Effects of marine windfarms on the distribution of fish, shellfish and marine mammals in the Horns Rev area

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Content:

1. SUMMARY AND CONCLUSIONS

The fish and shellfish fauna: The description of the fish fauna in the Horns Rev area is based on eleven years trawl surveys carried out by the Dutch Institute for Fisheries Research. The most common species are dab, plaice, hooknose, whiting, dragonet and grey gurnard. A total of 42 different fish species are listed. The relative abundance of the ten most common species is given for three different areas within and outside the windmill area. These mean figures indicate some systematic differences among the three areas for species like plaice, hooknose, whiting and gobies. However, there have been large fluctuations from year to year in the abundance of the species. A high abundance of the brown shrimp is observed east of the windmill area.

The effects of the marine windmills. The effects on fish, shellfish and marine mammals are in the following divided in 1. Effects of the physically presence of the windmills, 2. Artificial reef effects, 3. Effects of noise and 4. Effects of magnetic fields.

1) <u>Effects of the physically presence of the windmills</u>: As for whether and how the changes in environment below the sea surface due to placement of a windmill park and the cable tracé will affect the marine species considered, one should distinguish between *short term* effects and *long term* effects (permanent changes). *Short term effects.* It is very likely that during the construction period of both the wind mills and the cable tracé many of the fish species as well as marine mammals will be disturbed. They will disappear from the relatively small area due to temporary increased turbidity of the water, underwater water movements, noise and other activities on the sea bottom. If the cable tracé is placed in the Grådyb area the effects in the construction period will be considerable to small flatfish and the seals in the Langli area. The experience is, however, that once such construction activities have finished the species affected will return rather quickly. *Long term effects.* The underwater changes in the windmill area will be the stone and concrete foundations of mills and possibly some minor changes in local currents. The total area of that part of the seabed, which will be occupied by the foundations of the mills is so small (around 1000 m^2), that it can be considered insignificant. Also the total area of the proposed windmill area (27.5 km^2) is small, and the effects of any local environmental changes within this area will probably be small regarding the surroundings. The physically presence of the cables and any of the proposed cable tracés buried in the sea bed are not expected to cause any changes in the abundance of fish, marine mammals and crustaceans in the area. Five fish species, grey gurnard, lesser weever, snake pipefish, sea trout and lampern are listed on the current red list of endangered fish species for the Wadden Sea. Taking the biology of the species into concern no impact on their distribution is expected in the Wadden Sea due to the windmills at Horns Rev.

2. Artificial reef effects. The foundations of a marine windmill will to some extent function as an artificial reef providing hard-bottom on an otherwise even sandy bottom. The impact on the fish fauna will either be through increased *productivity* or simply through *attraction*. *Productivity*: The planned marine windmill park will provide a relatively simple artificial reef complex with equidistant, uniform elements of high profile structures of low complexity. The type of fauna and flora that develop on these structures is dependent on a number of parameters. Structure material and design together with hydrographic parameters are important factors determining the extent and rate of biofouling, as well as development of hard-bottom benthic organisms, which may provide the food-chain basis for fish fauna. These substrates may also attract predators feeding on smaller fish or epifauna attracted to the reef. Considering the hydrography and material and design of the Horns Rev structures, there is no indication that the windmill foundations will provide a significant food-chain basis. *Attraction:* Fish are highly attracted to underwater structures, their affinity being related to their life styles and requirements. Gadoids (codfish) are particularly attracted to high profile structures but their attraction to the windmill structures, which are relatively low-complex structures, may be limited. The abundance of cod in the area is relatively low and there is a sporadic summer fishery on this species. Providing that fishery is allowed close to and around these structures, and gadoids are attracted to windmill profile structures then the windmill reef complex could be a potential fishing area. Flatfish are also attracted to underwater structures resulting in a redistribution of resources. Because of their relatively high mobility between underwater structures, these species may become more vulnerable to fisheries, increasing the exploitable biomass.

3. Effects of noise. In the construction phase, noise will be expected to be generated by the construction operations (primarily the jack-up-rig ramming operations), by shipping operations (supply vessels coming and going as well as transportation within the area) and by helicopter traffic. The noise generated by these sources will primarily be of low frequencies with most energy probably below 1 kHz. This is not expected to affect the echolocation abilities of the harbour porpoises. However, it is not clear whether harbour porpoises use sounds with frequencies below 1 kHz for communication. If they do, this could potentially be affected by the noise sources mentioned. These noise sources are all temporary and of a localised nature, and although they will probably displace fish, porpoises and seals from the affected areas, it is expected that this displacement will be temporary. In the production phase, noise will be expected to be generated by the windmills and by helicopter traffic. The windmills are expected to generate noise above ambient levels only in frequencies below 1-2 kHz. Below 500 Hz, noise from the windmills could be considerably above ambient levels. This could potentially affect the communication of porpoises in the area, if they indeed use these frequencies. Since the noise from the windmills will be continuous, the porpoises will proba-

bly develop some tolerance to the noise, but the extent of this is impossible to predict. Fish typically respond strongly to low-frequency hydrodynamic/acoustic fields (below ca. 50 Hz). Significant noise contributions in this frequency range are expected to be confined to the immediate vicinity of the windmills, within a radius of no more than some hundreds of meters. However, because of the spatial extent of the low-frequency hydrodynamic/acoustic fields from the mills, fish will perceive them to be very different compared to the low-frequency fields of other animals. Therefore, fish are not expected to be impaired in their ability to detect and interpret the fields from different sources (i.e. windmills or animals). Furthermore, the continuous character of the windmill noise will likely promote habituation in the fish. Noise is also radiated in the frequency range 0.05–2 kHz with source levels up to 74 dB re 1 μPa. However, fish respond only weakly, and the influence of the windmills, especially compared to the level of marine antropogenic noise in general, is most likely minor. Above 2 kHz, no noise is expected from the windmills, and this frequency range may therefore be considered of no concern. In conclusion, it should be expected that harbour porpoises, harbour seals and fish will be displaced temporarily from the area affected by the construction of the park and maybe permanently from a smaller area in the production phase. But unless the affected area is a critical habitat for porpoises, the overall effect is expected to be negligible. There are no haulout sites for seals in the vicinity of the windmill park, and not many seals have been observed in the area. Since the noise from the windmills will be continuous, the seals and fish are expected to habituate to this and the overall effect is expected to be negligible.

4) <u>Effect of magnetic fields.</u> Magnetic fields from cable tracé, windmills, and the offshore transformer station may be expected to reach geomagnetic field-strength levels only in the immediate vicinity of these structures, at distances no more than 1 m. *Cartilaginous fishes* (sharks and rays) are, by way of their electroreceptive sense organs, able to detect magnetic fields, and they may use the geomagnetic field for navigation. For *bony fishes*, a true magnetic sense has been proposed, but the evidence is much less compelling. Thus, the weak magnetic fields from the marine windmill park at Horn Rev are not expected to pose any serious problem for the local fish species. Furthermore it does not appear likely that the magnetic fields generated by the power transmission cables will have any detectable effects on the harbour porpoises and seals in the area.

2. INTRODUCTION

In relation to the proposed establishment of an experimental marine windmill park at Horns Rev, ELSAMPROJEKT is conducting an Environmental Impact Assessment (EIA).

As a contribution to this EIA, the Danish Institute for Fisheries Research (DIFRES) has been contracted by ELSAMPROJEKT to provide a quantitative description of the fish and shellfish fauna in the area and to evaluate the effects of the windmill park on fish, shellfish and marine mammals.

The evaluation is based on descriptions of the physical properties of the proposed windmill park supplied by ELSAMPROJEKT in "*Særlige Betingelser, Bestemmelser og Beskrivelse*" (EP99-0/449 dated 10 June 1999, file no. EP11746.01), information contained in preliminary reports by other contributors to the EIA (*e.g.* ELTRA, Ødegaard & Danneskiold-Samsøe, Fiskeri og Søfartsmuseet) as well as information provided during meetings with ELSAMPROJEKT and the other consultants involved.

3. PURPOSE OF THE REPORT

The purpose of the report is:

- to give a quantitative description of the abundance of the fish and shellfish in the area surrounding the windmill area and to evaluate the effects of the physically presence of the windmills on the abundance of fish and shellfish in the area
- to evaluate the artificial reef effect in the windmill area
- to evaluate the effects of noise and electromagnetic fields on the abundance of fish and marine mammals

4. FISH AND SHELLFISH

4.1 Overview of the main fish species in the area.

4.1.1 Material and methods.

From the beginning it was decided not to select special impact and reference areas due to the fact that most species are very mobile and that there is considerable yearly variations in the distribution of the species. Time series on the distribution of species in the area were supposed to give a more relevant picture of the situation. The description of fish and shellfish is therefore based on beam trawl data from two Dutch research vessel surveys conducted in such areas in the North Sea considered important as nursery grounds for Plaice and Sole. The gear (beam trawl) used on these surveys are very suitable to catch all species of bottom (demersal) fish. The pelagic species are only caught occasionally which makes the estimates on their distribution more doubtful. However, to complete the species overview, the pelagic fish species commonly found in the area as well as the few commercially important invertebrate species found in the sampled area are mentioned

The Dutch surveys used in this report are:

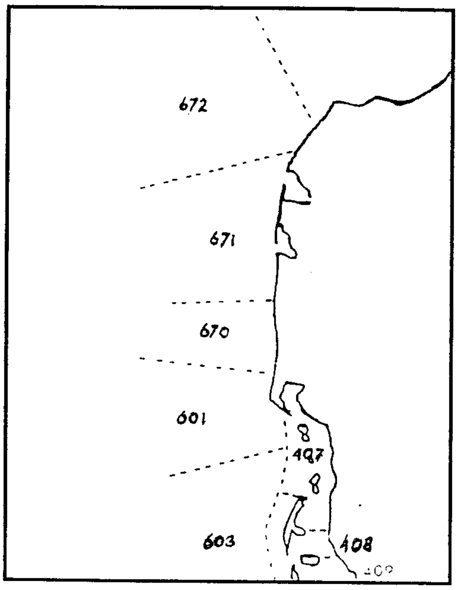
- The Sole Net Survey (SNS) conducted in the North Sea areas along the coast of Netherlands, Germany and Denmark. Initially this survey was conducted both in the spring and autumn in a year, but since 1991 only in the autumn van Beek, (1997). The survey design is based on a fixed number of trawl stations along transects parallel or perpendicular to the coastline. On each transect a number of fixed stations is fished. In total about 55 hauls are done each year, with at least 4 hauls in a transect. In some years an additional grid has been fished along the Danish coast between Esbjerg and the Skagerrak. The survey was carried out by R.V. 'Tridens 1' until 1989, between 1990 and 1995 by R.V. 'Tridens 2' and from 1996 onwards the SNS is conducted by R.V. 'Isis'. Fishing is done with two 6m beam trawls, each rigged with 4 tickler chains and a mesh size of 40 mm stretched mesh in the cod-end. The gear is fished with a fishing speed of 3.5 knots and haul duration is 15 minutes. (see table 1 for details)

- The Dutch part of an international Beam Trawl Survey (BTS), where also Belgium, Germany and the U.K. participate (ICES, 1997). In this survey the unit sampling area is the ICES (International Council for the Exploration of the Sea) statistical square of 30*30 nautical miles. Within this unit a minimum of 3 trawl stations are chosen in fishable locations. Fishing is done with two 8m beam trawls with a cod-end fitted with a 40 mm cod-end liner. Eight tickler chains are used. The hauls are conducted at a speed of 4 knots and duration of 30 minutes.

The sub-areas selected for this study are 407 and 601 of the SNS and the ICES squares 40F7, 39F7 and 39F8 of the BTS (figure 1). The positions of the hauls are shown in figure 2. The research area used for this study therefore extends beyond the Horns Rev are. However, selecting a smaller area would result in a very small number of stations surveyed. Data for the period 1989-99 are used. No data were available of the SNS for 1996 and 1997. Therefore, information for these years is based on BTS data only. The catch is converted into numbers per $1000m^2$ and average catches of all species were calculated on all sub-areas and all years. For the 10 most abundant species the average catch per year is calculated for the period 1989 – 1999.

Fig. 1. The Dutch survey areas with transects and ICES squares. The windmill park is shown in ICES square 39F7.

SNS



BTS

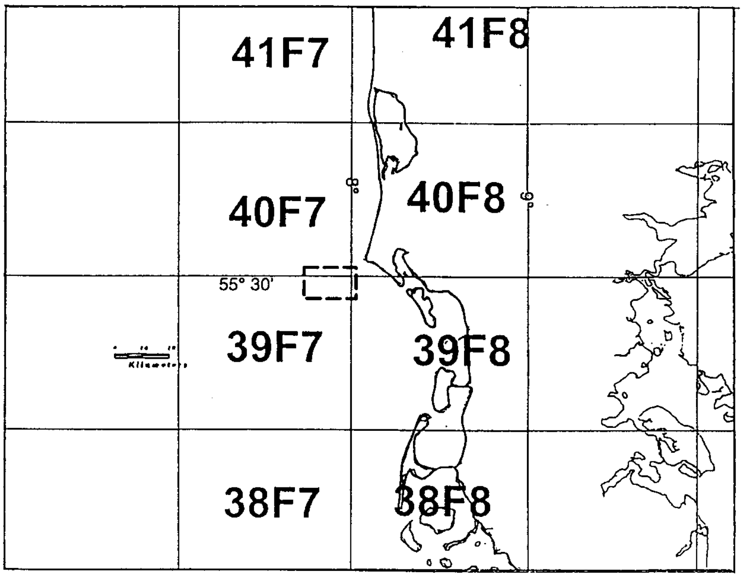


Table 1. Number of hauls per year per ship of the BTS- and SNS surveys used for this study.

