocity is determined by the water impedance. This is equal to the water density times the speed of sound, i.e. about 1.5 x 106 Ns/m^3. The particle movement is equal to the particle velocity by angular frequency. This means that the particle displacement at the same sound pressure in a sound wave becomes greater at low frequencies than in high frequencies. The particle acceleration is equal to the particle velocity times the angular frequency. Close to a sound source, high particle velocities with local pressure fluctuations may occur without the spreading of sound energy away from the source by a sound wave.

The sound characteristics may be measured and defined in several different units and based on various assumptions. This study considers the sound characteristics in general and by the level specified in dB re 1 μPa and the spectrum in 1/3 octave band level.

Examples of sound measurements are peak pressure (the highest level of sound achieved in a pulse), SEL (Sound Exposure Level; the level of sound for a moment standardized to a second) and RMS (the energy average of sound level over the whole sound pulse).

3.3 Hydrographic changes

3.3.1 Background

During the establishment of an offshore wind park, the foundation may affect the currents, the waves and the vertical mixing of the surface and the bottom water. This might affect the hydrographical conditions around the individual wind mill and potentially the whole wind park. A change in the hydrographical conditions could change the environment of the water and the composition of the sediment and thereby creating other conditions for the existing flora and fauna. It could also affect the motion of the waves and the water downstream from the wind park. If the wind park is established in the vicinity of sand bottom areas, which are constantly changing and where the waves and currents are relevant for the orientation of the shore-line, it may affect the area and might result in erosion and/or material accumulation. It is also important to avoid the possible affects on the inflowing oxygen-rich bottom water to the Baltic Sea and other enclosed water areas such as fjords and bays.

Models and calculations have been performed regarding possible affects on the hydrographic conditions in an area. The proceedings when currents and waves hit an obstacle are described below and is collected from SMHI:s

(Swedish Meteorological Hydrographic Institute) reports from the Skottarevet (Karlsson et al 2006) and the Kriegers Flak (Johansson 2004; Lindow et al 2007) and DHI:s (Danish Hydraulic Institute) reports from the Lillgrund (Møller & Edelvang 2001; Edelvang et al 2001; Sloth 2001).

As the water pass a wind park, the current velocity increases around the foundations. Internal waves and a downstream vortex are formed with a horizontal extension of two times the diameter of the obstacle in width and ten times the diameter of the obstacle in length. If the foundations are placed in stratified water, caused by differences in temperature or salinity (thermocline and halocline), the turbulence formed might result in an increased mixing of surface and bottom water which weaken the stratification and the heavy bottom water decreases in salinity. The size of the mixture is strongly related to the power of the current, where a stronger current results in an increased mixing. This mixing have been discussed in relation to its possible significance in the heavy oxygen-rich, high salinity water of the bottom current from Kattegat into the deep bottoms of the Baltic Sea and also if it might result in mixing of nutrients from the bottom water, which could increase the surface algal blooms.

In connection with the application for the establishment of the wind park at Skottarevet (outside Falkenberg, Kattegat) an investigation was made by SMHI regarding the foundations concerning if they locally may increase the vertical mixing through the stratified water (Karlsson et al 2006). The stratified water may vary in different areas and have, outside Falkenberg, been observed to be in the range at 10 – 15 meters depth, which means that the water column is mixed down to the halocline and below it is more homogeneous. Thus, in this area the mixing of surface and bottom water will only be affected by foundations placed deeper than 10 meters. The results from the calculations of SMHI, based on a non-stratified water column, showed that the mixing of water behind a foundation would increase with a factor of 10. This would give a 1% increased mixing above the background level if 30 monopile foundations in a 20 km^2 area were established. These calculations may be assessed as an upper limit as it does not take an existing halocline into account and are based on a horizontal mixing which requires less energy than a vertical mixing. A mixing of 1 % is equal or less than the natural variation of the mixing of water in the coastal waters of Kattegat and is thereby considered to be of minor importance.

Rough estimates on how a wind park at Kriegers Flat would influence vertical mixing of less salinity water down in the deep water was also made by SMHI. The results show that the impact of the wind park is less than 1 % compared to the natural average mixing and will not significantly affect the transport of deep water from Kattegat to the Baltic Sea (Johansson 2004).

Within the European project QuantAS, measurements have been made next to the bridge of Great Belt which have shown that internal waves and eddies around the poles has lead to variation in salinity and may be traced up to a kilometer downstream of the bridge (Lindow et al 2007). The plan is also to do laboratory experiments on turbulence in stratified waters in the project. Monopile foundations have been tested so far and preliminary results show that a bow wave is formed in front of the foundation and a line of vortices in the thermocline downstream. The effect in this study was limited to the immediate surroundings of the foundations. Other kinds of foundations are planned to be investigated as well.

DHI has, in connection with the permit application to Lillgrund, performed modeling that was concentrated on the deep water transport in to the Baltic Sea which is of great importance for the oxygen content of the Baltic Sea bottoms. This was also of great importance during the construction work of the Öresund bridge when the so called "zero solution" meant that the impact of the bridge on the water flow in to the Baltic Sea could not exceed 0.5 % of the conditions without the connection. The blocking effect from the foundations on the water flow was calculated by DHI to 0.0 % (±0.1 %), which is less than the uncertainty (±0.18 %) determined at the modeling work of the Öresund bridge where the same modeling system (MIKE3) was used. Thus, the Lillgrund blocking effect is insignificant in comparison to the flowing masses of water through Öresund, which also was the conclusion at the Öresund Bridge (Øresundskonsortiet 2000).

DHI also simulated the possible impact of Lillgrund Wind Park on the local current conditions. The results showed a less than 4 % reduced current velocity within the wind park, which is not considered to have any effect on the current velocity or the transport of sediment outside the park. The influence of the wind park on waves was also simulated. Wave pattern is dependent on water depth, incoming wave frequency, the design of the foundation and the number and position of the foundations. The calculations of DHI indicates a significant change on the wave pattern within 10 meters from every individual foundation with the results of a reduction in the energy content of the waves with less than 5 % in the wind park (Edelvang et al 2001).

3.3.2 Differences between ocean areas

The wind power might have an influence on the hydrographic conditions in a narrow channel, while an insignificant impact can be expected in an open sea area.

The mixing of the surface and bottom water is dependent on the strength of the stratification which is determined by the difference in densities between the different water masses. This means that variations may arise between areas with different hydrographical conditions.

A surface current of brackish water is flowing along the Swedish coast from the Baltic Sea through the Kattegat and the Skagerrak and a deeper bottom current in the opposite direction with water of higher salinity from the North Sea. The halocline formed between these two water masses may be more or less sharp and may be positioned at different depths.

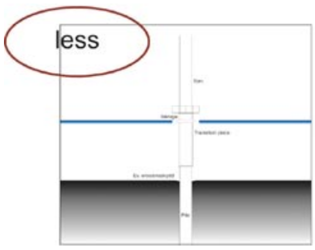
The halocline in Skagerrak is found at a depth of about 15 m and varies both in depth and strength with weather conditions where strong winds have an influence of the mixing and the salinity in the surface water. In the Kattegat, the halocline is rather stabile since the differences in salinity between the surface and bottom water is greater. When the bottom current has passed Kattegat and the shallow thresholds of Öresund and the Belt, the heavy bottom water are spread into the Baltic Sea. The halocline between the surface water and the bottom water is much deeper in the Baltic Sea, and in Bothnian Bay and Bothnian Sea the mixing and the supply of fresh water is so large that the stratification is very weak.

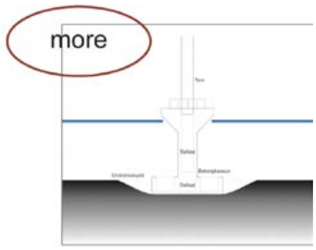
Thus, the depth of the area where the wind park is located is of importance for the influence of the mixing processes, although the influence is very little. This means that a wind park in the Kattegat could affect the vertical mixing already of depths of 10 m, whereas wind mills in the basin of Arkona (in the south of the Baltic Sea) have to exceed a depth of 30 m before the stratification weakens by the turbulence created by the foundations.

Due to the increased production by animals and plants on the foundations, the process of degradation of dead material on the bottoms below will increase and local oxygen deficiency might occur. In areas where the stratification is strong and the mixing of oxygen-rich water is limited, this impact may be larger. Oxygen deficiency occur periodically on bottoms of the Baltic Sea, The Belt, Kattegat and Skagerrak (Karlson et al 2002) as a result of eutrophication and a increased primary production at the surface. The oxygen deficiency usually occurs below the halocline. These areas are particularly sensitive to additional load of organic material.

3.3.3 Differences between the various foundations

The hydrographical changes caused by foundations in an offshore wind park are to be considered negligible. There are only local effects on the currents and mixing which are so low that it barely exceeds the natural variations. The models and calculations of SMHI and DHI have been performed on pillar-like structures and therefore it becomes difficult to estimate the impact of a gravity foundation. But it can be established that a gravity foundation with a diameter larger than the diameter of a monopile foundation should have a greater impact on the turbulence and the internal waves. Whether a jacket foundation should be considered as a single large monopile that blocks the water movements is decided by how the water is transported through the network of steel pipes which the jacket foundations are made of. Thus, this is difficult to comment on before any direct studies have been conducted. The jacket foundations are however, like oil platforms, designed so that the masses of water easily pass through.





Extract from Table 6. Summary of the different foundations relative influence on an eventual environmental impact from hydrographic changes. Knowledge: poor

3.3.4 Adjustments to reduce the negative impacts

Only in exceptional cases, like establishments in narrow sounds will the hydrographical changes that occur around wind mill foundations be likely to cause a significant environmental impact. The slight changes that appear are limited in close vicinity to the foundation. There are no direct comparisons between the different models of foundations regarding hydrographical changes, but smaller diameter of the foundation generates smaller impact.

3.4 Construction noise

3.4.1 Background

The work of construction during the establishment of offshore wind power involves multiple sources of underwater noise; including vessel traffic, dredging, paving, piling and scuba diving work.

