Catherine Zucco, Wolfgang Wende, Thomas Merck,
Irene Köchling and Johann Köppel (eds.)

Ecological Research on Offshore Wind Farms: International Exchange of Experiences

PART B: Literature Review of Ecological Impacts

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Cover Pictures (clockwise): Sea gull, research platform, benthic community (Krause & Hübner, BfN); Common Seal (Wollny-Goerke, Hamburg); windfarm Rønland (Steinhauer, TU Berlin); windfarm Nysted (background) (Krause & Hübner, BfN)

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Literature Review of Offshore Wind Farms with Regard to Seabirds

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1 Summary

With the prospect of many offshore wind farms planned in sea areas of north-western Europe, there is an increasing demand for information about their impact on the marine environment. Along with marine mammals and migrating birds, seabirds are in the focus of interest for scientists as well as for the public. In order to provide a comprehensive basis for the assessment of possible impacts from wind farms at sea, this report summarises the results of seabird studies conducted at already existing offshore wind farms (mainly Utgrunden and Yttre Stengrund in Sweden and Tunø Knob, Horns Rev and Nysted in Denmark) and discusses the extent and quality of the studies. Relevant results from coastal wind farms and other technical activities at sea are taken into account as well. The three main effects possibly affecting seabirds are: habitat loss due to disturbance, barrier effects, and fatal collisions.

According to recent studies, six out of the 35 seabird species regularly living in German waters strongly avoid offshore wind farms (Red-throated Diver, Black-throated Diver, Gannet, Common Scoter, Guillemot, Razorbill), and one other species (Long-tailed Duck) was recorded which showed much lower numbers in wind farm areas after construction than before. Seven species occur within wind farms which do not show any obvious effects, and three gull species even increased in numbers compared to the pre-construction period. For 18 seabird species, it is not known how and whether the wind farms affect their habitat use. Those species which do not occur in wind farm areas suffer habitat loss greater than the wind farm area itself, due to the distance they keep from the turbines. Physical habitat loss due to the introduction of a hard bottom fauna on foundations and scour protections seems to be of minor importance, but it is also not known whether, and if so to what extent, seabirds will make use of this new food supply, and also of attracted fish.

Information about flying seabirds is mostly restricted to migrating birds, which may behave differently to seabirds during local movements, such as foraging flights or flights to and from roosts. It appears that eight species (the same as those mentioned in the context of habitat loss, and also the Velvet Scoter and the Black Guillemot) commonly fly detours instead of crossing offshore wind farms. Detours were also noted for another four species, but it is not clear whether this happens regularly. A total of 15 species (mostly gulls and terns, but also staging Long-tailed Ducks and Red-breasted Mergansers) were found to fly through wind farms commonly; no information is available for eight species. Detours, especially if flown regularly, increase the energy consumption of seabirds, and it is even possible that the habitat fragmentation caused by the technical barriers will lead to their giving up certain sea areas.

Although one collision of Eiders was witnessed at a Swedish offshore turbine, no other information about mortality from collisions at offshore wind farms is available. As 13 seabird species belonging to different systematic groups were found as casualties at coastal wind farms, seabirds must fundamentally be regarded as vulnerable to collisions. However, collision rates, and hence estimates of additive mortality, remain to be investigated in future.

In addition to direct mortality, possibly occurring due to collisions, indirect effects may impact the population sizes of those seabird species which avoid offshore wind farms. If density-dependent effects lead to lower energy intake rates in replacement habitats after displacements from wind farm areas, the mortality rate should increase. In addition, carry-over effects may have negative impacts on the reproduction rate because of a possible connection between poor body condition on arrival and subsequent breeding success.

Proposed methodologies for the impact assessment at offshore wind farms are reviewed briefly and evaluated with respect to the recent results concerning seabirds at operating turbines. In general, assessment procedures can be improved by concentrating on those species which avoid wind farms. In addition, avoidance distances and thus the necessary sizes of buffer zones are now better known. However, as collision rates, effects of increased seabird densities at sea and possible habituation effects (most studies so far cover only one or two years of the operational period) are largely unknown, no methodologies yet exist which might help to fully assess these effects.

As the population sizes of seabirds are the comparative basis for the assessment of impacts, possible effects of offshore wind farms must be addressed in a cumulative approach, which cannot be restricted to other wind farms alone, but which must also consider such factors as disturbance and displacement by ship traffic and habitat loss due to sand and gravel extraction.

Open questions remain as to the behaviour of seabird species not covered by the recent studies and to seabird behaviour during adverse weather conditions (e.g. storms), when visibility and manoeuvrability may be negatively affected. In general, it appears that more direct observations (e.g. ship-based) should be undertaken in order to study avoidance and feeding behaviour of seabirds within wind farms. Furthermore, monitoring of prey species would help to get a better understanding of the distribution of seabirds in and around wind farms. However, in order to learn more about the impact of displacement and barrier effects on population sizes and population dynamics, fundamental studies of density effects in overwintering seabirds are essential.