	BTS - survey			SNS - survey			
ship	Isis	Trident 2	Total	Isis	Trident 1	Trident 2	Total
1989	5		5		10		10
1990	9	3	12			10	10
1991	9	7	16			10	10
1992	5		5			6	6
1993	9		9			6	6
1994	6		6			16	16
1995	6		6			6	6
1996	11		11				
1997	6		6				
1998	5		5	6			6
1999	6		6	6			6
Total	77	10	87	12	10	54	76

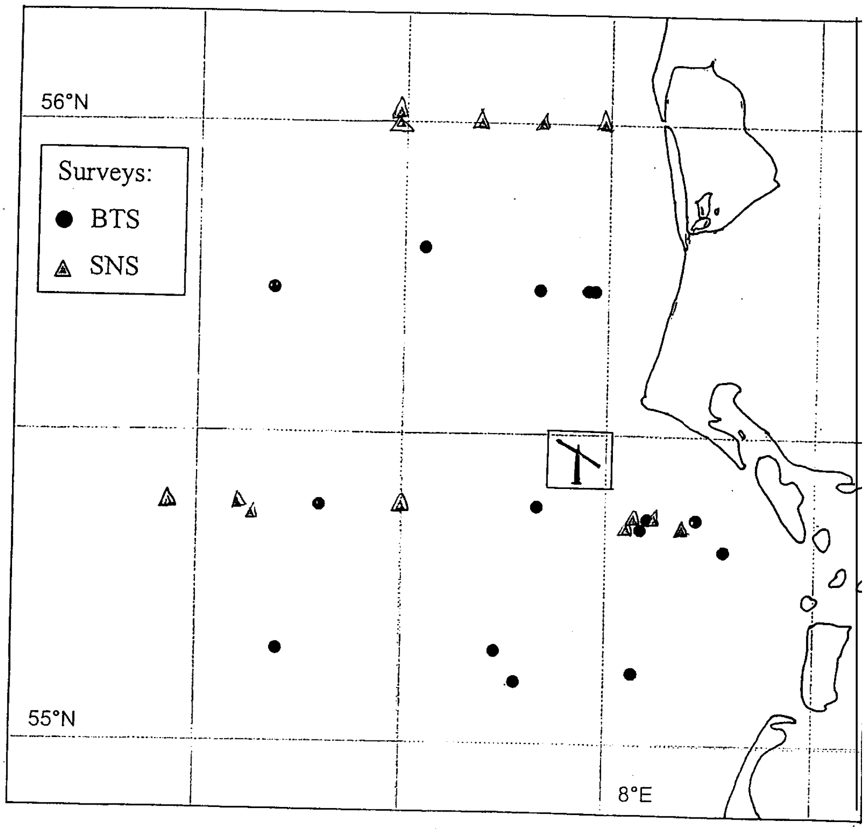


Figure 2. The positions of the hauls carried out by the Dutch ships.

4.1.2 Common fish species.

The two surveys have provided information on which demersal fish species are found in the area and on their relative abundance. Table 2 shows the average number per 1000 m^2 for the fish species caught regularly by the gear. The figures in table 2 are averages for the period 1989-99. Averages for all 3 ICES squares ('Total area') are presented for all species. To indicate the spatial variation in the density, table 2 also shows the density figures for the 10 most abundant species for each of the 3 squares. These mean figures indicate some systematic differences among the 3 squares for species like plaice, hooknose, whiting and gobies and the area 39F8 seems to be the most productive. However, there has been large fluctuations in distribution from year to year as shown in the following figures for the single species.

Table 2. Species observed. Numbers /1000 m^2 in the Horns Rev area 1989 – 1999.

English, Latin and Danish name	ICES squares	39F7	39F8	40F7	Total area
Dab *(Limanda limanda)*	*(Ising)*	69.6523	60.0559	65.6656	64.0434
Plaice *(Pleuronectes platessa)*	*(Rødspætte)*	34.0072	47.9838	16.9280	32.3228
Hooknose *(Agonus cataphractus)*	*(Panserulk)*	3.5151	10.2823	2.5760	4.7196
Whiting (Merlangius merlangus)	*(Hvilling)*	2.0057	11.7288	5.4246	4.5015
Dragonet *(Callionymus lyra)*	*(Stribet fløjfisk)*	2.0873	1.3281	0.7099	1.5804
Grey gurnard *(Eutrigla gurnardus)*	*(Grå knurhane)*	1.8296	0.0449	0.6142	1.2634
Solenette *(Buglossidium luteum)*	*(Glastunge)*	1.1498	0.7047	0.4309	0.9112
Gobies *(Gobiidae)*	*(Kutlinger)*	0.6382	2.2007	0.1445	0.8197
Sole *(Solea solea)*	*(Tunge)*	0.8845	0.8469	0.3881	0.7137
Scald fish *(Arnoglossus laterna)*	*(Tungehvarre)*	0.7119	0.1463	0.3231	0.5086
Bullrout *(Myoxocephalus scorpius)*	*(Alm.Ulk)*				0.4614
Cod *(Gadus morhua)*	*(Torsk)*				0.2949
Lemon sole *(Microstomus kitt)*	*(Rødtunge)*				0.2457
Eel pout *(Zoarces viviparus)*	*(Ålekvabbe)*				0.2271
Flounder *(Platichthys flesus)*	*(Skrubbe)*				0.2025
Top gurnard *(Trigla lucerna)*	*(Rød Knurhane)*				0.1440
3-spined stickleback *(Gasterosteus aculeatus)*	*(3-pigget Hundestejle)*				0.0979
Horse mackerel*(Trachurus trachurus)*	*(Hestemakrel)*				0.0853
Turbot *(Scophthalmus maximus)*	*(Pighvarre)*				0.0693
Nilsson's pipefish *(Syngnathus rostellatus)*	*(Lille tangnål)*				0.0522
Greater sandeel *(Hyperoplus lanceolatus)*	*(Tobis)*				0.0308
Red mullet *(Mullus surmuletus)*	*(Stribet mulle)*				0.0258
Brill *(Scophthalmus rhombus)*	*(Slethvarre)*				0.0243
Sprat *(Sprattus sprattus)*	*(Brisling)*				0.0132
Lesser weever *(Echiichthys vipera)*	*(Lille Fjæsing)*				0.0084
Pipefishes *(Syngnathidae)*	*(Nålefisk)*				0.0070
Garpike *(Belone belone)*	*(Hornfisk)*				0.0062
Snake pipefish *(Entelurus aequoreus)*	*(Snippe)*				0.0028
Herring *(Clupea harengus)*	*(Sild)*				0.0015
Poor cod *(Trisopterus minutus)*	*(Glyse)*				0.0014
Bib *(Trisopterus luscus)*	*(Skægtorsk)*				0.0010
Long rough dab *(Hippoglossoides platessoides)*	*(Håising)*				0.0010
Witch flounder *(Glyptocephalus cynoglossus)*	*(Skærising)*				0.0010
Norway pout *(Trisopterus esmarkii)*	*(Blåhvilling)*				0.0010
Norwegian topknot *(Phrynorhombus norvegicus)*	*(Småhvarre)*				0.0005
Hake *(Merluccius merluccius)*	*(Kulmule)*				0.0005
Five-bearded rockling *(Ciliata mustela)*	*(5-trådet havkvabbe)*				0.0002
Lesser-spotted dogfish *(Scyliorhinus canicula)*	*(Småplettet rødhaj)*				0.0002
Mackerel *(Scomber scombrus)*	*(Makrel)*				0.0002
Anglerfish *(Lophius piscatorius)*	*(Havtaske)*				0.0002
Lampern *(Lampetra fluviatilis)*	*(Flodlampret)*				0.0002
Sea trout *(Salmo trutta)*	*(Havørred)*				0.0001

Dab (*Limanda limanda*). As adults the dab is normally found at depths from 5-150 m in areas with sandy or soft bottoms. This flatfish species has a very widespread distribution in the entire North Sea. The larvae are pelagic and the juveniles are found at depths from 6-150 m. The importance of the dab to the commercial fisheries is rather small in spite of its abundance in the North Sea. The size distribution in the sampled area as observed in 1999 is shown in fig.3. This distribution probably reflects the overall size distribution of the North Sea dab. Fig. 4 shows the variation in density across the whole period. The patterns in year to year fluctuations in density are rather similar for each of the 3 squares.

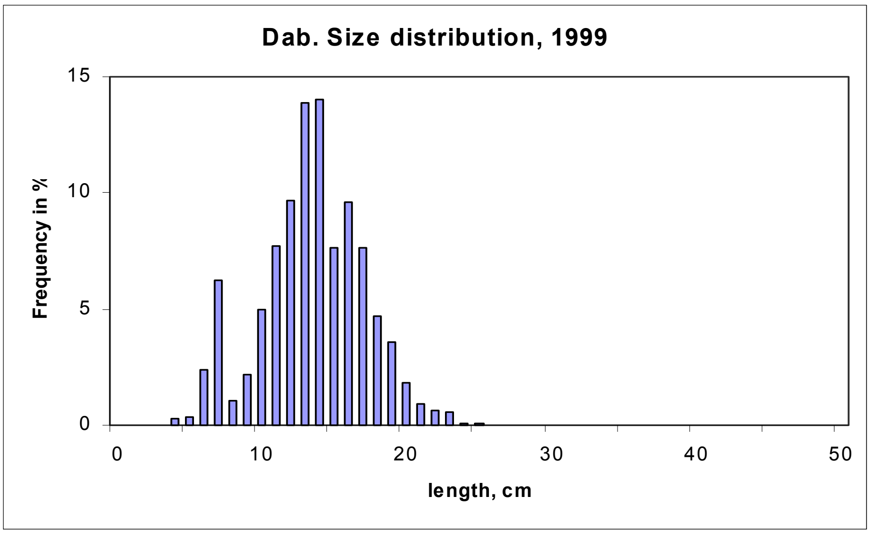


Figure 3. Size distribution of Dab.1999.

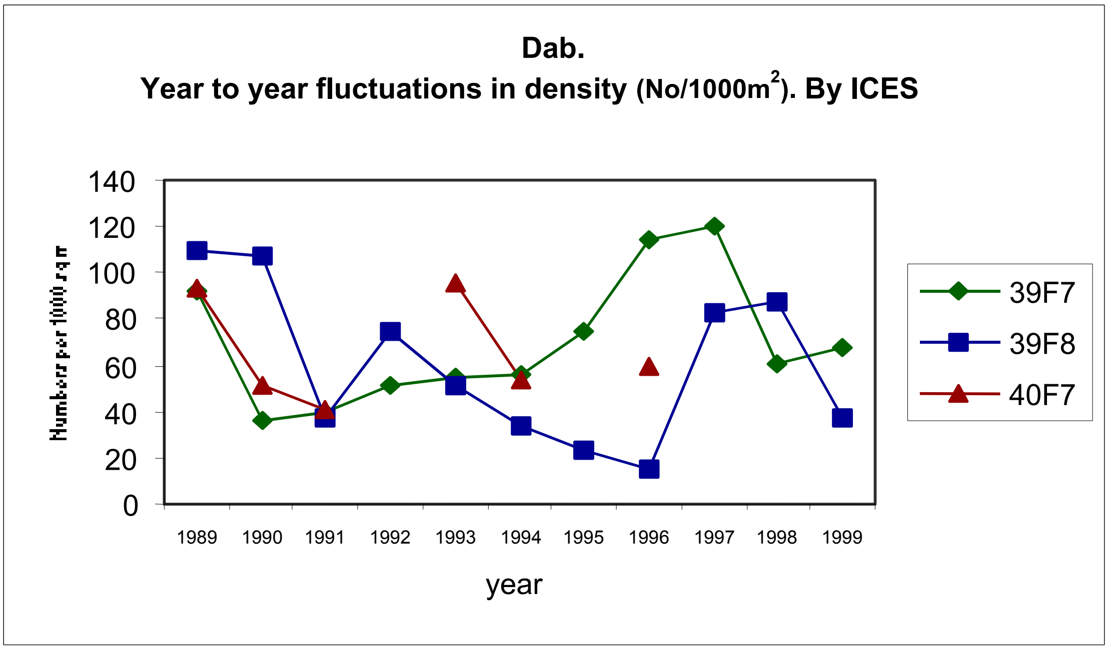


Figure 4. Variation in density for dab 1989-99

Plaice (*Pleuronectes platessa*). In the North Sea adult plaice are normally found at depths from 10–50 m. The larvae are pelagic and the juveniles are found mainly in coastal shallow waters. It has been estimated that approximately 70 % of the North Sea juvenile plaice are found in the coastal areas of Netherlands, Germany and Denmark, mainly in the Wadden Sea areas. The commercial importance of this species is well known. The size distribution in the sampled area as observed in 1999 is shown in fig. 5. The peak at 10 cm indicate the 0-group (the fish born in 1999).