Regardless of which foundation used, the work of construction generates an increase in vessel traffic. The emission of sound differs between various vessels. For example; it has been shown that a 5 m motorboat emits 152 dB re µPa at a distance of 1 m and a cargo ship of 170 m emits 192 dB re µPa at a distance of 1 m (Nedwell & Howell 2004). Vessels engaged in the offshore wind energy may be expected to emit sound in the range of 170 dB re µPa at a distance of 1 m (Nedwell & Howell 2004). The frequency range of vessel noise is generally 10 – 1000 Hz.

Dredging (excavation of bottom substrate) is used in the preparation of the bottom, and is particularly required in the establishment of gravity foundations. Except for the spreading of sediment, the dredging work generates noise within the frequency range of 20 – 1000 Hz, and the levels of sound have been measured to 160 dB re 1 µPa (RMS) at frequency peaks of 100 Hz (Madsen et al 2006). The level of sound differs between the individual wind mills but appears to be about 130 – 140 dB re 1 µPa at a distance of 200 m (Nedwell & Howell 2004).

The paving is done during the positioning of score protection and during the filling of concrete caissons (gravity foundations). Regarding the noise from paving in connection to offshore wind power there are no measurement data available; one measurement is however done regarding paving at a depth of 60 m but for another purpose. Any increase in the levels of sound related to the paving could not be detected; however low frequent noise was recorded from the vessel (Nedwell & Howell 2004).

Inspections and precision demanding work are done by scuba divers in connection with the establishment of foundations. Some of the operations require heavy equipment such as welding, drilling and cutting tools which may generate very loud levels of noise (measurements of up to 200 dB re 1 µPa have been detected by the source) (Nedwell & Howell 2004).

Piling work is the most significant source of construction noise associated with offshore wind power and many other activities (Madsen et al 2006). This is used in order to anchor the foundations of most models except for gravity or bucket foundations. The peak pressure of piling is largely due to the diameter of the piles and can be very loud, especially regarding the monopile foundation.

Smaller piles are powered down using a gravity hammer, in which a weight is hoisted up and then set down from a few meters. For larger piles, the diesel hammers are often used and for piles with diameters of several meters or for hard packed substrates the powerful hydraulic hammers are required (Reyff 2004). Under certain circumstances, it is possible to anchor piles using a vibration hammer which cause less harmful noise.

The driving of piles causes repeated pulses of loud noise; the beating frequency and the number of beats varies by the diameter of the piles, bottom substrate, the depth of penetration and the effect of the hammer. As an example: piling of a single monopile foundation (Ø = 3 m) at the Utgrunden I required 1320 beats during 1.5 hours (frequency 2 – 28 beats/minute) according to measurements on site (ØDS 2000), se further information in section 2.2.3.

The noise from piling may be defined in several different dimensions, including peak pressure (the highest level of sound reached in a pulse), SEL (Sound Exposure Level; level of sound for a moment standardized to a second) and RMS (the average of energy in the level of sound over the whole pulse). Peak pressure is considered to be the most adequate measurement regarding the direct damages to biological organs (Reyff 2004). The levels of sound at the source generally reach well above 200 dB re 1 µPa (both for peak pressure and SEL). The loudness of the generated noise is due to several factors, such as bottom substrate, the effect of the hammer and the size of the chosen piles.

During piling of a monopile foundation with a diameter of 3 m (Utgrunden I) most of the energy in every pulse was found within the frequency range of 100 – 2000 Hz, with a peak of around 300 Hz (ØDS 2000). Smaller piles generally generate higher frequencies and a lower level of sound compared to larger piles (ÅF-Ingemansson 2007).

Table 3. Level of sound (peak pressure) at the piling of different diameter piles, the level of sound is standarised to a distance of 100 m from the source of sound.

DIAMETER (m)	PEAK at 100 m (dB re 1 uPa)	PROJECT	REFERENCE
0.36	187	Bridge construction*	Reyff 2004
0.5	174	Harbour construction*	Nedwell & Howell 2004
0.9	186	Harbour construction*	Nedwell & Howell 2004
1.5	198	Harbour construction*	Elmer et al. 2007
1.5	192	Jacket -foundation*	Betke et al. 2005
1.7	190	Bridge construction*	Reyff 2004
2.4	205	Bridge construction*	Reyff 2004
3	199	Monopile-foundation*	Elmer et al. 2008
3	196	Monopile-foundation*	ØDS 2000
3.5	214	Monopile-foundation*	Elmer et al. 2007
4	213	Monopile-foundation*	Nedwell & Howell 2004
4.7	207	Monopile-foundation*	Parvin & Nedwell 2006

* Measured values are standardized to a certain distance using an assumed reduction of 4.8 dB for every doubling distance (based on ØDS 2000 and Nedwell & Howell 2004) -stated values should be regarded as approximate

** The calculations from the sound measuring at North Hoyle largely differ from the calculations made by Nedwell et al. 2003, since a 4.8 dB sound loss for every doubling distance is significantly smaller than the assumptions made in the earlier calculation

Table 3 shows a compilation of measurement data from piling works and in Figure 11 the peak pressure is illustrated as it increases linearly with increasing diameter of the pile. How much the sound diminishes with the distance is of great importance and varies from place to place depending especially on the bottom substrate and the depth.

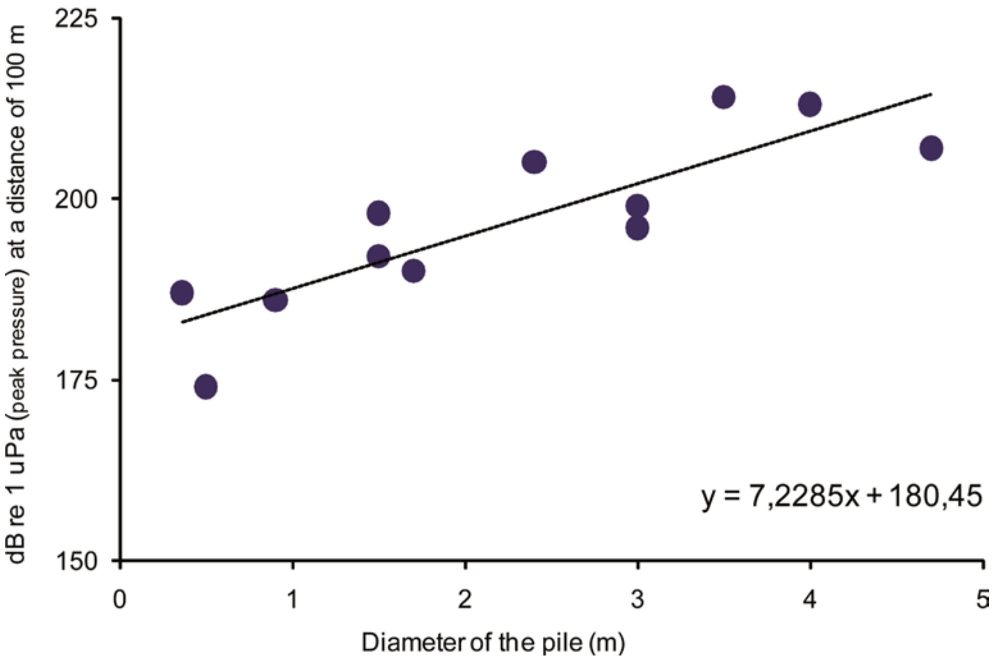


Figure 11. Measured levels of sound (peak pressure) at a distance of 100 m for the piling of the various diameters piles. The distance and diameter is significantly (p<0,001) correlated to an R-value of 0.86. Pearson two-tailed test.

The pulses of extreme levels of sound generated by the piling may cause reactions of escape and physical damages for the organisms in the surroundings. How far this impact extends is dependent on the level of noise produced, the depth of the water column for the receiver, the condition of the sea surface, the bottom substrate and the depth of the bottom (the sound decrease more rapidly in soft bottom substrate and in deep water). Fish with swim bladders are among the most sensitive organisms; cod and herring are estimated to have a escape reaction for many kilometers during unprotected piling work (Parvin & Nedwell 2006). In several cases dead fish have been found in connection with piling works, caused by the damage to internal organs from the noise pulses (Nedwell & Howell 2004; Reyff 2004).

Various fish species are sensitive to sounds in different frequency ranges and tolerate different levels of noise. In order to provide for the establishment of construction noise guidelines, Nedwell et al (2007) used a method where the level of tolerance for individual fish species are related to their threshold of hearing (dBht) and their audible range of frequency. The method is based on experimental studies where it could be concluded that the level of tolerance based on all tested fish species was 90 dB (i.e. 90 dB over the animals' threshold of hearing at the current range of frequency). A "strongly evasive reaction" is expected at levels of sound above that. At 130 dBht, the risk of damage on hearing and internal organs is possible even from single pulses of sound, such as a beat of a hammer during piling (see Table 2).

By applying the method above on the levels of the sound measured during piling work (Table 3) it is possible to calculate the range of the impact for the individual fish species. The method is based on several assumptions and the distances should of course be considered as very approximate; the interesting part in this context is the relative differences between the various foundations and the protective measures.

Table 4. Estimated range of avoidance reactions (90 dBht) and the detrimental effects (130 dBht) on cod during dredging and piling of various piles and also with different safety devices used. The estimations are based on a specific method (Nedwell et al 2007). There is however objections to this method and the generalization should be considered with caution. The estimated distance is also dependent of the site specific sound loss and should only be considered as values of comparison between different foundations and safety actions.