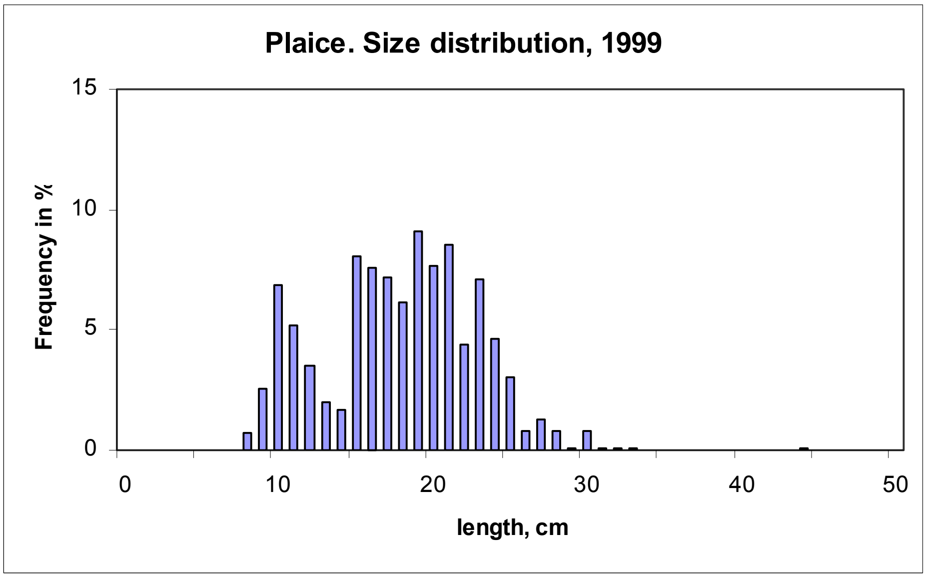


Figure 5. Size distribution of Plaice, 1999.

The patterns in year to year fluctuations in density are similar for ICES squares 39F7 and 39F8 for the years 1989 to 1994, with the highest densities observed north of Horns Rev, 39F8, fig. 6. From 1996 onwards it seems that the highest density has moved south to 39F7.

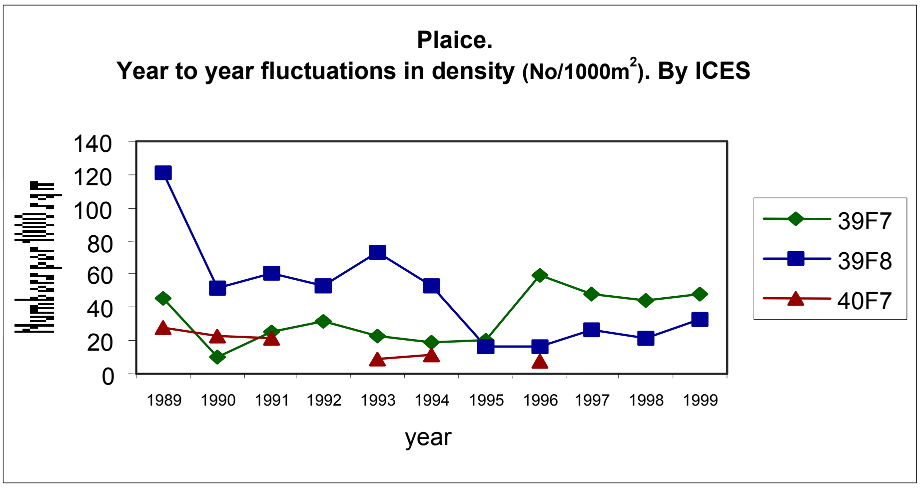


Figure 6. Variation in density for plaice 1989-99

Sole (*Solea solea*). In the North Sea the sole is found on soft or sandy bottoms from 10-150 m depth. In contrast to for instance plaice sole is a nocturnal species feeding mainly during night. The juveniles live in shallow waters along the coasts, in the North Sea mainly in the Wadden Sea areas. During winter this species migrate to deeper waters and the feeding rate decreases. The fishery for this commercially very important species mainly takes place in the shallow water and the main gears are beam trawls and gill nets. The size distribution in the sampled area as observed in 1999 is shown in fig 7. This size distribution, the majority of specimens being < 25 cm, suggests that the fish mainly belong to age groups 1-3. (fish age 1 to 3 years)

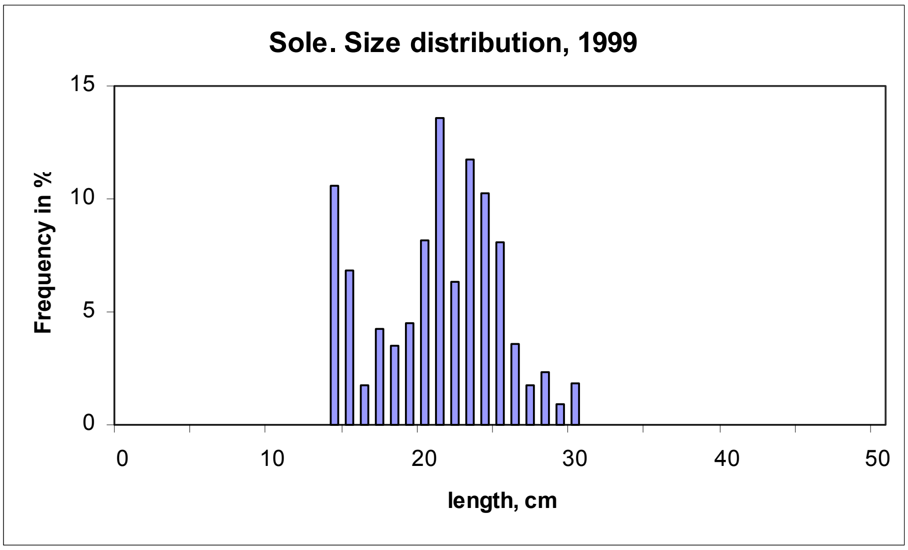


Figure 7. Size distribution of Sole, 1999.

The pattern in year to year fluctuations in density are similar for ICES squares 39F7 and 39F8, see fig.8. There seems to be a general decrease in stock size during the last 5-7 years.

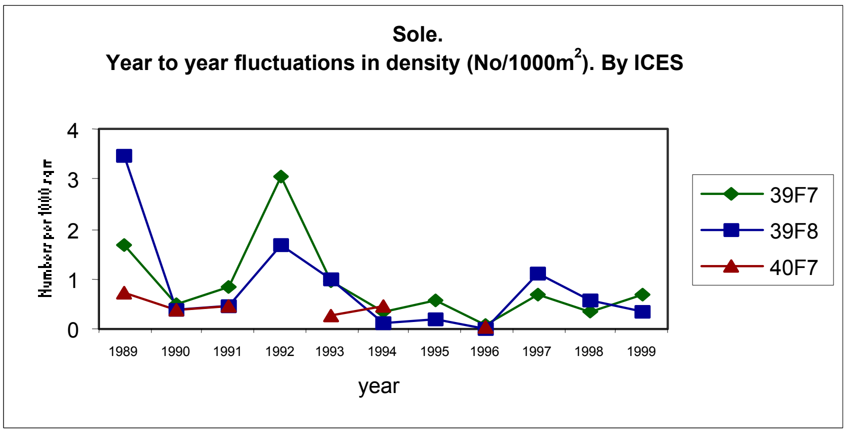


Figure 8. Variation in density for sole 1989-99.

Other Flatfish species. Among the other flatfish species commonly found in the area and of commercial importance are the turbot (*Scophtalmus maximus*) and the flounder (*Platichthys flesus*). The small solenette (Buglossidium luteum) and scald fish (*Arnoglossus laterna*) are also very common. They are of no commercial value. The year to year fluctuations for solenette and scald fish also follow rather similar trends at least in 39F7 and 39F8, see figs. 9 and 10.

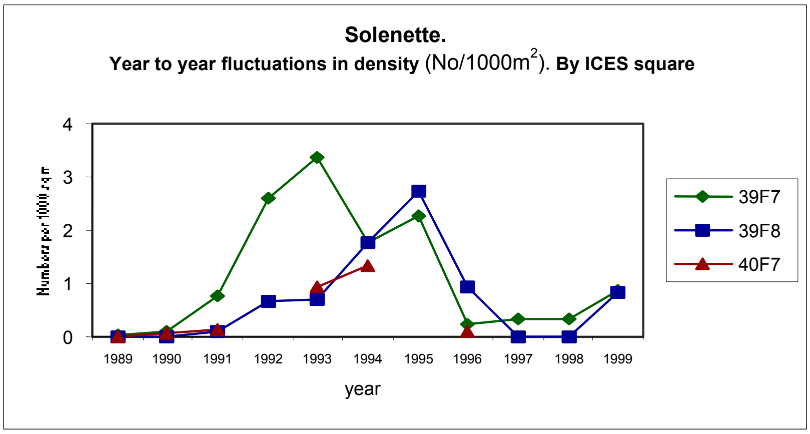


Figure 9. Variation in density for solenette 1989-99.

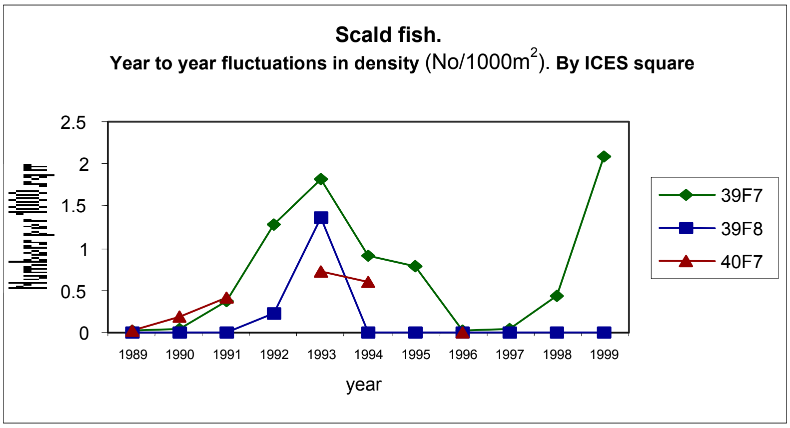


Figure 10. Variation in density for scald fish 1989-99

Whiting (*Merlangius merlangus*). This roundfish species is widely distributed in the North Sea at depths up to around 200 m. It is a mainly pelagic species. In the North Sea this species spawns mainly in depths of 30-100 m. The size distribution of whiting in the sampled area as observed in 1999 is shown in fig.11. Also for whiting the density patterns for 1989-1999 seems to be rather similar for the 3 ICES squares, with a small tendency of a higher concentration in the square close to the coast (39F8) - fig. 12.

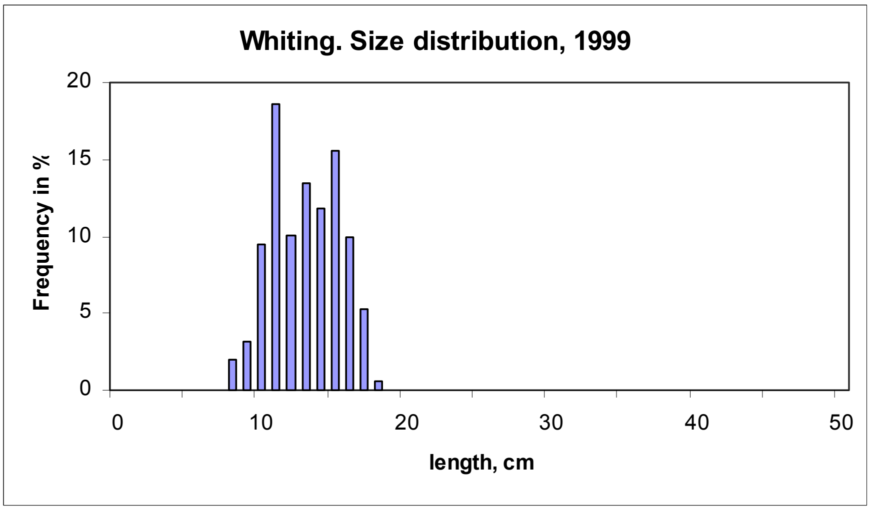


Figure 11. Size distribution of Whiting, 1999.

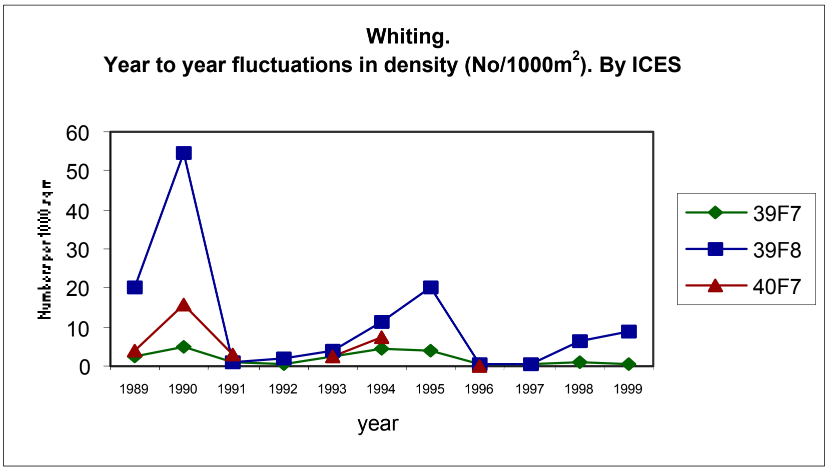


Figure 12. Variation in density for whiting 1989-99

Cod (*Gadus morhua*). This important species is found in the entire North Sea area, at depths from 5 – 500 m. According to the survey data and the fishery data the sampled area cannot be considered significant for cod. In 1999 the catch of cod in the survey samples consisted only of 1 specimen of size = 14 cm, i.e. probably belonging to age group 1 (one year old). However, it is well known that the spatial distribution of cod in the North Sea varies very much between seasons and years (see later in the chapter on artificial reefs).

Sprat (*Sprattus sprattus*). This species occurs in large shoals. During daytime sprat tends to keep close to the bottom, but during night the shoals move upwards in the water and tend to disperse. Since this species mainly is pelagic and shoal forming, the average density figure in Table 1 is probably biased. However, the significant local commercial fisheries (for oil and fish meal) for this species indicate that it is a seasonal common species in the area considered.

Herring (*Clupea harengus*). Also the herring forms large shoals, which are pelagic and frequently are found near the surface during night. In daytime the shoals stay closer to the bottom. As is the case with sprat, these diurnal vertical migrations are probably related to the availability of its food items. Herring is fished in the area considered, although the catch statistics indicate that in 1999 this species was of minor importance.

Sandeels (*Ammodytidae*). These fish normally lie buried in the bottom, when light intensity is low, i.e. during night in the summer season and for longer periods in the winter season. When emerging from the bottom to feed and spawn, the various species of sandeel become pelagic and aggregate in shoals. Due to this behaviour the density figure in table 2 is likely to be strongly biased (underestimated). Several species of sandeels (notably *Ammodytes marinus*) are represented in the locally important sandeel fishery conducted in areas around the proposed windmill park.

Grey gurnard (*Eutrigla gurnardus*). The Grey gurnard is one of the dominant species of the North Sea. It is common in most parts with a depth range being from around 10 m up to 100 m. According to survey data it seems that there may be some seasonal variation in the geographical distribution of Grey gurnard. During the winter season the species tend to concentrate in the western part of the central North Sea. In the summer season the highest densities were observed in the southern part of the North Sea, i.e. mainly south of 57° N. During the summer season this species may also be found in more shallow waters than during winter. This variation in spatial distribution may to some extent be related to preference for high water temperatures. The BTS and the SNS data are from the summer season and it is likely that the relative high densities of this species will decline in the winter season due to migration to deeper waters during winter. From table 2 it appears that the density is highest in 39F7. Fig. 13 shows that this difference is consistent for almost the whole period, which again indicate that this species is more common further from the coast.

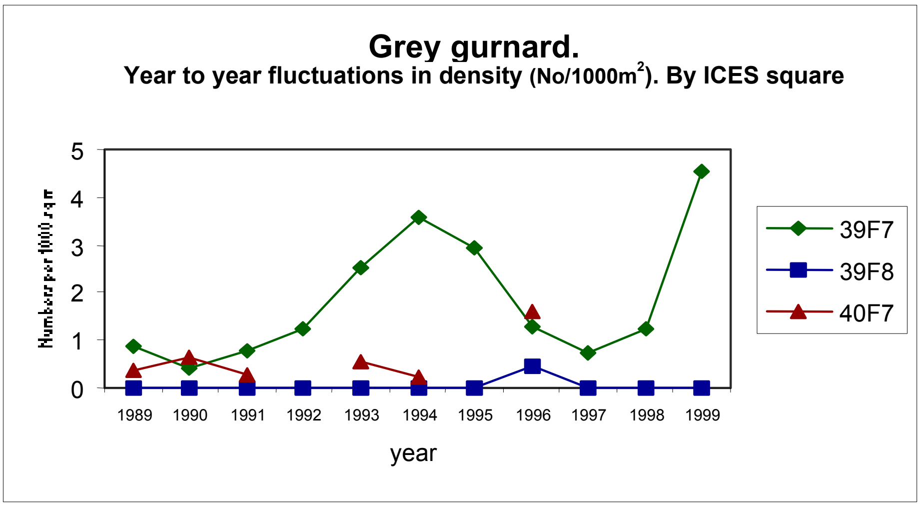


Figure 13. Variation in density for grey gurnard 1989-99

Eel pout (Zoarces viviparus). This species lives typically in shallow water and, apart for occasionally migration to slightly deeper waters during wintertime, is a very stationary species.

Common dragonet (*Callionymus lyra*). Three species of dragonets are common in the North Sea, of which the Common dragonet is the largest and most common of them. It is a typical demersal species and is frequent in coastal areas. One notes a single peak in density in 1994 only in 39F7. However, this might be due to a sampling artefact rather than a sudden increase in abundance in that year, see fig. 14

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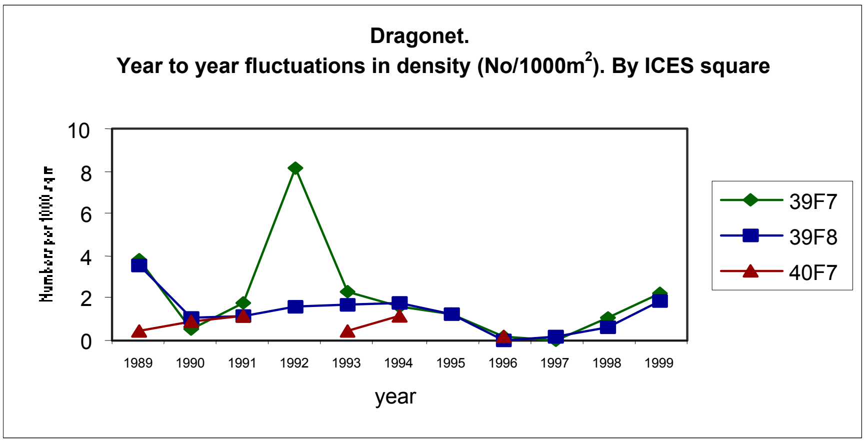


Figure 14. Variation in density for dragonet, 1989-99

Sculpins. Some species of the families *Agonidae* and *Cottidae* are abundant in the sampled area: the Hooknose and the Bullrout. These species are typical stationary and bottom dwelling species. They are of no commercial interest, but because of their abundance they must be considered important species in the area. For Hooknose the patterns in density variation between the 3 ICES squares 1989-1999 indicate a general higher abundance in 39F8, see fig. 15. As an indication of a general increase in abundance the high density in 39F8 during 1994 and 1995 should be considered cautiously. The peak might just reflect a single high density sample.

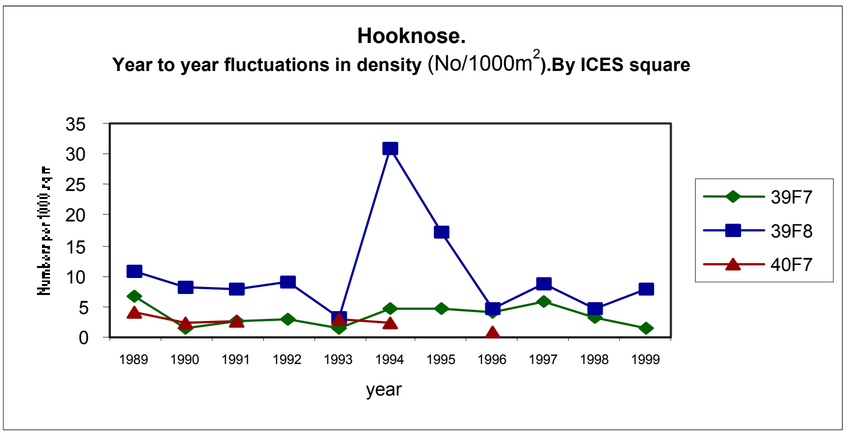


Figure 15. Variation in density for hooknose, 1989-99

Gobies. Species of the family *Gobiidae* are common in the area. The most common of the species is probably the Sand goby (*Pomatoschistus minutus*), but because of difficulties of identification the specimens have not been identified to species level. The gobies found in the area are typical shallow water species and constitute an important prey for other species. The density patterns are similar in 39F7 and 39F8 over the years, see fig. 16. Note the increase in abundance of gobies in 1997-1998 in 39F8

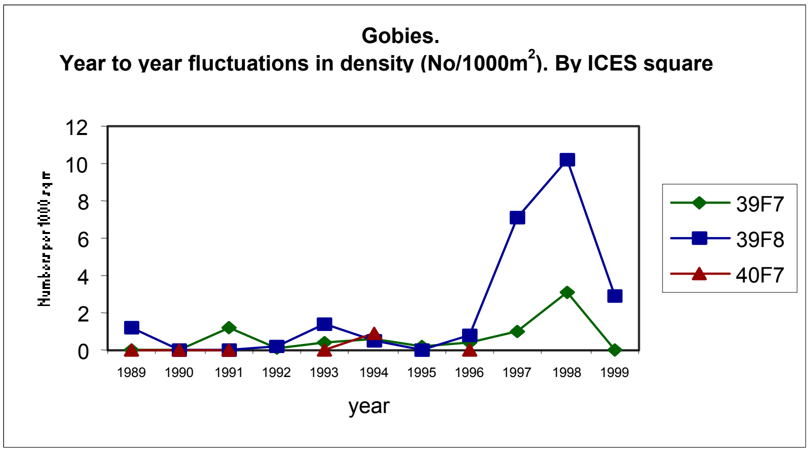
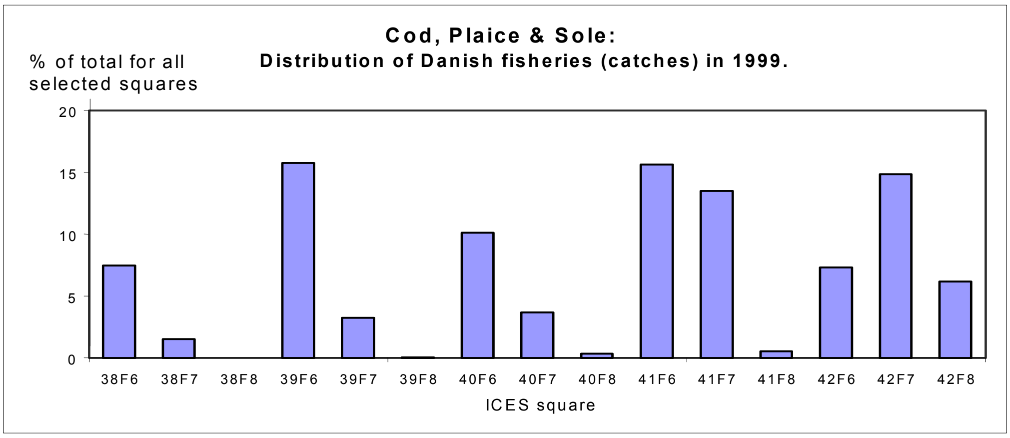


Figure 16. Variation in density for gobies, 1989-99

Fish species of special concern. For the Wadden Sea area, adjacent to the proposed windmill area, special concern has in recent years been given to species which for various reasons (for instance change of biotopes, overexploitation, human activities etc.) are believed to be either in decline or have disappeared entirely. When comparing the species listed in table 2 with the red listed species (Fricke et al. 1996), one notes five species, which are on the current red list: Grey gurnard, lesser weeverfish, snake pipefish, sea trout and lampern. The grey gurnard belongs to the common species in the area and the other species only occur in very small numbers.

4.1.3 Crustaceans and Molluscs.

Brown shrimp (*Crangon crangon*). This species is very common on sandy bottoms in all shallow coastal waters of the North Sea. It is not registered in numbers pr.m^2 in the Dutch surveys but it is known that it is distributed in the sampled area in small numbers. It is an important prey species for both sea birds and fish. This species is subject to important fisheries, especially in the Wadden Sea and the adjacent areas in the North Sea. At present an important fishing ground for the Danish brown shrimp fishery are located in the shallow water areas between the proposed windmill park and the coast. Catch data of cod, plaice, sole and brown shrimp from different squares in the North Sea are shown in figure 17. The highest catches of brown shrimp are from square 39F8 east of the windmill area. The catch of cod, plaice and sole are negligible in square 39F8. In square 39F7 which include the windmill area the catch of cod, plaice and sole are about 3% of the total North Sea catch. The brown shrimp fishery in 39F7 is only a few percentage of the total North Sea catch.



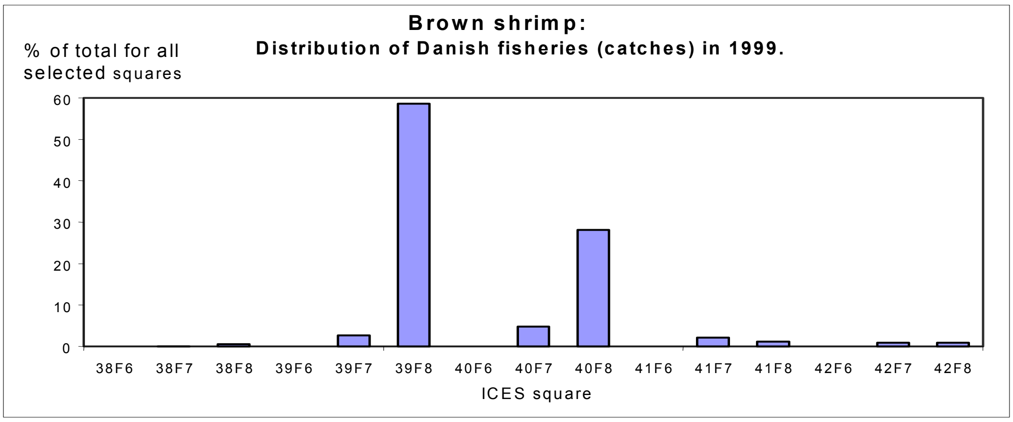


Figure 17. Danish catch of cod, plaice, sole and brown shrimp pr. square in the North Sea.