SOUND LEVEL dB at 100 m	TOP (Hz)	FOUNDATION MODEL*	SAFETY DEVICE	THE RANGE OF IMPACT ON COD	
				90 dB (ht)	130 dB (ht)
145	150	Gravitation (dredging)	none	2 m	-
210	300	Monopile (>3 m diameter)	none -5 dB -10 dB	25 km 12 km 6 km	80 m 35 m 18 m
195	300**	Fackverk (1.5 m diameter)	none -5 dB -10 dB	3 km 1,5 km 0,7 km	9 m 4 m 2 m

* see Table 3
** The interval of frequency is missing for small piles, but a peak within higher frequencies can be expected.
Observe: The distance is calculated based on an estimated sound loss of 4.8 dB per every doubling distance from measurements performed at Utgrunden 1 (ØDS 2000): see Table 5 for calculations of the higher sound loss measured at Burbo Bank

A cod with a hearing threshold of 82 dB re 1 µPa at 300 Hz (Nedwell & Howell 2004), 90 dBht corresponds to a distance of about 25 km from the piling of a monopile foundation (Ø > 3 m) respectively 3 km from the piling of a jacket foundation with a pile of a diameter of 1.5. See Table 4. These calculations are based on an audio loss of 4.8 dB per every doubled distance and are taken from the piling measurements at the Utgrunden I in the Baltic Sea (ØDS 2000). Significantly higher loss of sound have been measured during the piling work at Burbo bank in the Irish Sea, which generated considerably less range of impact (2 km for 90 dBht cod) (Parvin & Nedwell 2006). See Table 5 and Table 2. The reason for using the hearing threshold of 300 Hz for cod as above, is because that is the range of frequency shown to be the highest from the piling pulse noise of a Ø = 3 m pile (ØDS 2000).

Table 5. Parwin and Nedwell (2006) estimated the range for fish and mammals with avoidance reactions during the piling works at Burbo Bank (Irish Sea) monopile foundations; measured loss of sound were about 6.5 dB per every doubling distance. The pile diameter was 4.7 m. The distance and the generalization should be considered with caution since the method is based on several assumptions and the site-specific loss of sound.

SPECIES	RANGE 90 dBht
Herring *(Clupea harengus)*	2 600 m
Cod *(Gadus morhua)*	2 000 m
Seabass *(Dicentrarchus labrax)*	500 m
Dab *(Limanda limanda)*	500 m
Porpoise *(Phocoena phocoena)*	5 000 m
Bottlenose dolphin *(Tursiops truncatus)*	4 000 m
Harbor seal *(Phoca vitulina)*	3000 m

Marine mammals are expected to perceive sound from piling works beyond a distance of 100 km. In order to eliminate damage on the whales (e.g. porpoises) and seal (e.g. harbor seals), it has been argued that the level of sound should not exceed over 180 respectively 190 dB re 1 µPa (RMS). According to Madsen et al (2006), this means a security distance of about 2 km during piling works which corresponds to a 3 diameter monopile foundation. Thus, it should also be noted that the guided values (dB) above cannot be regarded as universal since possible effects depends on a large number of various factors (Wahlberg personal comment).

It is not yet known how the marine invertebrates are affected by extreme levels of noise from the works of piling, but generally they are expected to be less sensitive than fish and mammals since they have no air-filled body cavities.

Overall, the work of piling poses great risks of damage on marine organisms, especially fish, and it is important to take this into consideration in the choice of foundation and suitable damage preventions. Most other construction-related noise sources, such as vessels, dredging, paving and scuba diving generates lower levels of sound and are expected to result in reactions of avoidance rather than damages, even at small distances. If blasting is needed, it will lead to very high pressure peaks of sound.

3.4.2 Differences between ocean areas

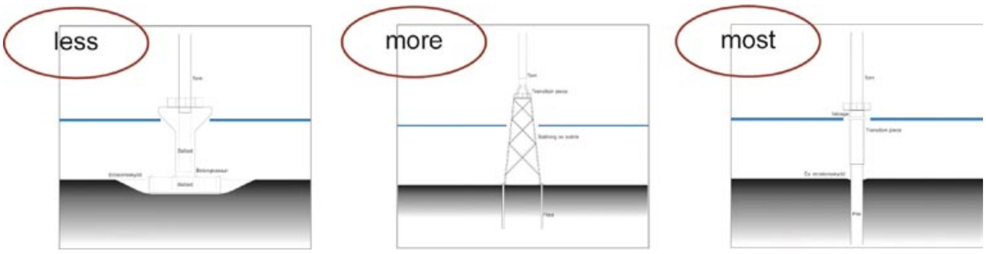
There are no general differences between the North Sea and the Baltic Sea regarding the environmental impacts from the construction noise. There could be very large differences in the range of sound due to the area's natural sound loss, which is because of the bottom morphology. Shallow water and hard bottom substrate contribute to a longer transmission of the sound and the influenced area becomes larger (Ingemansson 2005).

The possible environmental impacts are also depending on the ecological importance of the area, particularly regarding areas of reproducing and nursery for individual species.

3.4.3 Differences between the various foundations

In addition to the noise from an increased traffic of vessels, which arise regardless of the foundation chosen, the gravity foundation generates noise from the dredging, paving and diving. Monopile, tripod and jacket foundations do not require any dredging but generates extremely and potentially harmful levels of noise during piling. The piling of piles with a larger diameter generates a more powerful sound and as a consequence of this the monopile foundation generates the sound to a considerable larger area, see Table 3. During the establishment of tripod and jacket foundation, several smaller piles are used which influence a smaller area; although several smaller piles can also mean a longer period of installation.

The fact that smaller piles generate sound levels within a higher range of frequencies might lead to a further reduction of the avoidance range for the fishes with hearing of lower range of frequencies. However, this aspect has not been quantified here due to the lack of frequency charts from piling of small piles.



Extract from Table 6. Summary of the different foundations relative influence on possible environmental impact from construction noise. Knowledge: moderate

3.4.4 Adjustments to reduce the negative impacts

In order to exemplify the differences between the foundations regarding construction noise, Table 4 presents the calculated distance of avoidance and range of damage concerning cod (see also Table 5).

There are great differences between the various foundations according to the environmental impacts of construction noise as shown in Table 4. Gravity foundations generates minor disturbance from sound, unlike the piled foundations. In this case, since the differences between coarse and small piles are great regarding the range of harmful levels of sound, the jacket foundation is preferable compared to the monopile foundation. The tripod foundation should be in between.

Several methods are possible in order to reduce the detrimental effects of extreme sound levels during piling. These should be applied regardless to the size of piles but especially during the establishment of monopile foundations. Only a reduction of 5 – 10 dB is of great importance for the range of disturbance and detrimental effects. Consequently, reductions of 20 – 30 dB are of even greater value. The spreading of sound pulses may be reduced by safety devices, the output noise may be reduced by less noisy methods, the influence of sound on the surroundings may be reduced by warning actions, and maybe the most important factor of all, the time for the piling work can be adjusted to biologically sensitive periods:

Bubble curtain

An efficient way to isolate the piling work and reduce the high levels of sound is to create a dense screen of air bubbles, a bubble curtain. The achieved damping varies a lot between different technical designs; less ambitious bubble curtains have proven to be almost totally ineffective (Nedwell et al 2003; Reyff 2004) while the more advanced systems have been able to reduce up to 30 dB (Reyff 2004). The efficiency of the bubbles are substantially reduced in flowing water but special designed solutions have been developed even for water with a certain current (Reyff 2004).

Overall, a good system of bubble curtains is expected to give a reduction of at least 10 dB during piling in calm water and 5 dB in moving water. With particularly well-adjusted technology and favourable conditions, a further reduction may be achieved.

Cofferdam

During piling in shallow water, a cofferdam can be established around the attachment point. This means that a smaller area is enclosed with for example a screen of iron, whereupon the area is dried out by pumping out the water. In order to reach the surrounding water, the sound from the piling must then pass air or pass through the bottom substrate. This method has been shown to efficiently reduce the levels of sound from the work of piling (Reyff 2004) and has, among other things, been used in the extensive works of piling during the bridge construction of the Bay Bridge East Span, San Francisco.

Vibro piling (Vibration hammer)

Instead of slow heavy beats, the piling of smaller and medium sized piles can be done with a vibrating hammer which generates rapid and lighter beats vibro piling. The method, which is limited to the piling of smaller and medium sized piles, may result in a certain reduction of the sound levels (Nedwell et al 2003; Reyff 2004). However, the levels of sound when using vibro piling have been shown in certain cases to be higher (pile Ø = 0.7 m: 200 dB peak pressure at 10 m); the method should therefore be considered with caution (Reyff 2004).

Insolation

Another way to damping the noise during piling is to use a tube of plastic foam with steel on the outside which is lowered down over the piles. This method has been shown to give a significant damping at high frequencies (about 10 dB reduction > 1000 Hz) and a certain damping (0 – 10 dB) at lower frequencies (ÅF-Ingemansson 2007).

Ramp-up / warning method

A simple method in order to reduce physical damages on fish and other mobile animals in the water is to initially start up the piling with gentle hammer beats and thereafter increase in power of the beats as the animals escape the area. This method has been used both in bridge constructions and during establishment of wind power monopile foundations (Reyff 2004; EWEA 2007). Mammals and fish may also be frightened away using acoustic signals with extremely high levels of sound (like the "seal-scarers") (Nedwell et al 2003). The methods of premonition reduce the risks of physical damage and mortality of fish and mammals. However, disturbance and evasive reactions take place with maintained range.

Non-technical methods

It is also possible to use observers in order to reduce the risks of damage on marine mammals. These observers scan the surrounding area visually from about 2 h before piling to ensure that no whales, dolphins or seals are located within harmful distance (Nedwell et al 2003). This method is of course far from reliable and only work in daylight. A way to do it more efficient is to use acoustic instruments to be able to detect whales, dolphins and to some extent fish schools (Nedwell et al 2003). These methods lead to a reduced flexibility for the entrepreneur since the establishment of a specific foundation at a certain time will not be able to predict.

Biological protection periods

In order to avoid permanent or prolonged damages, especially on fish stocks, piling should not be performed, not even with any of the safety protections mentioned above, during the periods where threatened or area important species are aggregated for spawning (the time for spawning varies between different species). Piling with high levels of sound should also be avoided in certain nursery areas during spring and early summer since many species may be particularly sensitive at that time.