Blue mussel (*Mytilus edulis*). This species is common in those coastal areas in the North Sea, where the bottom substrate allows settlement. In the Wadden Sea this species has been and still is subject to commercial exploitation. Although this species might not be particular abundant in the proposed windmill area at present, it can be expected to increase in abundance, if concrete foundations for windmills are constructed. Experience from other localities (bridge pillars etc.) suggest that such structures improve possibilities for settlement of mussels.

Cockles (C*erastoderma edule*)**, Carpet** and **Venus clams** (Veneridae), **Trough clams** (*Mactra sp.* and *Spisula sp.*) and **Razor clams** (*Solenidae*). These species are living in the bottom. Some of the species have been exploited occasionally in this area as well as in the adjacent Wadden Sea areas. The stocks seems to fluctuate considerably due to environmental conditions in the area.

4.2 Effects of the physically presence of the windmills on the distribution of fish and shellfish.

As for whether and how the changes in environment below the sea surface due to placement of a windmill park and the cable traché in the area will affect the marine species considered, one should distinguish between short term effects and long term effects (permanent changes).

- *Short term effects.* It is very likely that during the construction period of both the windmills and the cable tracé many of the fish species mentioned above will be disturbed and disappear from the area due to temporary increased turbidity of the water, underwater water movements and other activities on the sea bottom. If the cable tracé is placed in the Grådyb area the short term effects on small flatfish in the shallow waters along Langli will be considerable. The experience is, however, that once such construction activities have finished the species affected will return rather quickly.
- *Long term effects.* The under-water changes in the windmill area will be the stone and concrete foundations of mills and possibly some minor changes in local currents. The total area of that part of the sea bed, which will be occupied by the foundations of the mills is so small (around 1000 m^2), that it can be considered insignificant. Also the total area of the proposed windmill area (27.5 km^2) is small, and the effects of any local environmental changes within this area will probably be small regarding the surroundings. If any changes of relative species abundance will be observed these are likely to be caused by factors such as *artificial reef impact* (see later in this report). The presence of the cable traché buried in the seabed is not supposed to cause any changes in the distribution of fish and crustaceans in the area.
- *Red list*. Five fish species grey gurnard, lesser weever, snake pipefish, sea trout and lampern are listed on the current red list of endangered fish species for the Wadden Sea. Taking the biology of the species into concern no impact on their distribution is expected in the Wadden Sea due to the windmill activities at Horns Rev.

5. THE ARTIFICIAL REEF EFFECT OF MARINE WINDMILL FOUNDATIONS.

5.1 Artificial reefs

The following text is compiled on the basis of the information gathered through a nationally funded project entitled "Deployment of artificial reefs for stock enhancement of lobster and the protection of nursery grounds for marine fish". The information contained in this work is utilised here to evaluate the reef impact of marine windmill foundations.

Artificial reefs are here defined as man-made constructions placed intentionally or unintentionally underwater, which function as a basis for growth and production of marine life. These constructions may, if properly designed, provide habitat for a variety of marine fauna and flora, providing food and refuge to a number of fish species and generally contribute to the biodiversity of the region. However, there are examples of artificial reefs aimed at enhancing local fish stocks which have failed their purpose, due to poor design.

The foundations of marine windmills will to all intents and purposes provide a hard substrate in an otherwise sandy-bottom habitat and fit under the definition of an artificial reef. The type of flora and fauna that may colonise these foundations depends on the size and shape of the construction, the material and the local environment. Artificial reefs have been documented to attract some fish species, but the extent to which these same structures actually enhance fish populations has not been documented. However, a few studies have documented artificial reefs as a primary food source for certain fish species.

A number of parameters including the size, height, shape, profile, scale and complexity of the structure, the material used and rugosity influence the type of flora and fauna that may settle and colonise the artificial reef. The morphological complexity of the reef, area provided and volume covered will also impact the numbers and type of fish utilising the reef to a smaller or larger extent. The complexity of the structure will be the primary factor determining what type of local fauna and flora will profit from this added hard substrate in the local environment. On the other hand, the geographic site, depth location, distance from natural reef areas, surrounding biotope, strength and nature of local currents, storm impacts and the stability of the structure and the surrounding sediment will affect population densities through physiological and reproductive constraints on colonisers. Further, temperature and salinity will prevent or favour settlement and colonisation of specific species and determine the rates of different processes. All these factors also are of importance to fish in determining the extent to which the new construction will provide suitable habitat (foraging habitat, refuge from predators or in other ways appeal to fish). In conjunction with information of fish species and fisheries in the area the impact of the reef function of the windmill foundations may be evaluated, at least at a theoretical level since empirical data is not available.

This text aims at describing the possible artificial reef impact on fish of the foundations of marine windmills to be deployed in the vicinity of Horns Rev. The windmill park will cover an area of 27,5 km² constituting a relatively large reef complex. Usually, an artificial reef complex constitutes 4-6 reef structures composed of 2 - 6 reef units built up of one, two or more types of reef elements. The reef complex of the Horns Rev windmill park is more simple consisting of 80 uniform units (equivalent to elements in this case) equidistant to each other. These high profile structures are 3.5 m in diameter forming an 8 x 10 grid, 550 metres apart. This distance between elements is larger than typically found in deployed reefs. The aspects relevant to the artificial reef functions of the foundations will be addressed in the following text.

5.2 Productive role of windmill foundations

Structure material and design are important in determining the rate and extent of biological production. The principal type of foundations being considered for Horns Rev windmills is a mono-pile structure of diameter of 3.5 m with a steel outer surface. This type of surface is in terms of 'roughness' (rugosity) comparable to that in steel structures used in connection with oil and gas facilities in the North Sea. In contrast to the jacket-like, open latticework structures of oil and gas platforms, these windmill foundations provide low structure complexity. Because of the risk of scouring events, which may cause instability and jeopardise the permanence of the windmills, a protection layer may be required around each foundation base. This protection layer is suggested to consist of stones of a size large enough to ensure stability even through storms.

This type of windmill foundation would provide a high profile, compact or closed structure of poor complexity and low rugosity. Species diversity and possibly productivity is assumed to increase with reef complexity (Wickens and Barker, 1996). Yet the complexity of this type of structure is very low. The high profile encourages a range of habitats throughout the water column allowing species to remain at their favourable depth and increase their vertical range and the hard-bottom structure in conjunction with water circulation encourages abundant biofouling and benthic hard-bottom species. However, the relatively small surface area of this compact structure provides limited habitat for biofouling and benthic hard-bottom species. An examination of biofouling around a monitoring unit placed in the Horns Rev area, before and after a storm showed a sandblasting effect of the storm on the structure. Thus the hydrography in the area will prevent any permanent biofouling and a potential benefit from providing substrate for food-chain basis for fish are negligible.

The protection layer on the other hand provides a low profile structure with high structural complexity yet low rugosity. Depending on the size of stones and the intensity of storm events, there is a probability that the peripheral stones may move or be upturned. The central stones are expected to remain unaffected. In most localities, this type of structure provides a wide range of different-sized holes and a large surface area and spatial diversification, resulting in high biodiversity. Unfortunately, the lack of a firm seabed, the possibility of regular scour and/or burial events and severe storm conditions may reduce any food-chain base benefits of this type of structure in this locality.

It is unlikely that these foundations would produce significant amounts of new production of commercially fished species. Breeding takes place elsewhere and the spawning behaviour of the major commercial species being fished in the area such as sand eel, sprat, sole and plaice do not require the presence of a reef substratum.

Concluding remarks

It is unlikely that the windmill foundations in this locality will provide any measurable food chain basis for fish species in the area since the structure design or material will permit only limited biofouling and benthic hard-bottom organisms to flourish. This is further compounded by the severe ambient hydrographical conditions. Thus it is unlikely that these foundations will contribute to increased production of the species considered.

5.3 Attractive role of windmill foundations.

Artificial reefs have been demonstrated to attract and aggregate fish (Santos et al., 1996). Fish have different affinities to hard-bottom substrate and profile structures. They may seek these structures for food, refuge, orientation or in response to other needs. These responses have been summarised under five criteria (Thierry, 1988):

rheotaxy: orientation with respect to the direction of current.
geotaxy: orientation with respect to the coast
thigomtaxy: physical contact with the reef
phototaxy: response to light
chemotaxy: response to olfactory stimuli (arbitrarily also includes response to sound)

Different fish species have different affinities to submarine structures. Further, these affinities may change during their lifestages.

Gadoids (cod fish) in particular are susceptible to being attracted to high profile structures. These include species such as whiting *Merlangius merlangus*, and cod *Gadus morhua*. In the North Sea, studies around oil and gas platforms have revealed noticeable aggregations of cod (Valdemarsen, 1979) and saithe *Pollachius virens* (Cripps & Aabel, 1995). Shoals of about 2000 saithe at densities of 3 m^{-3} and of about 100 large cod (100 cm long) at densities of 0.2 m^{-3} were observed. The windmill foundations do not exhibit the same degree of complexity as those for oil and gas platforms, which have a high profile, open latticework structure and which generate ample light-shadow effects. Thus, attraction to the windmill foundations may not be as efficient as that for complex steel structures already studied, but some degree of aggregation is expected, rendering these species more accessible to fishery if this activity is allowed close to these structures. An increase in the catch per unit effort (CPUE) relative to the surrounding area would be expected from a fishery directed at these structures. A well-documented increase in CPUE has been demonstrated for artificial reefs (Ambrose & Swarbrick, 1989) and has been described for wreck fishery around Denmark (Krog, 1999). In many cases, the larger individuals may aggregate, their presence excluding that of younger forms, increasing the economic value of the catch.

According to Byskov and Krog (pers.comm.), there is during some years a limited cod fishery using gillnets in the area around Horns Rev. This takes place during the summer period. In comparison, an increase in fish catch in the range of 5% – 4000% has been indicated from the literature (Santos et al., 1996). Providing that fishery is allowed close to and around these structures, and that the gadoids are attracted to the high profile structures, then the windmill reef complex could be a potentially fishing area.

The abundance of plaice *Pleuronectes platessa* around Horns Rev provides the basis for the important seine fishery for plaice, although this species is also caught in trawl and gillnet fishery in the area. This species, as other flatfish species are attracted to artificial reefs (Polovina & Sakai, 1989) although it is believed that they visit the reefs primarily to forage. Studies have shown that a reef height of 3 m is sufficient for demersal fish and it is recommended to deploy large areas of low profile structures for enhancing flatfish (Bohnsack et al., 1991). Therefore, the presence or absence of the protection layer around each foundation may be of importance together with the development of biofouling and hard-substrate benthic organisms on this layer. On the other hand, flatfish such as plaice, dab and sole were also found in and around gas and oil platforms (Cripps & Aabel, 1995).

The distance between the units is within the sensory range for flatfish. Flatfish such as flounder *Platichthys flesus*, sole *Solea solea* and dab *Limanda limanda* were shown to be attracted to submarine structures at distances of 600 m and flounder was shown to move between 2 reef structures as a distance of 900 m (Grove et al., 1989). In the study of Polovina and Sakai (1989), the artificial reef was shown to simply redistribute the resources without increasing the biomass and tagging experiments showed that the fish moved to and from the natural and artificial habitat. According to Bohnsack et al. (1991) the species may become more accessible to fishery, increasing their vulnerability, which in cases where the fish population is recruitment limited may have a detrimental effect. In this case the increased vulnerability may be independent on whether or not fishery is allowed in the vicinity of the marine windmill part. The impact on the exploitable biomass of plaice outside the windmill reef complex is not known.

The attractive qualities of the windmill structures may like other artificial reefs influence the migratory patterns at different temporal scales or alter migration routes for fish species. This kind of information can, however, only be elucidated from tagging studies. The windmill structures at Horns Rev, however, are not expected to have any measurable effects on migratory patterns for fish.

5.4 Concluding remarks.

Depending on the species abundant in the area and that being exploited different scenarios are envisaged. The attraction of gadoids by high profile structures may be exploited in the fisheries to gain improved access and improve the fishery efficiency as long as it is allowed close to or around the structures. The strength of the attraction is not known but is expected to have a low impact relative to for example oil and gas platforms, which have complex structures. Whether or not this would impact the cod fishery outside the windmill area is not known. The protection layer intended around the foundation base may be particularly attractive to flatfish species and these may be expected to move between the windmills as well as to and from the windmill park. An increased vulnerability to fishery is anticipated, increasing the exploitable biomass.

6. THE EFFECTS OF NOISE FROM MARINE WINDMILLS ON FISH AND MARINE MAMMALS

6.1 The windmills as sound sources

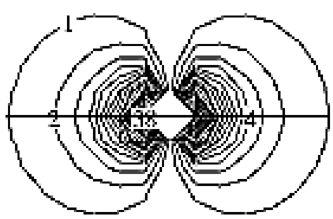
At frequencies above 2 kHz, no contributions above background noise are expected (Ødegaard & Danneskiold-Samsøe). At frequencies below 2 kHz, the windmills are expected to contribute significantly to the background noise, but at the critical low frequencies, the disturbances are practically confined to the vicinity of the mills, within a few hundred meters (Westerberg, 1994).