3.5 The spread of sediment during the construction phase

3.5.1 Background

During the preparation of the bottom (dredging) required for the establishment of gravity foundation, the fine grained sediment is suspended and spread. Also during the piling work there might be spreading and suspended sediment in those cases where drilling is necessary in able to drive down the piles into the bottom substrate. The spreading of sediment in connection with construction work and dredging/deposition is a commonly used operation in the marine environment and the effects are relatively well known. High levels of suspended sediment may lead to negative environmental effects especially within the following areas:

- Reduced production and distribution of the bottom vegetation such as eel grass meadows (Onuf 1994) and algal belts (Lyngby & Mortensen 1994); the effects appear when the transparacy decreases due to the dissolved particles in the water.
- Increased mortality of egg and larvae (Auld & Schubel 1978; Westerberg et al 1996); the effects appear when the particles of sediment attach to the eggs or blocking the gills of the larvae.
- Escaping reaction of fish (Westerberg et al 1996; Fiskeriverket -Swedish Board of Fishery 2007); the effects appear most likely when the sediment particles attach to the gills and reduce the uptake of oxygen, and reduce the visibility.

Heavy sediment spread may also lead to disturbance for filtrating animals or the spread of possible environmental toxins bound to sediment particles. Thus, the spread of sediment is a risk especially for the juvenile stages of fish (egg, larvae and fry) (Fiskeriverket -Swedish Board of Fishery 2007).

Reactions of avoidance in fish have been noticed down to a sediment concentration of 3 mg/l and harmful effects have been registered from about 100 mg/l and more. However, the sensitivity for suspended sediment varies between different species (Auld & Schubel 1978) and between different types of bottom substrates. Especially calcareous sediments appear to be more harmful for fish and fry than sediments with a slighter larger grain size such as silt (see Auld & Schubel 1978; Kiørboe et al 1981; Westerberg et al 1996).

Consequently, high levels of sediment may lead to damages in the marine environment. It has, however, been demonstrated that the effects may be local and temporary even during very large sediment dissemination activities provided a clear regulation and preventing actions. Examples of this is the connection construction of Öresund (dredging of 8 000 000 m^3 calcareous stone/clay) during the years 1995 – 1998 and the dredging project of Safer Routes in the harbor entrance of Gothenburg (dredging of 11 800 000 m^3 clay) year 2003 – 2004. Efforts to minimize the spread of dissolved sediment were performed in both projects which resulted in no registered permanent environmental effects on the basis of a comprehensive control program (Valeur & Jensen 2001; Anon. 2001; Eriksson et al 2004). About 1000 m^3 of sediment is required to be dredged for the attachment of a gravity foundation (concrete caisson) in the depth of 5 – 10m (see section 2.1.3).

During the dredging of gravity foundations at the offshore wind park of Lillgrund (Öresund) the sediment spill was estimated to 4.8 % of the dredged masses. This was based on a measured sediment concentration of <10 mg/l in water (with rare exceptions) at a distance of 200m. The grain size was measured to 4.2 µm (median) (DHI 2006).

Environmental changes with long-termed effects on the bottom conditions after dredging have been studied for the gravity foundations at Middelgrund (Öresund). The distribution of blue mussels decreased significantly while the distribution of eelgrass increased (Hedeselkabet 2004). These changes were found, however, both by the wind park and at the adjacent area of reference (about 200 – 1000m from dredged area). Whether this change is an effect of the sediment spreading activity cannot be assessed. However, it can be verified that no decrease in eelgrass occurred.

3.5.2 Immediate effects of construction work at Lillgrund wind park

In order to study the immediate effects on fish during the establishment of gravity foundations, a study during the construction work at the Lillgrund wind park was made in 2006. Small fishes (juveniles and small grown species) were caught with a bottom trawl close to the construction work and also in a remote control area with otherwise similar conditions. The study was performed according to the statistical model BACI (Before/After Control/Impact) and the different samplings were made at a distance of 60 – 200 m from ongoing or recently completed construction work. The purpose was primarily to study and determine the distance of any eventual immediate effects (such as temporary escape of small fishes). The following factors were studied at individual foundations; A) effects 1 month after dredging, B) effects 24 h after dredging and C) effects during stone bedding. The large variance of catches complicated the interpretation of the result but the following conclusions were drawn:

- The construction works at the individual foundations did not lead to any decrease of the amount of fish species (small fishes) during any phase of the work.
- No effects of the construction works were observed at the sampling one month after dredging.
- A significant larger increase in abundance and biomass of the small fish was observed 150 m from the dredging site at Lillgrund when sampling 24 hours after dredging. The difference was mainly represented by adult two-spotted goby. This higher occurrence of small fish could not be determined with certainty if it was connected with the recently completed work of dredging or if other unknown factors had caused the differences

from the area of reference. If the difference was a consequence of the dredging work, a possible explanation would be that fish escaped from the direct dredging position and aggregated at a distance of 150 m. Another alternative explanation is that some species of fish are attracted towards the dredging site due to the increased amount of potential food particles in the water.

- At the sampling during the stone bedding it was found that the increase in abundance and biomass since the previous sampling were significantly higher in the control area than at Lillgrund. Abundance and biomass of small fish had, however, increased even at Lillgrund and no differences were found between the distances 60 respectively 200 m from the stone bedding. This indicates that the differences were not related to the work of stone bedding. However, it cannot be excluded that the activities at Lillgrund as a whole has resulted in a reduction of small fish species in comparison with the control area. This could be the consequences of sediment spreading, noise or the loss of eelgrass in the area.

All in all, the study at Lillgrund (gravity foundations) indicates that every individual part of the construction work cause small or no negative impacts on the distribution and the abundance of small fish species at a distance greater than about 100 m. The result should be compared to construction works which include piling where the temporary immediate effects on fish are significant (Reyff 2004; Thomsen et al 2006). All the results of the study are presented in the publication; "Studies of small fish at the offshore wind park of Lillgrund –Studies of impacts during the work of construction and establishment of gravity foundations" ("Studier på småfisk vid Lillgrund vindpark –Effektstudier under konstruktionsarbeten och anläggning av gravitationsfundament", Vindval[2] 2008).

3.5.3 Differences between ocean areas

Environmental impacts from dredging in connection to the attachment of the foundation to the bottom are likely to vary between different ocean areas. The level of exposure in the area is of great importance for the spreading (and dilution) of disturbed sediment. Spreading of sediment is expected to cause less environmental impacts on natural exposed soft bottoms (clay/sand) than in a sheltered area with stagnant water. This is because the dilution in an exposed area is rapid together with the fact that exposed bottoms are occupied by a more interference-tolerant flora and fauna.

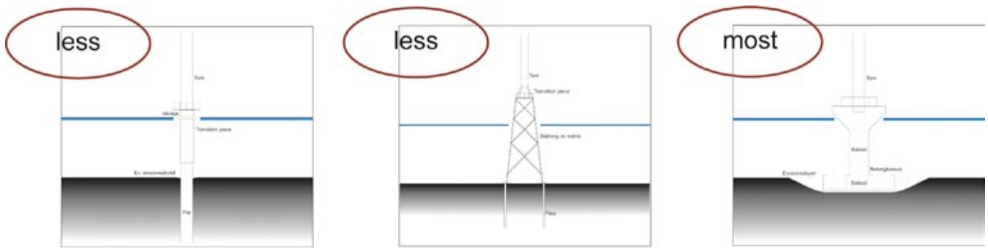
The substrate of the bottom is an important difference between various areas regarding the damaging effects from sediment spreading. A fine-grained sediment such as limestone (powder) and soft clay may cause more damage on fish, larvae and egg compared to silt and sand since the small particles easily attaches to biological membranes.

Sediment spreading in areas with contaminated layers in the sediment, such as harbors, makes the environmental toxins to enter up to the water column where they become available for organisms that might absorb the substances through the gills or food intake.

Level of exposure, substrate and degree of pollution varies on a region and local scale; any general differences between the Baltic Sea and the North Sea are however not present.

3.5.4 Differences between various foundations

The gravity foundation implies a greater requirement for dredging and generally involves a greater sediment distribution than other foundations. Also monopile foundations may lead to sediment distribution in those cases when drilling is used and the bottom substrate contains both clay and boulders.



Extract from Table 6. Summary of the different foundations relative influence on possible environmental impact from sediment spreading. Knowledge: enough

3.5.5 Adjustments to minimize negative impacts

In areas sensitive for sediment distribution activities, like certain nursery areas for fishes in need of protection, it is important to take the work of sediment spreading into consideration during planning and designing of the foundations. This is especially necessary where the biological sensitive areas coincide with factors such as fine-grained bottom substrate and little natural level of exposure. It is then important to adapt the sediment spreading activities to suitable biological periods (to avoid spawning and nursery periods).

In order to minimize damages from sediment distribution in especially sensitive areas, the piled foundations can be recommended instead of gravity foundations. The amount of dredged masses obtained from gravity foundations is however rather small in comparison with other types of construction work, where it has been shown that permanent damages can be avoided using adjusted periods of construction and regulation of allowed levels of water in the sediment.

4 Foundation optimization

Chapter 2 and 3 describe how the different offshore wind power foundations vary regarding their impact on the marine environment. In relation to the environmental benefits of wind power as emission-free renewable energy sources, the possible local negative impact on the marine environment may be considered as small or insignificant. Minor changes may however have a significant impact in a heavy loaded marine environment and the offshore wind power is expected to expand in the near future. The modern, offshore wind power involves large-scale establishments with up to several hundred individual wind mills. Thus, the environmental impacts lead to an ascending scale from individual mills to one big coherent system. The period of establishment in those cases could be extended to several years.

By taking the different foundation´s environmental impacts into account during both planning and construction, the negative environmental effects may however be reduced.

4.1 Summary – Gravity foundation

Gravity foundation can be used at establishments on shallow water; today (2007) down to a depth of 10 m and possibly down to 20 – 30 m in the future. Adjustments can be done for most types of bottom substrates except for clay and unstable sand. The construction work involves dredging and score protection is required for stabilization. See Figure 1 and 2.