All sound sources have:

1. A region close to the source where the sound field has the character of a hydrodynamic *flow field*[1]
2. A region further away from the source that has the character of a *propagating sound field*[2]

The lower the frequency, the farther is the extent of the hydrodynamic region, and the weaker the production of propagating sound. For a frequency of 10 Hz, the field does not attain the character of propagating (i.e. "regular") sound until well beyond 100 m.[3] Moreover, sources[4] may—somewhat simplified—produce hydrodynamic/acoustic fields by performing either v*olume changes*, in which case they are termed *monopoles*, or by *vibrating* along an axis (without volume changes), in which case they are termed *dipoles*. Of these two types, dipoles are the least efficient in producing propagating sound, especially at low frequencies. Also, dipoles do not propagate sound equally in all directions; the radiated sound is at its strongest along the axis of vibration, but in all other directions it is weaker—proportionally to the angle to this axis—decreasing to zero in the direction perpendicular to the axis of vibration. However, a hydrodynamic flow field is present all around the dipole (Kalmijn, 1988; 1994). It is unlikely that the rigid windmill foundations undergo volume changes during operation of the mills. Rather, they are expected to vibrate, and in the low-frequency range—which is critical for fish (see below)—they are consequently expected to behave as dipole sources.

For an actual evaluation of the influence of the windmills at frequencies below 50 Hz, we may turn to Westerberg's (1994) measurements of the hydrodynamic/acoustic field from a Swedish marine windmill, *Svante 1*. Westerberg found the operating windmill to increase noise levels (up to 20 dB) in the water surrounding the mill, also in the low-frequency range. Thus, most harmonics of the fundamental frequency of 2 Hz (corresponding to the rotor-blade passage frequency) were distinguishable above ambient noise. The dominating infrasonic frequency was the 8th harmonic at 16.7 Hz.



Schematic drawing of the pressure field isolines from a dipole, which is vibrating to and fro along the horizontal axis indicated (values are arbitrary). At any point, the local flow (not shown) runs perpendicularly to the pressure isolines.

[1] Where the effect of the compressibility of water is negligible.

[2] Which owes its very existence to compressibility.

[3] For spherical monopoles, the contribution from the two phenomena is equal at a distance of $\lambda/2\pi$, with λ the wavelength of the sound. For spherical dipoles, the corresponding distance is $\lambda/1.4\pi$ (in the direction along the axis of vibration). Only at several times this distance may the hydrodynamic contributionn be ignored (Kalmijn, 1988).

[4] When they are small compared to the wavelength of the resulting sound. The wavelength is inversely proportional to the frequency.

Although the noise from the windmill thus extended into a frequency range that is very critical for fish (see below), it was only significantly above background noise in the immediate vicinity of the mill. The far-field sound level at the dominating frequency of 16.7 Hz was weak—at 300 m distance, the sound level was a mere 5 dB above background noise, in accordance with the theoretically based expectation that only the hydrodynamic, local part of the acoustic field rises significantly above background noise. However, Westerberg did not establish the field configuration of *Svant*e *1*, and—assuming a dipole configuration—the measurements may not have been made in the direction along the axis of vibration. Thus, the measurements may to some extent underestimate the noise in this direction.

Westerberg found wind not to be critical since stronger winds increased the background noise proportionally, leaving the ratio between windmill noise and background noise constant. At Horns Rev, the number of windmills is larger, and this likely means higher noise levels compared to the noise from *Svante 1*. However, the most significant contribution remains the hydrodynamic, local part of the hydrodynamic/acoustic field, and although this noise may be noticeable at longer distances, it is still a rather local phenomenon. In addition Horns Rev is a rather turbulent and noisy environment and this will reduce the relative significance of noise from the windmills.

Noise is also radiated in the frequency range 0.05–2 kHz (Westerberg, 1994; Ødegaard & Danneskiold-Samsøe, 2000), with source levels up to 74 dB re 1 µPa. However, as detailed below, noise in this frequency range is of less concern. Above 2 kHz, no noise is expected from the windmills (Ødegaard & Danneskiold-Samsøe, 2000).

6.2 Responses to sound - fish

A fundamental understanding of the fish ear and its working modes is a prerequisite for a meaningful evaluation of possible reactions to noise and vibrations.

Since biological tissue is largely sound transparent under water, the appearance of fishes (and porpoises) does not bear witness to their auditory capabilities—a set of external ears as may be seen in terrestrial animals would not serve any purpose. Instead, fish rely solely on the inner ear for hearing. The inner ear of fish somewhat resembles the inner ear of humans. Fish do not have a cochlea, though. Instead, they hear with the sensory organs which in humans serve exclusively as gravistatic organs. These sensory organs are inherently *accelerometers* (Kalmijn, 1988, 1994), and this fact is very important for the understanding of the fish ear. In its original form—as is still seen in elasmobranchs (sharks and rays), flatfish and mackerels—the fish ear is thus completely insensitive to the pressure fluctuations which we humans associate with sound and—consequently—tend to use to describe and measure sound.

Flow detection. Fundamentally, the relevant stimuli for the fish inner ear are thus gravity and any other accelerations experienced by a fish, either stemming from its own motion or from the surrounding water.[5] The most important water motions that fish encounter are the flow fields caused by the motion of other animals whether these are predators or prey (Kalmijn, 1988, 1994). These flow fields are all of a low-frequency nature depending on the size of the animal. The frequency content arising from ordinary swimming movements is usually well below 40–50 Hz. Higher frequencies are generated only in the case of abrupt movements, such as escape responses or predator attacks, but still the frequency content does not exceed 200–300 Hz.

The flow fields from moving animals have a (largely) dipolar configuration. When a fish passes through such a field from another animal, it experiences a water flow that rapidly changes in terms of both strength and spatial direction. Fish are believed to use these cues for escaping predators and for locating prey (Enger *et al.*, 1993; Kalmijn, 1988, 1994).

Sound detection. Although the fish ear in its original form is insensitive to pressure fluctuations, numerous families have developed what may be called regular hearing. This has occurred with the aid of the swim bladder. As opposed to the surrounding tissue, the gas-filled swim bladder is readily compressed and therefore influenced by sound. In a sound field, the swim-bladder wall vibrates rather strongly, and the distance to the inner ears is sufficiently small that the ears are influenced. In fact, often protrusions extend forward from the swim bladder, the most extreme case for marine fishes being the *Clupeiformes* (herring fishes), in which a gas-filled compartment resides in the middle of the ear, connected to the swim bladder only by a narrow canal.

Such mechanisms have extended the hearing range of fishes considerably, an ability that is probably used mostly for detecting vocalisations of conspecifics. Still, most fish are insensitive to frequencies above 0.5–2 kHz, although in recent years, evidence has accumulated that fish, particularly *Clupei-*

[5] Since fish are nearly neutrally buoyant, they follow uniform water movements in synchrony (unless, of course, they are actively swimming, in which case the water movements are added to the swimming-induced movements). Parenthetically, it might be noted that is a widespread conception that the *lateral line*—a system of superficial mechanoreceptors—is a *hearing* organ for low-frequency sounds. This conception is wrong—the lateral line is a flow detector (Kalmijn 1994). To stimulate the lateral-line sensory receptors, it takes a differential motion between the fish skin and the surrounding water. In other words, the fish must swim or experience a nonuniform water flow. This latter phenomenon only occurs in the immediate vicinity of sources of hydrodynamic disturbances, where steep spatial gradients of water flow exist.

formes may respond to intense ultrasound as well. Sensitivity to frequencies as high as 130 kHz has been observed (Nestler *et al.*, 1992; Mann et al., 1998; Astrup, 1999).

Responses. Despite the wide hearing range of fish taken together, they only respond consistently to sound and vibrations of either very low or very high frequency (Knudsen 1992; 1994; Nestler *et al.*, 1992). Sounds in the mid-frequency range (0.05–2 kHz) generally produce only short-term startle responses at sound onset (Knudsen, 1992, 1994; Westerberg, 1995), and since the windmills are not expected to produce ultrasound, we need mainly concern ourselves with noise of frequencies below about 50 Hz.

Low-frequency flow fields are thought to be of crucial importance for fish, since the awareness and correct interpretation of them likely mean the difference between life and death, as well as subsistence and starvation (Kalmijn, 1988; Enger *et al.*, 1993). This is probably the reason why low-frequency disturbances[6] produce such consistent behavioural responses in fish (Knudsen, 1992, 1994), and—in turn—the reason why we must concern ourselves first and foremost with the possible low-frequency contributions from the windmills, and need not worry overly about noise of higher frequencies.

Although low frequencies may be very effective for deterring fish, the spatial dimension of the windmill fields will be of a much larger size compared to the hydrodynamic fields of swimming animals. As stated above, a fish swimming through the field from another animal experiences a water flow that rapidly changes in terms of both strength and spatial direction. For the windmill fields, this will not be the case because of their larger size. Therefore, fishes in the surrounding waters will probably not be impaired in their ability to detect predators and prey. In addition, the continuous character of the windmill noise is likely to promote habituation. This may also be seen from Westerberg's (1995) observation that the Farø bridge and the Storstrøm bridge—even though they produce considerable low-frequency fields—do not act as barriers to fish migrations.[7]

In the frequency range 0.05–2 kHz, the windmills may have some negative influence on the acoustic communication between fish, but compared to the level of marine antropogenic noise in general, this influence is most likely minor.

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[6] At least when presented in a pulsed, noncontinuous mode.

[7] Westerberg did find a tendency for fish to gather upstream, though. This may signify that noise from the bridges cause an initial avoidance in the fish when they approach. The response seems to wear off, however, since many fish were found close to the bridges' pillars.

6.2.1 Concluding remarks

Fish typically respond strongly to low-frequency hydrodynamic/acoustic fields (below ca. 50 Hz). Significant noise contributions in this frequency range are expected to be confined to the immediate vicinity of the windmills, within a radius of no more than some hundreds of meters. However, because of the spatial extent of the low-frequency hydrodynamic/acoustic fields from the mills, fish will perceive them to be very differently compared to the low-frequency fields of other animals. Therefore, fish are not expected to be impaired in their ability to detect and interpret the fields from different sources (i.e. windmills or animals). Furthermore, the continuous character of the windmill noise will likely promote habituation in the fish. In the frequency range 0.05–2 kHz, fish respond only weakly, and the influence of the windmills, especially compared to the level of marine antropogenic noise in general, is most likely minor. Above 2 kHz, no noise is expected from the windmills, and this frequency range may therefore be considered of no concern. As a whole the effect of noise from the windmills are expected to be negligible.

6.3 Responses to sound - marine mammals

A number of marine mammal species can occur in the area around Horns Rev, but only harbour porpoises (*Phocoena phocoena*) and harbour seals (*Phoca vitulina*) are present in appreciable numbers within the area that can be affected by the construction and running of the marine windmill park. For this reason only these two species are considered in detail in the following.

Generally little is known about marine mammal hearing. Behavioural audiograms, *i.e.* graphical representations of how absolute hearing thresholds vary with frequency, are difficult to construct, as they require specially trained animals. Consequently, audiograms for most species are based on one or two animals, and thus the effect of individual variability can be relatively large. This individual variability can be natural as well as the result of hearing impairment in the form of temporary or permanent threshold shifts. Audiograms can also be based on what is termed "auditory evoked potentials". These AEP-audiograms represent the relative sensitivity of some part of the nervous system to different sounds and are not directly comparable with behavioural audiograms (Richardson *et al.,* 1995).

Relatively more is known about marine mammal sound production, and especially the technological advances with powerful computers in recent years have made it easier to record and analyse vocalisations by marine mammals in captivity as well as in the wild. However, there are still considerable uncertainties regarding *e.g.* whether sounds recorded around porpoises in captivity are actually produced by the animals in the wild or the result of the conditions under which the recordings were made. These caveats are important to keep in mind when evaluating the limited and sometimes conflicting information on marine mammal hearing and sound production.

6.3.1 Harbour porpoise

Sound production. Harbour porpoises use click sounds for echolocation, and early studies detected frequency components around 2 kHz and around 130 kHz (Schevill *et al*., 1969; Andersen, 1970). Later Kamminga & Wiersma (1981) reported a 20 kHz component, similar in waveform to the 130 kHz component. Amundin (1991) found evidence that the 2 kHz component was used for communication, but was unable to confirm the existence of the 20 kHz component. These studies all concentrated on frequencies above 1 kHz, and they all detected only echolocation type signals. Verboom & Kastelein (1995), studying the acoustic signals of two rehabilitated porpoises**,** confirmed the 2 kHz and the 130 kHz components and in addition found low energy components at 30 kHz and 60 kHz and a broadband component between 13 kHz and 100 kHz. More interesting, however, is their detection of whistle-like sounds with frequencies varying between 47 Hz and more than 600 Hz, not previously reported for harbour porpoises.In summary, harbour porpoises seem to use a variety of signals with frequencies spanning from around 47 Hz to above 130 kHz.

Hearing. Andersen (1970) presents the only behavioural audiogram for a harbour porpoise published so far. The best sensitivity was found between 8 and 30 kHz (below 50 dB re 1 μPa) and good sensitivity between 1 and ca.150 kHz (below 80 dB re 1 μPa). Popov *et al.* (1986) presents an audiogram based on AEP-data from 4 porpoises, suggesting peak sensitivities around 30 kHz and around 125 kHz. No studies have been published on sensitivities to frequencies below 1 kHz, but considering that porpoises produce sounds with frequencies well below 1 kHz (see above) it seems logical that they have a relatively good sensitivity below 1 kHz.

Reactions to noise. Harbour porpoises are normally considered neophobic and their reaction to disturbances is flight. They tend to change behaviour and move away from approaching vessels, sometimes at distances up to 1500 meters (Richardson *et al.,* 1995; Grøn & Buchwald, 1997), but do not generally seem to avoid areas of intense shipping activity. Their reactions to aircraft are less well documented, and in some cases it is unclear whether the animals react to noise from the aircraft or to seeing the aircraft (Richardson *et al.,* 1995). No studies on the reaction of harbour porpoises to marine windmills have been published.

6.3.1.1 Concluding remarks.

In the construction phase, noise will be expected to be generated by the construction operations (primarily the jack-up-rig ramming operations), by shipping operations (supply vessels coming and going as well as transportation within the area) and by helicopter traffic[8]. The noise generated by these sources will primarily be of low frequencies with most energy probably below 1 kHz and is not expected to affect the echolocation abilities of the porpoises. However, if porpoises use sounds with frequencies below 1 kHz for communication, this could potentially be affected by the noise sources mentioned. These noise sources are all temporary and of a localised nature, and although they will probably displace porpoises from the affected areas, it is expected that this displacement will also be temporary.

In the production phase, noise will be expected to be generated by the windmills and by helicopter traffic. The windmills are expected to generate noise above ambient levels only in frequencies below 1-2 kHz (Ødegaard & Danneskiold-Samsøe A/S). Below 500 Hz, noise from the windmills could be considerably above ambient levels. This could potentially affect the communication of porpoises in the area, if they indeed use these frequencies. Since the noise from the windmills will be continuous, the porpoises will probably develop some tolerance to the noise, but the extent of this is impossible to predict.

In conclusion, it should be expected that harbour porpoises will be displaced temporarily from an area affected by the construction of the park and the cable tracé and maybe permanently from a smaller area in the production phase. But unless the affected area is a critical habitat for porpoises, the overall effect is expected to be negligible.

6.3.2 Harbour seal

Sound production. Harbour seals produce a variety of underwater sounds, which seem to fall into one of two categories. Click like sounds have frequencies between 8 kHz and 150+ kHz with dominating frequencies of 12-40 kHz. Sounds described as roars, bubbly growls, grunts, groans and creaks have frequencies from below 100 Hz to around 4 kHz with dominating frequencies of 0.1-2 kHz (Richardson *et al.,* 1995). It has been suggested that the click like sounds are used in echolocation (Renouf *et al.,* 1980), but clear evidence for this is lacking. The low frequency sounds, which are also produced in air, are coupled to social interactions and serve as communication in various behavioural contexts (Richardson *et al.,* 1995; Riedman, 1990). Of particular importance are the

[8] It is assumed that transit flights will be at sufficiently high altitudes that the level of noise entering the water will be negligible.

350 Hz calls of the harbour seal pup, which are individually distinct and used by the mother to recognise and maintain contact with her pup (Perry & Renouf, 1988).

Hearing: Underwater behavioural audiograms for harbour seals show that they have good hearing between 1 kHz and 50 kHz, where the threshold is below 85 dB re 1 μPa (Møhl, 1968; Terhune & Turnbull, 1995). The only published data for harbour seals below 1 kHz are for one animal, whose 100 Hz threshold was 96 dB re 1 μPa (Kastak & Schusterman, 1995).

In air, the area of best sensitivity is shifted towards lower frequencies compared to underwater. Harbour Seals seem to be most sensitive around 2 kHz and 8-16 kHz where thresholds are around 45 dB re1 μPa (Møhl, 1968; Terhune & Turnbull, 1995). The threshold at 100 Hz is 90-95 dB re1 μPa (Kastak & Schusterman, 1995). In comparison, the human 100 Hz threshold is around 60 dB re 1 μPa.

It should be noted that although the in-air and underwater thresholds are given in the same units, they are not directly comparable because the acoustic impedance differs between air and water. Comparing them correctly, *i.e.* after the pressure units have been converted to intensity levels, which are not affected by acoustic impedance, reveals that the hearing sensitivity of harbour seals is better in water than in air (Richardson *et al.,* 1995).

Reactions to noise. Richardson *et al.* (1995) provides a comprehensive review of the reaction of harbour seals to noise from various sources. Most studies on the reaction of harbour seals to noise have been conducted on hauled out animals, and very little is known about the effects of noise on seals in the water. Furthermore, it has rarely been possible to determine whether the reactions recorded were to the emitted noise or were caused by a visual cue.

The reaction of hauled out seals to disturbances varies from alert postures to rushing into the water, depending on factors like ambient conditions, noise levels and type of visual cue. As newborn pups are unable to follow their mother into the water, disturbances can cause separation and may lead to the death of the pup. Aircraft flying below 120 m, helicopters below 305 m and boats approaching within ca. 100 m are mentioned by Richardson *et al.* (1995) as stimuli that will cause harbour seals to vacate their haulout sites. However, seals normally habituate rapidly to repeated stimuli that lack significant consequences for the animals (Bonner, 1982; Grøn & Buchwald, 1997). Seals in the water most often react to disturbances by moving away or by diving.

6.3.2.1 Concluding remarks

There are no haulout sites in the vicinity of the windmill park, and not many seals have been observed in the area (S. Tougaard, pers. com.). In the construction phase, noise will be expected to be generated by the construction operations (primarily the jack-up-rig ramming operations), by shipping operations (supply vessels coming and going as well as transportation within the area) and by helicopter traffic. These noise sources are all temporary and of a localised nature, and although they will probably displace seals from the affected areas, it is expected that this displacement will also be temporary. If the cable tracé is placed in the Grådyb area the effects in the construction phase will be considerable for the seals in the Langli area.

In the production phase, noise will primarily be generated by the windmills and by helicopter traffic. Since the noise from the windmills will be continuous, the seals are expected to habituate to this. In conclusion, it should be expected that harbour seals will be displaced temporarily from an area affected by the construction of the park and also temporarily by helicopter traffic in the production phase, but the overall effect is expected to be negligible.

7. THE EFFECTS OF MAGNETIC FIELDS ON FISH AND MARINE MAMMALS

7.1 Magnetic fields from cables, windmills, and transformer

According to the evaluation by Eltra (2000), significant magnetic fields—i.e. with field strengths comparable to the geomagnetic field of 30–50 µT—may be expected only at distances less than 1 m from the structures. Thus, at 100 m (horizontal) distance, the magnetic field around a 150 kV single-conductor PEX cable is two orders of magnitude smaller than the geomagnetic field; for the other cable types in question, the field is 3–4 orders of magnitude smaller.

In windmills with steel housings, magnetic fields from the mills themselves are practically non detectable outside the mill; at 1 m distance, mills with concrete housings have weak magnetic fields of less than 0,20 µT, i.e. 2 orders of magnitude weaker than the geomagnetic field.

7.2 Responses to magnetic fields in fish

7.2.1 Cartilaginous fishes (sharks and rays).

Water currents flowing through - as well as fish swimming through - the Earth's magnetic field generate inductive electric fields (Kalmijn, 1974). *Cartilaginous fishes* (sharks and rays) possess electroreceptors—extremely sensitive sensory organs for detecting the electric fields of e.g. prey. Close to the structures associated with the windmill park, where the magnetic field strength approaches the geomagnetic field, the inductive electric fields will thus be altered. It has been suggested that sharks and rays utilise the inductive electric fields to navigate (Kalmijn, 1974), and this ability may, of course, be slightly influenced in the vicinity of the cable. As for detection of prey, however, sharks and rays normally operate in the presence of the Earth's magnetic field, and the introduction of fields from the windmill park will not impair their ability to detect prey.

7.2.2 Detection of magnetic fields in *bony fishes.*

While the detection of magnetic fields by cartilaginous fishes rests firmly on principles of classical physics, the evidence for magnetoreception in bony fishes is much less compelling. The magnetic sense is proposed to be based on magnetite particles, but a magnetoreceptor has thus far evaded identification. Walker *et al.* (1997), however, for the first time present some experimental support for the identification of a candidate magnetoreceptor (associated with the olfactory organ), but evidence remains patchy compared to knowledge of classical sensory systems. Therefore, possible consequences of magnetic fields from the windmill park are difficult to predict, but given the weak fields in question, they are not expected to have an appreciable influence.

7.2.3 Concluding remarks

Magnetic fields from cables, cables tracé and windmills and offshore transformer station may be expected to reach geomagnetic field-strength levels only in the immediate vicinity of these structures, at distances no more than 1 m. Cartilaginous fishes (sharks and rays) are, by way of their electroreceptive sense organs, able to detect magnetic fields, and they may use the geomagnetic field for navigation. For bony fishes, a true magnetic sense has been proposed, but the evidence is much less compelling. Thus, the weak magnetic fields from the marine windmill park are not expected to pose a serious problem.

7.3 Marine mammals

Live strandings of a number of toothed as well as baleen whales have been correlated with local geomagnetic anomalies (Kirschvink *et al.,* 1986) or with disruptions in the normal patterns of daily geomagnetic fluctuations (Klinowska, 1986), suggesting that cetaceans are capable of sensing geomagnetism and of using geomagnetic cues for navigation. This could explain how some cetacean species are able to undertake highly accurate long-distance migrations across apparently featureless seas. However, a suitable system for reception of geomagnetic information in cetaceans has not yet been identified, despite findings of magnetite in the head of common dolphins (Zoeger *et al.,* 1981).

Harbour porpoises were not found by Kirschvink *et al.* (1986) to live-strand consistently at either geomagnetic minima or maxima, suggesting that they may not depend on geomagnetic cues for navigation. Harbour porpoises normally occur in relatively shallow waters on the continental shelves, where a number of alternative cues, *e.g.* temperature, salinity and bathymetry, perhaps are more efficiently used for navigation.

It should be noted, however, that geomagnetic intensity variations of less than 50 nT according to Kirschvink *et al.* (1986) are enough to influence stranding locations for some cetacean species. If harbour porpoises are using geomagnetic cues for navigation, the magnetic fields created by the power transmission cables (Eltra, 2000) could influence navigation for these animals.

There are no indications in the literature that seals should be sensitive to magnetic fields.

7.3.1 Concluding remarks

It does not appear likely that the magnetic fields generated by the power transmission cables will have any detectable effects on the harbour porpoises and seals in the area.

8. DANSK RESUMÉ OG KONKLUSION

Fisk og skaldyr: Beskrivelsen af fiskefaunaen i Horns Rev området er baseret på fangstdata indsamlet årligt i perioden 1989-1999 med trawlredskaber af det Hollandske Institut for Fiskeriforskning. De almindeligste arter er ising, rødspætte, panserulk, hvilling, stribet fløjfisk og grå knurhane. Den relative mængde, udtrykt som antal fisk/1000m^2, er opgjort for i alt 42 forskellige fiskearter i og udenfor mølleområdet. Der synes at være visse forskelle i udbredelsen af rødspætte, panserulk, hvilling og kutlinger områderne imellem, dog er der store variationer fra år til år i de enkelte områder. Hesterejer er relativt fåtallige i selve mølleområdet, men mere talrige øst for møllerne.

Effekten af vindmøllerne: Beskrivelsen af den effekt havmøllerne kan have på fisk, skaldyr og marine pattedyr er i det følgende opdelt i**:** **1**) forandringer i havbunden*,* **2**) kunstige rev effekter*,* **3**) effekter af støj fra møllerne samt **4**) effekter forårsaget af magnetiske felter.

1. *Forandringer i havbunden.* Der bør i forbindelse med *effekter* skelnes mellem *korttids* effekter *og langtids* effekter (vedvarende ændringer). *Korttid*: I byggefasen vil mange fiskearter og de marine pattedyr blive forstyrret og forsvinde fra byggeområdet, hvor der vil være støj, trafik, ændrede bundforhold og aktiviteter på bunden. Såfremt kabeltracé føres gennem Grådyb-området, må der forventes store forstyrrelser dels for sælerne på Langli og dels på yngel af fladfisk i det lavvandede område op mod Langli. Erfaringen er imidlertid, at ved afslutningen af sådanne midlertidige forstyrrelser, vil dyrene vende tilbage til områderne. *Langtidseffekter:* De fysiske ændringer, der vil ske i mølleområder, er etableringen af fundamenterne omkring møllerne, samt mindre ændringer i lokale strømforhold. Arealet, der bliver benyttet til fundamenter er på ca. 1000m^2, hvilket stort set antages at være uden betydning for udbredelsen af fisk og skaldyr. Den fysiske tilstedeværelse af kabler og kabeltracé, der er nedgravet i havbunden, antages ikke at ændre på udbredelsen af fisk og skaldyr. Blandt de fiskearter, der forekommer i mølleområdet er fem arter (grå knurhane, lille fjæsing, snippe, havørred og flodlampret), der står på den internationale rødliste over truede fiskearter i Vadehavet. Bygningen af havmøllerne forventes ikke at have nogen effekt på de pågældende arters udbredelse i Vadehavet.

2. Kunstige rev effekter. Fundamenter til havmøller vil i nogen udstrækning fungere som kunstige rev. Påvirkningen af den lokale fiskefauna kan ske enten i form af øget *produktivitet* eller i form af simpel *tiltrækning. Produktivitet:* Fundamenterne vil fremstå som relativt simple kunstige rev i samme indbyrdes afstand, bestående af ens elementer af simpel konstruktion. Etablering af en flora og fauna, der kan øge mængden af fødeemner for fisk, er i høj grad bestemt af materialernes struktur samt de hydrografiske forhold i området. På baggrund af disse forhold i Horns Rev området antages det, at havmøllerne ikke vil tilføre området en significant øgning i produktiviteten. *Tiltrækning:* Mange fiskearter bliver i høj grad tiltrukket af revstrukturer, vrag o.lign. Især torskefisk findes ofte tæt på stenrev og vrag. Møllerne vil derfor virke tiltrækkende på torskefisk i området, der dog ikke synes at rumme en særlig tæt bestand. Fladfisk tiltrækkes også af undervandsfundamenterne, og de vil flytte sig mellem møllerne. Såfremt der tillades fiskeri i mølleområdet, kan der blive tale om forbedrede muligheder for visse typer af fiskeri.