Advantages

The largest environmental benefit with gravity foundations is that no piling is required during the establishment. Also, the score protections can be designed in order to benefit the reef-effect and thereby create greater conditions for colonized organisms. This may be considered as a positive aspect if an increase of hard bottom associated fish and bottom fauna is desirable.

Potential disadvantages

The negative environmental consequences during the establishment are confined largely to the sediment distribution of dredging. However, the volume of the dredging are of smaller scale and the sediment distribution can be limited. The greatest risk for negative effects arises in areas which contain calcareous sediment and poor water circulation. A limited temporary disturbance of fish may occur during the noisy activities of construction. These are carried out during several non-contiguous periods of a couple of days per every individual foundation.

Gravity foundations with score protection occupy a larger area than other foundations and thereby occupy more of the natural bottom area. This may be of importance if the establishment occurs in habitats of particularly high conservation value, such as eelgrass meadows. The relative larger diameter of the foundation compared to other foundations may in exceptional cases like establishment in narrow passages, reduce the natural flow of water.

The emission of low frequency sound is most likely higher for the gravity foundation than jacket foundation during the operational phase. It cannot be excluded that the sound in some way may affect certain marine organisms. Until further notice this should be considered as a potential, though very limited, environmental impact regarding future larger wind turbines of gravity foundation.

Gravity foundation may be environmentally optimized for example by the following proceedings:

- The work of the dredging activities can be performed during less sensitive biological periods. This should be related to the reproduction periods of the important animal species in the area and also the periods of growth for plant species of conservation value.
- In areas with eventual desirable reef-effects it can be benefited and expanded by especially designed score protection (heterogeneous structure with various sizes of cavities).
- Technical adjustments may eventually reduce the emission of low frequency sound in operation.

4.2 Summary – Monopile foundation

Monopile foundation is a well tested foundation and can be used in shallow water and down to a depth of 20 – 25 m in sandy, stabile clay or stone-mixed substrates. Other substrates may also be used by drilling penetration. The construction work is performed by piling which causes extremely powerful sound pulses. Score protection is often required at the bottom, but this can also be replaced by a deeper penetration. See Figure 3.

Advantages

One advantage with monopile foundation is the rapid activity of construction with a piling process in less than an hour (1h). Moreover, the monopile foundation claims a minimal surface of the bottom and creates minimum conditions for reef-effects provided no use of score protections. Thus, the monopile foundations without score protection lead to a minor change of the natural bottom than other constructions.

Potential disadvantages

Piling with a hammer (pile driver) during construction work is commonly used and this generates very powerful sound pulses which are harmful for especially fish and marine mammals over distances of around 100 m – and might generate disturbances over very great distances (a magnitude of several 10 kilometers). It is of great importance in these cases that the construction work is not performed within biological sensitive periods.

A monopile wind mill in operation generates most likely a higher emission of low frequent sound than a jacket foundation. It cannot be excluded that the sound in some way may affect certain marine organisms. Until further notice, this should be considered as a potential, though very limited, environmental impact regarding future larger wind turbines of monopile foundations. It is not yet clear, however, whether larger versions of monopile foundations will generate higher or lower levels of sound.

Monopile foundation may be environmentally optimized for example by the following proceedings:

- Major efforts should be done regarding development of well adjusted actions in order to reduce the levels of sound during piling; see section 3.4.4.
- The work of piling should not be performed during biological sensitive periods such as reproduction periods of important animal species, generally highly productive periods and periods where fish and mammals undertake migration through the sea area.
- The piling work at a larger wind park should as much as possible be concentrated in a smaller number of high-intensive periods in order to avoid a prolonged period of impact.
- Possible desirable reef-effect may be extended by especially designed score protection (heterogeneous structure with various sizes of cavities).
- A non desirable reef-effect may be minimized by excluding the score protection and compensate with a deeper plunging of the foundation; see section 2.6.
- Technical adjustments may eventually reduce the emission of low frequency sound during the operational time.

4.3 Summary – Tripod foundation

The tripod foundation is developed to be used at depths of 20 – 40 m where the anchorage is done by piling of several medium-sized piles. The demands of bottom substrate are thus similar to monopile foundation. Score protection might be required or be replaced by a deeper anchorage. See Figure 4.

Advantages

The advantage of tripod foundations is the smaller diameter of the anchorage piles compared to monopole foundation on corresponding depth. Generally, these smaller piles generate lower noise pulses during the piling. Also, the increased structure of tripod foundation may result in a stronger reef-effect which may be considered as positive if it is desirable with increased conditions for hard bottom substrate associated fish in the area.

Potential disadvantages

The most significant negative impact of tripod foundation is generated during the piling work, as for the monopole foundation. The piling involves very powerful noise pulses, harmful for particularly fish and marine mammals. Although the piles used for a tripod foundation are smaller than what a monopile would require on the same depth, the dimensions are of the same size range as the current monopile foundations (Ø = 3 – 4 m). Consequently, it is of great importance that the construction work does not occur within biological sensitive periods. The fact that several piling work (3) for every tripod foundation is required and generally means a longer impact period is also of significance.

Tripod foundations may be used on greater depths and requires a larger total surface bottom area than monopile foundations. This leads to a greater change of the natural bottom.

It is possible that the colonizing organisms (e.g. mussels, sea squirts) on the structures later on may accumulate on the bottom beneath the foundation where degradation together with low water flow may cause oxygen deficiency.

Regarding noise emissions it is not yet (2007) known in what frequencies a tripod foundation emit. However, since the dimensions of the steel pipes are large it can be assumed to have similarities with smaller monopile foundations. Until further notice, this should be considered as a potential, though very limited, environmental impact regarding future larger wind turbines of monopile foundations.

Tripod foundation may be environmentally optimized for example by the following proceedings:

- Major efforts should be done regarding development of well adjusted actions in order to reduce the levels of sound during piling; see section 3.4.4.
- The work of piling should not be performed during biological sensitive periods such as reproduction periods of important animal species, generally highly productive periods and periods where fish and mammals undertake migration through the sea area.
- The piling work at a larger wind park should as much as possible be concentrated in a smaller number of high-intensive periods in order to avoid a prolonged period of impact.
- Technical adjustments may eventually reduce the emission of low frequency sound during the operational time.

4.4 Summary – Jacket foundation

A jacket foundation is mainly an alternative for deeper bottoms down to a depth of over 50 m. The jacket foundation is anchored by piling of several smaller piles in clay, sand or stone-mixed substrate. Se Figure 5.

Advantages

During the construction work the piling is performed with smaller piles than for the monopile foundation. Generally, this generates significantly lower levels of noise and is consequently an advantage. It is also possible that jacket foundations compared to other foundations emit less low frequent noise (< 200 Hz) during the operational phase. Furthermore, the complex structure of jacket foundation generates greater opportunities for the reef-effect which may be considered positive if an increased environment for reef-associated fish is desirable in the area.

Potential disadvantages

The loud pulses of noise created in connection with the piling may be of significant disturbance for great distances on marine organisms. It is important to follow safety measures in order to minimize the damage/impact.
The jacket foundation occupies a larger bottom surface area and may be used on greater depths compared to the monopile foundation. The organisms fallen down to the bottom may cause a local oxygen deficiency if the water circulation by the bottom is low (such as beneath the thermocline). Even the reef-effect may be considered negative if the wind park is established in an area where the fauna associated to hard bottom substrate is not desirable. This may be the case for example in conservation valued sand or clay bottoms.
What kind of frequency noise that is emitted from jacket foundations during operation is not yet (2007) known, and it is uncertain if that kind of noise would lead to any environmental impacts. Therefore the noise should be considered as a potential, though limited, source of disturbance in particular conservation valued areas even for jacket foundation.

Jacket foundation may be environmentally optimized for example by the following proceedings:

- Piling should be performed by well applied methods in order to minimize the levels of noise; see section 3.4.4.
- The work of piling should not be performed during biological sensitive periods such as periods of reproduction for endangered species or for other reasons important fish species.
- Technical adjustments may eventually reduce the emission of low frequency noise during operational phase.

4.5 Summary – Other foundations

The solutions for other foundation models should be evaluated based on the four foundations described above. Thus, the technical design of other foundation models, such as hybrids, bucket and floating foundations (see Figure 6 & 7), may vary.

A floating foundation may for example consist of either a floating jacket foundation construction or deep concrete pendant. Regarding the sources of impact, the two variants may be resembled to jacket and monopile foundation in fouling and reef-effects.

Many combinations (hybrid foundations) involve anchorage by piling and the size of piles determines how extensive the construction noise then is expected to be.

4.6 Other sources of impact

There are also other imaginable sources of impact where there are no significant differences between the various foundations. Some of them are; electromagnetic fields from cables, engine oil discharges and metal excretion from corrosion protection anodes.

4.7 A relative degree of influence on the environmental impact

Based on the results of the study, Table 6 presents the degree of influence for the foundation on every source of impact and is classified between one (1) and three (3). The classification should be considered as a relatively estimated measure. It should only be compared between the different foundations at the same site and for the same amount of load (depth of bottom and installed power).The erosion protection is not included in the classification of foundation models but is presented in a separate column - to be considered in case the construction of an erosion protection is required. One important part in the table is the column Base of knowledge that presents where the specific uncertainties exist. Again, Table 6 does not present how important or how negative every source of influence might be. This must be decided from case to case according to site-specific conditions and revision of the knowledge base. However, Table 6 evaluates how much each foundation model contributes to reinforce every source of influence.

Table 6. Relative classification regarding to what extent every foundation model affect each source of environmental impact. Chapter 3 and Information box 4 should be read before observing Table 6. The table should only be used in accordance with what is described in section 4.8.