3. *Effekter af støj fra møllerne.* I byggefasen må der forventes støj fra de forskellige byggeaktiviteter samt fra skibstrafik og helikoptere. Den støj, der dannes fra disse kilder, vil primært være lavfrekvent under 1 kHz. Støjen vil være midlertidig, og selv om den muligvis vil skræmme fisk og pattedyr væk fra stærkt påvirkede områder, forventes det, at en sådan påvirkning forsvinder, når byggefasen afsluttes. I produktionsfasen vil der være støj fra vindmøllerne samt fra helikoptere. Møllerne forventes kun at producere støj over baggrundsstøjen i frekvenser under 1-2 kHz. Under 500 Hz kan det forventes, at der produceres støj væsentligt over baggrundsstøjen. Dette kan muligvis forstyrre marsvinenes kommunikation, såfremt de benytter disse frekvenser, hvilket ikke er klarlagt til bunds. Da støjen fra møllerne vil være mere eller mindre kontinuerlig, vil marsvinene sandsynligvis udvikle en tolerance over for støjkilden. Graden af en sådan tilvænning er det ikke muligt at forudse. Fisk reagerer normalt kraftigt på lavfrekvente svingninger under 50Hz. Væsentlige støjkilder i dette frekvensområde forventes kun at forekomme indenfor en radius af ca. 100 m fra møllerne. På grund af den store rumlige udstrækning af den lavfrekvente lyd fra møllerne vil svømmende fisk dog registrere dem som meget forskellige fra de rumligt langt mindre lavfrekvente svingninger fra andre dyr. Det forventes derfor ikke, at fisk vil miste deres evne til at adskille lyd fra de forskellige kilder (vindmøller eller fisk). Da lyden endvidere er mere eller mindre kontinuerlig fra møllerne, forventes en vis tilvænning. I området fra 50 Hz til 2 kHz med kildestyrker op til 74 dB re 1 μPa reagerer fisk kun svagt, samtidig med at lyden fra møllerne sammenlignet med andre menneskeskabte lyde i området er meget svag. Over 2 kHz forventes ingen støj fra møllerne. Konkluderende må det forventes, at fisk og marine pattedyr vil forsvinde midlertidigt fra påvirkede områder i byggefasen og muligvis permanent fra mindre områder i produktionsfasen. Selv om et sådant område er en kritisk habitat for marsvin, vil den overordnede effekt være ubetydelig. Der er ingen landgangsplads for sæler i mølleområdet, og da der kun er observeret få individer, forventes der ingen lydeffekt på sælbestanden.

4. Effekter forårsaget af magnetiske felter. De magnetiske felter omkring kabler, kabeltracé og undervandstransformere forventes indenfor en afstand af 1 m at blive af samme størrelsesorden som jordmagnetismen. Bruskfisk (hajer og rokker) er i stand til at registrere magnetiske felter, og benytter muligvis jordmagnetismen til navigation. Da felterne har så ringe udstrækning, forventes de ikke at genere eventuelle hajer og rokker i område. Hos benfisk er der ikke overbevisende påvist magnetoreceptive organer, hvorfor en effekt af de svage felter omkring kabler og kabeltracé ikke forventes at blive noget problem for fiskene i området. Der findes ikke iagttagelser af, at sæler skulle være følsomme overfor magnetfelter, ligesom det ikke er sandsynligt, at der vil være en målbar effekt på marsvin forårsaget af de magnetiske felter, der genereres af vindmølleparken.

9. REFERENCES

Ambrose, R.F., Swarbrick, S.L. 1989. Comparison of fish assemblages on artificial and natural reefs off the coast of southern California. Bull. Mar. Sci., 44: 718-733.

Amundin, M. 1991. Sound production in odontocetes, with emphasis on the Harbour Porpoise, *Phocoena phocoena*. PhD-dissertation, University of Stockholm, 128 pp. + plates.

Andersen, S. 1970. Auditory sensitivity of the harbour porpoise *Phocoena phocoena*. *Invest. Cetacea* 2:255-259.

Astrup, J. (1999): Ultrasound detection in fish - a parallel to the sonar-mediated detection of bats by ultrasound-sensitive insects? *Comp. Biochem. Physiol.* A 124, 19–27.

Bohnsack, J.A., Johnson, D.L., Ambrose, R.F. 1991. Ecology of artificial habitats and fishes. In: Seaman, W. & L.M. Sprague (Eds.) Artificial habitats for marine and freshwater fisheries. Academic Press, San Diego, California: 61-107.

Bonner, W.N. 1982. *Seals and man. A study of interactions*. University of Washington Press, Seattle, WA, 170 pp.

Brocken F. and I. de Boois, 2000. Dutch beam trawl survey data for the Horns Rif area. RIVO Report C004/00. Netherlands Institute for Fisheries Research.

Cripps, S.J., Aabel, J.P. 1995. DPI –Fish survey using R.O.V. data. RF-Rogaland Research Report No. RF-95/301. Stavanger, Norway. 12 p.

Eltra (2000): Beregning og måling af magnetfelter omkring kabler og vindmøller. Internt notat 2000-238.

Enger, P. S., Karlsen, H. E., Knudsen, F. R. & Sand, O. (1993): Detection and reaction of fish to infrasound. *ICES mar. Sci. Symp.* 196, pp. 108–112.

Fricke, R. et al.(1996): IX. Red list of Lampreys and Marine Fishes of the Wadden Sea. Helgoländer Meeresunters. 50, suppl.,101-105.

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

Grøn, P. & E. Buchwald.1997. Effekter af hurtigfærgesejlads på havfugle, sæler og marsvin. Bio/consult as & Carl Bro as for Skov- og Naturstyrelsen, 91 pp + appendices.

ICES, 1997. Description and evaluation of the International Beam Trawl Surveys of the European continental shelf. Theme Sessions on the Synthesis and Critical Evaluation of Research Surveys: ICES CM 1997/Y:23. 7pp.

Kalmijn, A. J. (1974): The Detection of Electric Fields from Inanimate and Animate Sources Other Than Electric Organs. In: *Handbook of Sensory Physiology*, vol. III/3 (ed. A. Fessard) pp. 147–200. New York. Springer-Verlag.

Kalmijn, A. J. (1988): Hydrodynamic and Acoustic Field Detection. In: *Sensory Biology Of Aquatic Animals* (eds. J. Atema, R.R. Fay, A.N. Popper, W.N. Tavolga) pp. 83–130. New York. Springer-Verlag.

Kalmijn, A. J. (1994): Near-field acoustic detection. I. Physical principles and biological relevance. *Sensory Systems* 8(3–4), pp. 202–209.

Kamminga, C. & H. Wiersma. 1981. Investigations on cetacean sonar II. Acoustical similarities and differences in odontocete sonar signals. *Aquat. Mamm.* 8(2):41-62.

Kastak, D. & R.J. Schusterman 1995. Aerial and underwater hearing thresholds for 100 Hz pure tones in two pinniped species. *In*: R.A. Kastelein, J.A. Thomas & P.E. Nachtigall (eds). *Sensory systems of aquatic mammals.* De Spil Publishers, Woerden, The Netherlands.

Kirschvink, J.H., A.E. Dizon, & J.A. Westphal. 1986. Evidence from strandings for geomagnetic sensitivity in cetaceans. *J. exp. Biol.* 120:1-24.

Klinowska, M. 1990. Geomagnetic orientation in cetaceans: behavioural evidence. *In*: J.A. Thomas & R.A. Kastelein (eds). *Sensory abilities of cetaceans.* Plenum Press, New York.

Knudsen, F.R., Enger, P.S. & Sand, O. (1992): Awareness reactions and avoidance responses to sound in juvenile Atlantic salmon, *Salmo salar* L.. *J. Fish Biol.* 40, pp. 523–534.

Knudsen, F.R., Enger, P.S. & Sand, O. (1994): Avoidance responses to low frequency sound in downstream migrating Atlantic salmon smolt, *S. salar*. *J. Fish Biol.*. 45, pp. 227–233.

Krog, C. 1999. Vrag og revfiskeri i Kattegat. In: J.G. Støttrup (Ed.) Kortlægning af stenrev, stenfiskeri og fiskeri på hårdbund samt metoder til videnskabelige undersøgelser af rev og hårdbund. DFU-report nr. 63-99.

Mann, D.A., Lu, Z, Hastings, M.C., Popper, A.N. (1998): Detection of ultrasonic tones and simulated dolphin echolocation clicks by a teleost fish, the American shad (*Alosa sapidissima*). *J. Acoust. Soc. Am.* 104, pp. 562–568.

Møhl, B. 1968. Auditory sensitivity of the common seal in air and water. *J. Aud. Res.* 8(1):27-38.

Nestler, J. M., Ploskey, G. R., Pickens, J., Menezes, J. & Schilt, C. (1992): Responses of Blueback Herring to High-Frequency Sound and Implications for Reducing Entrainment at Hydropower Dams. *N. Am. J. Fish. Man.* 12(4), pp. 667–683.

Perry, E.A. & D. Renouf. 1988. Further studies of the role of harbour seal (*P. vitulina*) pup vocalizations in preventing the separation of mother-pup pairs. Can. J. Zool. 66(4):934-938.

Polovina, J.J. 1991. Fisheries applications and biological impacts of artificial habitats. In: Seaman W. & L.M. Sprague (Eds.) Artificial habitats for marine and freshwater fisheries. Academic Press, San Diego, California: 153-176.

Polovina, J.J., Sakai, I. 1989. Impacts of artificial reefs on fishery production in Shimamaki, Japan. Bull. Mar. Sci., 44: 997-1003.

Popov, V.V., T.F. Ladygina & A.Ya. Supin. 1986. Evoked potentials of the auditory cortex of the porpoise, *Phocoena phocoena*. *J. Comp. Physiol*. A 158(5):705-711.

Renouf, D., G. Galway & L. Gaborko. 1980. Evidence for echolocation in harbour seals. *J. Mar. Biol. Assoc. U.K.* 60(4):1039-1042.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme & D.H. Thomson. 1995. *Marine mammals and noise*. Academic Press, San Diego, 576 pp.

Riedman, M. 1990. The Pinnipeds. Seals, Sea Lions, and Walruses. University of California Press. Berkeley, Los Angeles, Oxford. 439 pp.

Riedman, M. 1990. *The Pinnipeds. Seals, Sea Lions, and Walruses*. University of California Press. Berkeley, Los Angeles, Oxford. 439 pp.

Santos, M.N., Monteiro, C.C., Lassèrre, G. 1996. Finfish attraction and fisheries enhancement on artificial reefs: a review. In: Jensen, A.C. (Ed.) European artificial reef research. Proceedings of the 1st EARRN conference, Ancona, Italy, March 1996. Pub. Southampton Oceanography Centre: 97-114.

Schevill, W.E., W.A. Watkins & C. Ray. 1969. Click structure in the porpoise, *Phocoena phocoena*. *J. Mammal.* 50(4):721-728.

Terhune, J. & S. Turnbull. 1995. Variation in the psychometric functions and hearing thresholds of a harbour seal. *In*: R.A. Kastelein, J.A. Thomas & P.E. Nachtigall (eds). *Sensory systems of aquatic mammals.* De Spil Publishers, Woerden, The Netherlands.

Thierry, J.-M. 1988. Artificial reefs in Japan – A general outline. Aquacult.Engineering, 7: 321-348.

Van Beek, F., 1997. Recruitment surveys on juvenile plaice and sole in continental nurseries in the North Sea by the Netherlands. ICES C.M. 1997/Y:30, Theme Session Y. 25 pp.

Verboom, W.C. & R.A. Kastelein. 1995. Acoustic signals by Harbour porpoises (*Phocoena phocoena*). *In:* P.E. Nachtigall, J. Lien, W.W.L. Au & A.J. Read (eds). *Harbour porpoises – laboratory studies to reduce bycatch*. De Spil Publishers, Woerden, The Netherlands.

Valdemarsen, J.W. 1979. Behaviour aspects of fish in relation to oil platforms in the North Sea. ICES C.M., B:27.

Walker, M.M., Diebel, C.E., Haugh, C.V., Pankhurst, P.M., Montgomery, J.C., Green, C.R. (1997): Structure and function of the vertebrate magnetic sense. *Nature* 390, pp. 371–376.

Westerberg, M. (1994): Fiskeriundersökningar vid havsbaserat vindkraftverk 1990–1993. Rapport 5 - 1994. 44 pp. Jönköping: Göteborgsfilialen, Utredningskontoret i Jönköping, Sweden National Board of Fisheries.
Westerberg, M. (1995): Undervattensbuller och fisk. *TemaNord* 513, pp. 97–109.
Wickens, J., Barker, G. 1996. Quantifying complexity in rock reefs. In: Jensen, A.C. (Ed.) European artificial reef research. Proceedings of the 1st EARRN conference, Ancona, Italy, March 1996. Pub. Southampton Oceanography Centre: 423-430.
Zoeger, J., J.R. Dunn & M. Fuller. 1981. Magnetic material in the head of a common Pacific dolphin. *Science* 213:892-894.
Ødegaard & Danneskiold-Samsøe A/S (2000): Havvindmøller – VVM. Støjundersøgelse – undervandsstøj. Report 00.792

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