SOURCE OF IMPACT	FOUNDATION MODEL							
	Gravitation (concrete)	Monopile	Tripod	Jacket	Bucket	Floating	Erosion protection	Knowledge base
OPERATION PHASE								
Fouling*	3	3	3	3	3	3	3	moderate
Reef effect*	2	1	2	3	1	1-3	2	moderate
Sound transmission	3	2	2	1	2	RM	-	moderate
Hydrographic changes	2	1	RM	RM	1	RM	1	weak
Exploitation of bottom surface	3	1	2	2	2	1	3	enough
CONSTRUCTION (temporary)								
Construction noise	1	3	2	2	1	2	1	moderate
Sediment spreading	3	1-2	1	1	RM	1	1	enough

EXPLANATION
1 = Less
2 = More
3 = Most
RM = references missing

* *Fouling*, i.e a production of attached algae and animals. It is here separated from the *reef effect* which is defined as an increased presence of mobile animals; as a result of either aggregation or an increased production

Information box 4. Premises when using Table 6

The table is intended to be used by the method described in section 4.8. It is important to notice when using the table that it does not take into consideration how significant the environmental impact is or if the environmental impact is positive or negative (see for example reef-effects and fouling which in many cases are considered as a positive effect; section 3.1.3). The table only describes: A) How the various foundations are related to the different sources of impact. Assessments in the importance of every source of impact should be based on site-specific conditions. B) The text in chapter 3 and C) From an update complementary addition of the knowledge base (see the flowchart below). For example, the noise of construction is generally to be considered as a more serious negative environmental impact than hydrographic changes. So, hydrographical changes with the classification 3 may be less negative than e.g. construction noise with classification 2. It is also possible that no significant environmental impact is assumed from any part of the classification range 1 – 3. The environmental impact from offshore wind power is today (2007) not fully elucidated and it is site-specific. But a flexible classification according to Table 6 is judged to be of value in the work to prevent negative environmental impacts during future establishments.

4.8 Recommendations in the choice of foundation

How much the different models of foundations affect the various sources of impact is summarized in Table 6. The importance of every individual source of impact is however dependent on the existing conditions of the establishment location. A certain amount of knowledge about an area is required in order to evaluate which of the sources of impact that is the most worthy of attention for that specific location; the hydrography, the bottom substrate and the ecological relations. After identifying the most important sources of impact the well justified trade-offs may be done using Table 6 and the other content. A recommendation of the most environmental suitable foundation and suggestions of protective actions or other specific design can be suggested. The suggested approach above is described in the following flowchart (next page):

Site specific orientation of factors

Inventory of local conditions such as

-Bottom substrate
-Existing biological habitats
-Ecological relations (e.g. spawning areas)
-Hydrography

↓

Priority between the sources of impact

Determine which sources of impact are predominant based on the site specific area factors.
See below *Examples of priorities based on local conditions*

↓

Ranking of the foundations

Which foundation model is most suitable from the environmental perspective?
Are there any foundation models that are particularly inappropriate?
See especially Table 6 and chapter 3. Also, conduct an update of the current knowledge base

↓

Connect to technique and economy

Which of the foundation models are technical possible to use? How big are the differences in costs between the relevant foundations?

↓

Selection of foundation

and

Design of adequate mitigation measures

Examples on priorities based on local conditions

The section below gives some examples on how the different sources of influence may be prioritized based on local conditions:

Specific spawning area for endangered or important species:

- High level of noise may disturb the spawning –the significance of CONSTRUCTION NOISE is increased during certain periods
- Dissolved sediment may disturb the development of egg and larvae –the significance of SEDIMENT SPREADING is increased during certain periods

Migration routes for fish or marine mammals:

- High levels of noise may eventually disturb migratory animals –the significance of CONSTRUCTION NOISE is increased during certain periods

The presence of vegetation worthy of protection:

- Increased sensitivity for muddy water –the significance of SEDIMENT SPREADING is increased
- Great value of bottom surface (special habitat) –the significance of the EXPLOITATION OF BOTTOM SURFACE is increased

The nearness to archipelago or wetland:

- High levels of noise may disturb nesting birds –the significance of CONSTRUCTION NOISE is increased during certain periods

Limestone containing bottom substrate:

- Increased sensitivity for fish –the significance of SEDIMENT SPREADING is increased

Environmental toxins in the bottom substrate:

- The dredging may release harmful substances dispersed in the sediment –the significance of SEDIMENT SPREADING is increased

Especially valuable sand or clay bottoms without the closeness to natural hard bottoms:

- Risk of increased immigration of new hard bottom associated species which may (secondary) interfere in the existing ecosystem –the significance of FOULING and REEF EFFECT is increased (negatively)

Desired local increase of fish and other organisms which are associated to hard bottom:

- Addition of artificial structures may create increased living space for several species -the significance of FOULING and REEF EFFECT is increased (positively)

Specific presence of conservation valuable sensitive species:

- It is unclear whether some species may be disturbed by low frequency noise –the significance of SOUND TRANSMISSION is increased

Establishment in narrow sound:

- The water flow is of particularly significance –HYDROGRAPHICAL CHANGES

In context, one should pay attention to that the construction noise and the sediment spreading is temporary sources of impact compared to the sources of impact during the wind park in operation. Large-scale establishments may however involve construction work spread out over several years. Furthermore, it is important to

consider the whole wind park as an area of impact during the operational phase. Even if every individual foundation is placed with large spacing (500 – 1500 m) it is not known to what extent the possible interactions of environmental impacts may occur. In addition, it should be emphasized that this study does not include the impact on sea birds, bats or cultural values.
This study is based on the knowledge up to the year 2007.

Increased knowledge and future outlook
During the compilation of this study (2007) a special need of increased knowledge was identified concerning low frequency sound; partly its effects and habituation for different animal groups and partly the differences in emission between the foundation models, regarding both the strength of sound and the frequency interval. Furthermore, there is no specific knowledge concerning the impact of the different foundation models on hydrography (local water movements). Also, it is not known in detail how the artificial erosion protection favours different colonizing species.

- The effects and habituation of sound should be explored in the future both through continuing controlled experiments and by detailed monitoring programs at established wind power.
- Regarding the differences in sound emission from different foundation models it is suggested to carry out coherent noise measurements at several wind parks of each foundation model. Theoretically, the jacket foundation might deliver less low frequency sound than other foundations. Although, the hypothesis should be studied during actual conditions in the field.
- The development of larger wind power turbines requires continuous measurements of sound, both from the operational phase and from the construction works.
- Scientific investigations should be carried out in field in order to quantitatively determine the extent to which different species of fish and bottom fauna is favored by artificial designed erosion protections.

Own inspection of the report
Niklas Grahn, Vattenfall Power Consultant –Technique (chapter 2)
Martin Almgren, ÅF-Ingemansson AB –Sound (chapter 2 and 3)
Jan-Åke Jacobsson, Favonius AB –Denominator perspective
Emelie Johansson, Triventus Consulting AB –Denominator perspective

Inspection of the report through Vindval
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References

Achmus M., Abdel-Rahman K. 2006. Modelling Soil-Structure-Interaction for Offshore Wind Energy Plant (VII), Institute of Soil Mechanics, Foundation Engineering and Waterpower Engineering, University of Hanover.

Anderson M.J., Underwood A.J. 1994. Effects of substratum on the recruitment and development of an intertidal estuarine fouling assemblage. J. Exp. Mar. Biol. Ecol. 184:217-236.

Anderson M.J. 1996. A chemical cue induces settlement of Sydney rock oysters, Saccostrea commercialis, in the laboratory and in the field. Biol. Bull. 190: 350-358

Anon. 2001. Slutrapport om miljön och den fasta förbindelsen över Öresund (sammanfattning av miljöpåverkan av anläggningsarbetet), Miljö- og Energiministeriet, Trafikministeriet samt Kontroll- och styrgruppen för Öresundsförbindelsen.

Auld A.H., Schubel J.R. 1978. Effects of suspended sediment on fish eggs and larvae: A laboratory assessment. Estuar. Coast Mar. Sci 6: 153-164.

Bacchiocchi F., Airoldi L. 2003. Distribution and dynamics of epibiota on hard structures for coastal protection. Estuarine, Coastal and Shelf Science 56: 1157-1166.

Bell N., Smith J. 1999. Coral growing on North Sea oil rigs. Nature vol. 402.

Betke K., Elmer K.-H., Gabriel J., Gerasch W.-J., Matuschek R., Neumann T. 2005. Underwater noise emissions of offshore wind turbines First International Meeting on Wind Turbine Noise: Perspectives for Control, Berlin.

Betke K. 2006. Measurement of underwater noise emitted by offshore wind turbines at Horns Rev and Nysted. Report ITAP – Institut fur technische und angewandte Physik GmbH, Oldenburg.

Boaventura D., Moura A., Leitão F., Caravalho S., Cúrida J., Pereira P., Fonseca L.C., Santos M.N., Monteiro, C.C. 2006. Macrobenthic colonisation of artificial reefs on southern coast of Portugal (Ancão, Algarve). Hydrobiologia 555: 335-343.

Bohnsack J.A. 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioural preference? Bull Mar Sci 44: 631-645.

Buckley R.M. 1982. Marine habitat enhancement and urban recreational fishing in Washington. Mar. Fish. Rev. 44: 28-37.

Bulleri F. 2005. The introduction of artificial structures on marine soft- and hard-bottoms: ecological implications of epibiota. Environmental Conservation 32 (2): 101-102.

Chapman M.G. 2003. Paucity of mobile species on constructed seawalls: effects of urbanization on biodiversity. Mar. Ecol. Prog. Ser. 264: 21-29.

Conell S.D., Glasby T.M. 1999. Do urban structures influence localabundance and diversity of subtidal epibiota? A case study from Sydney harbour, Australia. Marine Environmental Research 47: 373-387.

Dean T.A., Hurd L.E. 1980. Development in an estuarine fouling community: the influence of early colonists on later arrivals. Oecologia 46: 295-301.

DHI. 2006. Spill Monitoring at Lillgrund, DHI Water & Environment, Horsholm.

Donskoy D., Ludyanskiy M.L. 1995. Low frequency sound as a control measure for zebra mussel fouling. pp. 103-108. Proceedings of The Fifth International Zebra Mussel and Other Aquatic Nuisance Organisms Conference, Toronto.

DWIA. 2003. www.windpower.org, Danish Wind Industry Association.

Edelvang K., Møller A.L., Hansen E.A. 2001. DHI. Lillgrund Vindkraftpark, Environmental impact assessment of hydrography and sediment spill. Final Report.

Elmer K.-H. 2007. Measurement and Reduction of Offshore Wind Turbine Construction Noise DEWI Magazin.

Emu Ltd. 2006. Kentish Flats Fisheries Comparative Study, Final. Report No. 06/J/I/03/0672/0610. pp. 36. Emu Ltd., Southampton.

Enderlein P., Wahl M. 2004 Dominance of Blue mussels versus consumer-mediated enhancement of benthic diversity. J. Sea Res. 51: 145-155.

Eriksson K., Henriksson A., Kevan E., Edvardsson T., Tholander G., Wollinder C., Nilsson O. 2004. Projekt Säkrare Farleder till Göteborg - Slutrapport. pp. 78, Säkrare Farleder, Göteborg.

EWEA. 2007. Offshore Wind 2007 Conference & Exhibition, European Wind Energy Association, Berlin.

Fabi G., Grati F., Puletti M., Scarcella G. 2004. Effects on fish community induced by installation of two gas platforms in the Adriatic Sea. Mar. Ecol. Prog. Ser. 273: 187-197.

Fiskeriverket. 2007. Revidering av kunskapsläget för vindkraftens effekter på fisket och fiskbestånden, Fiskeriverket.

Gaines S., Brown S., Roughgarden J. 1985. Spatial variation in larval concentrations as a cause of spatial variation in settlement for the barnacle, Balanus glandula. Oecologia 67: 267-272.

Gill A. 2005. Offshore renewable energy: ecological implications of generating electricity in the coastal zone. Journal of Applied Ecology 42: 605-615.

Gill A.B., Gloyne-Philips I., Neal K.J., Kimber J.A. 2005. Electromagnetic fields review - the potential effects of electromagnetic fields generated by sub-sea power cables associated with offshore wind farm developments on electrically and magnetically sensitive organisms - a review, Institute of Water and Environment Cranfield University, Silsoe.

Glasby T.M., Conell S.D. 1999. Urban structures as marine habitats. Ambio 28: 595-598.

Glasby T.M., Conell S.D. 2001. Orientation and position of substrata have large effects on epibiotic assemblage. Mar Ecol Prog Ser 214: 127-135.

Grove R.S., Sonu C.J., Nakamura M. 1989. Recent Japanese trends in fishing reef design and planning. Bull Mar Sci 44: 984-996.

Harlin M.M., Lindebergh J.M. 1977. Selection of substrata by seaweeds: optimal surface relief. Mar. Biol. 40: 33-40.

Hedeselskabet. 2004. Middelgrunden Biologisk undersogelse ved vindmolleparken på Middelgrunden ved Kobenhavn, efterår 2003, Hedeselskabet Miljo- og Energi as, Kobenhavn.

Ingemansson. 2002. Vindkraftpark på Fladengrund, Ingemansson Technology AB, Göteborg.

Ingemansson. 2003. Utgrunden off-shore wind farm - Measurements of underwater noise, Ingemansson Technology AB, Göteborg.

Ingemansson. 2005. Skottarevet, Falkenberg havsbaserad vindkraftpark, Ingemansson Technology AB, Göteborg.

Jensen A.C., Collins K.J., Lockwood A.P.M. 2000. Artificial reefs in European seas. Kluwer Academic Publishers: London. 508 pp.

Johansson L. 2004. SMHI. Påverkan på djupvattnet i Arkona av fundament på Kriegers Flak – enkel överslagsberäkning. Rapport 2004-37.

Jonasson K. 2002. Ljud i havet - påverkan på marina djur. 12 pp. Göteborg Energi, Stockholm.

Karlson K., Rosenberg R., Bonsdorff E. 2002. Temporal and spatial large-scale effects of eutrophication and oxygen deficiency on benthic fauna in Scandinavian and Baltic Waters – a review. Oceanography and Marine Biology 40: 427-489.

Karlsson A., Liungman O., Lindow H. 2006. Överslagsberäkning av vertikal blandning vid Skottarevet vindkraftpark. SMHI, Rapport 2006-52.

Kautsky N. 1982. Growth and size structure in a Baltic Mytilus edulis population. Mar. Biol. 68(2): 117-133.

Kautsky H. 1989. Quantitative distribution of plant and animal communities of the phytobenthic zone in the Baltic Sea. Askö contributions 35: 1-80.

Kautsky H., Kautsky L., Kautsky N., Kautsky U., Lindblad C. 1992. Studies on the Fucus vesiculosus community in the Baltic Sea. Acta Phytogeogr. Suec. 78:33-48

Kautsky H., Van der Maarel E. 1990. Multivariate approaches to the variation in Phytobenthic communities and environmental vectors in the Baltic Sea. Mar. Ecol. Prog. Ser. 60:169-184.

Kiorboe T., Frantsen E., Jensen C., Sorensen G. 1981. Effects of suspended sediment on development and hatching of herring (Clupea harengus) eggs. Estuarine, Coastal and Shelf Science 13: 107-111.

Klaustrup M. 2006. Few effects on the fish communities so far. I: Danish offshore wind key Environmental Issues. Published by: DONG energy, Vattenfall, The Danish Energy Authority, The Danish Forest and Nature Agency. 64-79.

Knott N.A., Underwood A.J., Chapman M.G., Glasby T.M. 2004. Epibiota on vertical and horizontal surfaces on natural reefs and on artificial structures. J. Mar. Biol. Ass. U. K. 84: 1117-1130.

Leonhard S., Birklund J. 2006. Infauna, Epifauna and Vegetation, change in diversity and higher biomass. I: Danish offshore wind key Environmental Issues. Published by: DONG energy, Vattenfall, The Danish Energy Authority, The Danish Forest and Nature Agency. 44-63.

Lindow H., Lindahl S., Kriezi E., Nerheim S., Nordblom O., Wickström K. 2007. Strömning, skiktning och blandning över grundområden, Pilotstudie Kriegers flak. SMHI, Rapport 2007-22.

Lindquist D.C., Shaw R.F., Hernandez F.J. 2005. Distribution patterns of larval and juvenile fishes at offshore petroleum platforms in the north-central Gulf of Mexico. Estuarine, Coastal and Shelf Science 62: 655-665.

Littorin B., Gilek M. 1999. Vertical patterns in biomass size structure growth and recruitment of Mytilus edulis in an archipelago area in the northern Baltic proper. Ophelia. 50(2): 93-112

Løkkeborg S., Humbortad O-B., Jørgensen T., Soldal A.V. 2002. Spatio-temporal variation in gillnet catch rates in the vicinity of North Sea oil platforms. ICES J Mar Sci 59: 294-299.

Love M.S., Schroeder D.M., Nishimoto M.M. 2003. The ecological role of oil and gas production platforms and natural outcrops on fishes in southern and central California: a synthesis of information. U.S. Department of the Interior, U.S. Geological Survey, Biological Resources Division, Seattle, Washington, 98104, OCS study MMS 2003-032. (www.id.ucsb.edu/lovelab).

Lubchenco J. 1983. Littorina and Fucus: Effects of herbivores, substratum, heterogeneity and plant escape during succession. Ecology 64: 1116-1123.

Lyngby J.E., Mortensen S.M. 1994. Effects of dredging activities on growth of Laminaria saccharina 29. European Marine Biology Symposium, Vienna.

Länsstyrelsen västra Götalands län 2007. Hummerrevsprojektet, Slutrapport. Rapport 2007:40

Mc Guiness K.A., Underwood A.J. 1986. Habitat structure and the nature of communities on intertidal boulders. J. Exp. Mar. Biol. Ecol. 104: 97-123

Madsen P.T., Wahlberg M., Tougaard J., Lucke K., Tyack P. 2006. Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Marine Ecology Progress Series 309: 279-295.

Michel J., Dunagan H., Boring C., Healy E., Evans W., Dean J.M., McGillis A., Hain J. 2007. Worldwide Synthesis and Analyses of Existing Information Regarding Environmental Effects of Alternative Energy Uses on the Outer Continental Shelf, MMS U.S. Department of the Interior Minerals Management Service, Columbia.

Milon J.W. 1989. Artificial marine habitat characteristics and participation behaviour by sport anglers and divers. Bull. Mar. Sci. 44: 853-862.

Møller A.L., Edelvang K. 2001. DHI. Lillgrund vindkraftpark, Assessment of effects to the zero solution in Öresund. Final Report.

Naturvårdsverket 2006a. Hur vindkraft påverkar livet på botten. – en studie före etablering. Vindval Rapport 5570.

Naturvårdsverket 2006b. Inventering av marina naturtyper på utsjöbankar. Rapport 5576.

Nielsen K.J. 2001. Bottom-up and top-down forces in tide pools: Test of a food change model in an intertidal community. Ecol. Monogr. 71(2): 187-217.

Nedwell J., Langworty J., Howell D. 2003. Assessment of sub-sea acoustic noise and vibration from offshore wind turbines and its impact on marine wildlife; initial measurements of underwater noise during construction of offshore windfarms, and comparision with background noise, Subacoustech, Southampton.

Nedwell J., Howell D. 2004. A review of offshore windfarm related underwater noise sources, Subacoustech, Southampton.

Nedwell J.R., Turnpenny A.W.H., Lovell J., Parvin S.J., Workman R., Spinks J.A.L., Howell D. 2007. A validation of the dBht as a measure of the behavioral and auditory effects of underwater noise, Subacoustech Ltd, Bishop's Waltham.

OES. 2007. Kentish Flats Offshore Wind Farm FEPA Monitoring Summary Report. pp. 66. Offshore Environmental Solutions Ltd. Fredericia.

Onuf C. 2002. Seagrasses, Dredging and Light in Laguna Madre, Texas, U.S.A. Estuarine, Coastal and Shelf Science 39: 75-91.

Parvin S.J., Nedwell J.R. 2006. Underwater noise survey during impact piling to construct the Burbo Bank Offshore Wind Farm, Subacoustech Ltd. / COWRIE.

Perkol-Finkel S., Benayahu Y. 2005. Recruitment of benthic organism onto a planned artificial reef: shifts in community structure one decade post-deployment. Mar. Environ. Res. 59: 79-99.

Peter Madsen Rederi. 2006. Method Statements: Foundation and seabed preparation, Peter Madsen Rederi A/S, Report to Vattenfall.

Petersen J.K., Malm T. 2006. Offshore Windmills Farms: Threats to or Possibilities for the Marine Environment. Ambio 35 (2):75-80.

Petersson M. 2000. Vindkraft till havs - en litteraturstudie av påverkan på djur och växter, Naturvårdsverket 55 pp.

Pickering H., Whitmarsh D. 1997. Artificial reefs and fisheries exploitation: a review of the attraction versus production debate, the influence of design and its significance for policy. Fisheries Research 31: 39-59.

Popper A.N., Salmon M., Horch K.W. 2001. Acoustic detection and communication by decapod crustaceans. Journal of Comparative Physiology 187: 83-89.

Qvarfordt S. 2006. Phytobenthic communities in the Baltic Sea –seasonal patterns in settlement and succession. Doctoral thesis, Department of Systems Ecology, Stockholms Universitet.

Qvarfordt S., Kautsky H., Malm T. 2006. Development of fouling communities on vertical structures in the Baltic Sea. Estuarine, Coastal and Shelf Science 67: 618-628.

Reyff J. 2004. Underwater Sound Levels Associated with Marine Pile Driving - Assessment of Impacts and Evaluation of Control Measures Noise-Con, Baltimore.

Saier B. 2001. Direct and indirect effects of seastars Asterias rubens on mussel beds (Mytilus edulis) in the Wadden Sea. J. Sea Res. 46: 29-42.

Schröder A., Orejas C., Joschko T. 2006. Benthos in the Vicinity of Piles: FINO 1 (North Sea). I: Köller J., Köppel J., Peters W. Offshore Wind Energy Research on Environmental Impacts. Springer-Verlag Berlin Heidelberg. 185-200.

SGS. 2005. Support Structure Concepts. pp. 13, SGS Group, Report to Vattenfall.

Sloth P. 2001. DHI. Hydrographic Conditions for Örestad Vindkraftpark, Sweden. Final Report.

Soldal A.V., Svellingen I., Jørgensen T., Løkkeborg S. 2002. Rigs-to-reefs in the North Sea: hydroacoustic quantification of fish in the vicinity of a ”semi-cold” platform. ICES Journal of Marine Science 59: 281-287.

Sorensen H.C., Hansen L.K., Molgaard-Larsen J.H. 2002. Middelgrunden 40 MW Offshore Wind Farm Denmark - Lessons Learned, Realities of Offshore Wind Technologies, Case: Middelgrunden, Orkney.

Stanley D.R., Wilson C.A. 1996. Abundance of fishes associated with a petroleum platform as measured with dual-beam hydroacoustics. ICES J. Mar Sci 53: 473-475.

Svane I., Petersen J.K. 2001. On the Problems of Epibioses, Fouling and Artificial Reefs, a Review. Mar. Ecol. 22(3): 169-188.

Svensson J.R., Lindegarth M., Siccha M., Lenz M., Molis M., Wahl M., Pavia H. 2007. Maximum species richness at intermediate frequencies of disturbance: consistency among levels of productivity. Ecology 88(4): 830-838.

Talisman. 2006. Beatrice Wind Farm Demonstrator Project Environmental Statement, Talisman Energy (UK) Limited, Aberdeen.

Thomsen, F., K. Ludemann, R. Kafemann & W. Piper. 2006. Effects of offshore wind farm noise on marine mammals and fish, Biola, Hamburg.

Unabia C.R.C., Hadfield M.G. 1999. Role of bacteria in larval settlement and metamorphosis of the polychaete Hydroides elegans. Mar Biol. 133: 55-64.

Underwood A.J., Anderson M.J. 1994. Seasonal and temporal aspects of recruitment and succession in an intertidal estuarine fouling assemblage. J. Mar.Biol.Ass. U.K. 74:563-584.

Valeur J.R., Jensen A. 2001. Sedimentological research as a basis for environmental management: The Oresund fixed link. The Science of the Total Environment 266: 281-289.

Wahlberg M., Westerberg H. 2005. Hearing in fish and their reactions to sounds from offshore wind farms. Marine Ecology Progress Series 288: 295-309.

Wennberg T. 1992. Colonization and succession of macroalgae on a breakwater in Laholm bay, a eutrophicated brackish water area (SW Sweden). Acta Phytogeogr. Suec. 78: 65-77.

Westerbom M., Kilpi M., Mustonen O. 2002. Blue mussels, Mytilus edulis, at the edge of the range: population structure, growth and biomass along a salinity gradient in the north-eastern Baltic Sea. Mar. Biol. 140: 991-999.

Westerberg H. 1994. Fiskeriundersökning vid havsbaserat vindkraftverk 1990-1993. Rapport5 Göteborgsfilialen. Utredningskontoret i Jönköping, 44 pp.

Westerberg H. 1996. Ljud- och vibrationsmätningar vid broar, Fiskeriverket Kustlaboratoriet, V. Frölunda.

Westerberg H., Roennbaeck P., Frimansson H. 1996. Effects on suspended sediments on cod egg and larvae and on the behaviour of adult herring and cod. 13 pp. Counc. Meet. of the Int. Counc. for the Exploration of the sea, ICES, Copenhagen, Denmark, Reykjavik, Iceland.

Wieczorek S.K., Todd C.D. 1998. Inhibition and facilitation of settlement of epifaunal marine invertebrate larvae by microbial biofilm cues. Biofouling 12 (3): 81-118

Wilhelmsson D., Malm T., Öhman M.C. 2006a. The influence of offshore windpower on demersal fish. ICES J. Mar. Sci. 63: 775-784.

Wilhelmsson D., Yahya S.A.S., Öhman M.C. 2006b. Effects of high-relief structures on cold temperate fish assemblages: A field experiment. Marine Biology Research 2: 136-147.

Vindval1 2008. Wikström A., Granmo Å. Effekter och anpassningar av marin mjukbottenfauna till ljudstörningar från havsbaserade vindkraftverk. 44 pp., Marine Monitoring vid Kristineberg AB – Vindval.

Vindval2 2008. Hammar L., Wikström A., Börjesson P., Rosenberg R. Effektstudier på småfisk under konstruktionsarbeten vid Lillgrund vindpark - anläggning av gravitationsfundament, Marine Monitoring vid Kristineberg AB – Vindval.

WPD. 2005. Preliminary Study on Foundation Concepts in relation to Kriegers Flak II and Pilotprojekt Vindval. pp. 15, WPD Scandinavia AB, Report to Vattenfall.

Young G.A. 1985. Byssus-thread formation by the mussel Mytilus edulis: effects of environmental factors. Mar. Ecol. Prog. Ser. 24: 261-271.

Zettler M.L., Pollehne F. 2006. The impact of Wind Engine Constructions on Benthic Growth Patterns in the Western Baltic. I: Köller J., Köppel J., Peters W. Offshore Wind Energy Research on Environmental Impacts. Springer-Verlag Berlin Heidelberg. pp. 201-222.

ÅF -Ingemansson. 2007. Fundamentoptimering PM, ÅF-Ingemansson AB, Göteborg.

ÅF –Ingemansson Technology 2007. Ljud från fundament vid byggnation och i driftskede. (This study is included as an appendix in the Swedish version; Miljömässig optimering av fundament för havsbaserad vindkraft)

Öhman M.C., Wilhelmsson D. 2005. VINDREV - Havsbaserade vindkraftverk som artificiella rev: effekter på fisk. Vindforsk, FOI/ Energimyndigheten. Rapport. 17 pp.

ØDS. 2000. Offshore Wind-Turbine Construction - Offshore Pile-Driving Underwater and Above-water Noise Measurements and Analysis, Odegaard & Danneskiold-Samsoe A/S, Copenhagen.

Øresundskonsortiet. 2000. Environmental impact of the construction of the Øresund fixed link. Copenhagen 96 pp.

Personal communication

Almgren, Martin. ÅF-Ingemansson. 2007-11.

Anders, Nielsen. DHI Water Environment Health. 2007-12.

Dahlén, Göran. E.ON. 2007-05.

Grahn, Niklas. Vattenfall Power Consultant. 2006-06.

Wahlberg, Magnus. Fjord & Bælt. 2008-02

Electronic sources

Bay Bridge East Span, San Francisco.
http://biomitigation.org/

Sea Cult - Reef Systems A/S. 2007.
http://www.seacult.com/

Öresundskonsortiet. 2004. Environmental accounting.
http://www.oresundsbron.com/library/index.php?menu=116&subject=10

Adapting offshore wind power foundations to local environment

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Conditions for marine life are affected on sites where new materials and surfaces are introduced to the bottom of the ocean.

The offshore wind mill foundations are all made of hard structures but the effects on the marine life varies depending on the surface conditions of the foundation and the methods of installation. Another factor of impact is the type of habitat existing before establishment.

This report describes the various types of changes in the marine habitat which can be expected during establishment of offshore wind mill foundations on different types of bottom substrates.

The knowledge can be used as a basis for planning, licensing and environmental impact assessments concerning offshore wind parks.

Vindval is a programme that collects knowledge on the environmental impact of wind power on the environment, the social landscape and people's perception of it. It is aiming to facilitate the development of wind power in Sweden by improving knowledge used in IEAs and planning- and permission processes. Vindval finances research projects, analyses, syntheses and dissemination activities. The programe has a steering group with representatives for central and regional authorities and the wind power industry.

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