2 Zusammenfassung

Mit der fortschreitenden Planung von Windparks in Seegebieten Nordwest-Europas besteht wachsender Bedarf von Kenntnissen über den Einfluss solcher Anlagen auf die Meeresumwelt. Neben Meeressäugetieren und Zugvögeln stehen dabei Seevögel im Mittelpunkt des Interesses, sowohl bei Wissenschaftlern als auch in der Öffentlichkeit. Als Basis für die Bewertung von möglichen Auswirkungen von Offshore-Windparks werden in diesem Bericht die Ergebnisse von relevanten Studien über Seevögel an bereits in Betrieb befindlichen Windenergieanlagen auf See (vor allem Utgrunden und Yttre Stengrund in Schweden sowie Tunø Knob, Horns Rev und Nysted in Dänemark) zusammengefasst, bewertet und diskutiert. Relevante Ergebnisse aus Windparks an der Küste bzw. in Küstennähe und von anderen technischen Eingriffen auf See werden ebenfalls berücksichtigt. Die drei wichtigsten Effekte, die wahrscheinlich auf Seevögel einwirken, sind Lebensraumverlust durch Scheuchwirkung, Barrierewirkung und tödliche Kollisionen.

Von den 35 regelmäßig in deutschen Gewässern (Hoheitsgewässer und Ausschließliche Wirtschaftszone) lebenden Seevogelarten zeigen nach bisherigen Ergebnissen sechs eine starke Meidung von Offshore-Windparks (Sterntaucher, Prachttaucher, Basstölpel, Trauerente, Trottellumme, Tordalk). Zudem kamen Eisenten in Windparks in niedrigerer Zahl vor als im selben Gebiet vor dem Bau der Anlagen. Sieben Arten kommen innerhalb von Windparks vor, ohne dass auffällige Effekte zu erkennen waren. Im Vergleich zur Zeit vor der Errichtung der Windenergieanlagen nahmen drei Möwenarten sogar zu. Für 18 der 35 Seevogelarten ist allerdings bisher unbekannt, inwiefern Lebensraumverlust durch Offshore-Windparks auftreten kann. Bei denjenigen Arten, die Windparks meiden, ist der nicht mehr nutzbare Lebensraum größer als die Windparkfläche selbst, da auch zu den am Rand stehenden Anlagen ein

Abstand eingehalten wird. Ein Verlust von Lebensraum durch die Einführung von Hartsubstrat (Fundamente und umgebende Schüttung) scheint dagegen unbedeutend zu sein. Bisher ist aber nicht bekannt, ob und in welchem Ausmaß Seevögel die neu entstandene Hartbodenfauna bzw. von ihr angelockte Fische als Nahrung nutzen.

Informationen über fliegende Seevögel beschränken sich zumeist auf ziehende Vögel, während das Verhalten bei lokalen Flugbewegungen (z. B. Nahrungs- und Schlafplatzflüge) weniger bekannt ist. Allem Anschein nach vermeiden es acht Arten (dieselben wie bei Lebensraumverlust, zusätzlich Samtente und Gryllteiste), Offshore-Windparks zu durchqueren und umfliegen diese stattdessen. Umwege wurden bei weiteren vier Arten festgestellt, doch ist nicht klar, wie regelmäßig diese auftreten. Insgesamt 15 Arten durchquerten für gewöhnlich Windparks, vor allem Möwen und Seeschwalben, aber auch in den entsprechenden Gebieten rastende Eisenten und Mittelsäger. Für acht Arten liegen keine diesbezüglichen Informationen vor. Umwege, besonders wenn sie regelmäßig in Kauf genommen werden müssen, erhöhen den Energieverbrauch der Seevögel. Außerdem ist denkbar, dass die technischen Barrieren zu Habitatfragmentierung führen und deshalb bestimmte Seegebiete als Lebensraum aufgegeben werden.

Außer der Beobachtung einer Kollision von ziehenden Eiderenten an einer schwedischen Windenergieanlage gibt es keine weiteren Informationen über Mortalität durch Kollisionen in Offshore-Windparks. Weil in küstennahen Windparks 13 verschiedene Seevogelarten aus verschiedenen systematischen Gruppen als Kollisionsopfer festgestellt wurden, müssen Seevögel grundsätzlich als kollisionsgefährdet eingestuft werden. Messungen tatsächlicher Kollisionsraten sowie Schätzungen zur hierdurch entstehenden additiven Mortalität und ihrer Wirkung auf Seevogelpopulationen sollten zukünftig vorrangig durchgeführt werden, um so fundierte Bewertungen der Auswirkungen von Kollision zu ermöglichen.

Zusätzlich zu direkter Mortalität durch Kollisionen können Populationen derjenigen Seevögel, die Offshore-Windparks meiden, von indirekten Einflüssen betroffen sein. Falls nach der Aufgabe der Windparkfläche dichteabhängige Effekte zu geringerer Energieaufnahme in Ersatzlebensräumen führen, könnte die Mortalitätsrate steigen. Da der Reproduktionserfolg – wie bei vergleichbaren Vogelarten gezeigt – mit der Körperkondition im Winterquartier und während des Heimzuges zusammenhängen kann, ist auch eine negative Beeinflussung der Populationsdynamik auf Seiten der Fortpflanzung denkbar.

Methoden, die zur Bewertung der Einflüsse von Offshore-Windparks auf Seevögel vorgeschlagen wurden, werden im Licht der Ergebnisse operierender Windparks zusammenfassend betrachtet. Grundsätzlich gewinnen diese Verfahren an Wert, wenn sie sich auf die Windparks vermeidenden Arten konzentrieren. Außerdem erlaubt eine inzwischen bessere Kenntnis von zu Windenergieanlagen eingehaltenen Abständen eine bessere Abschätzung der Größe von Pufferzonen. Da aber weder Kollisionsraten noch Gewöhnungseffekte – die meisten Studien beziehen sich nur auf die ersten 1-2 Jahre der Betriebsphase – bekannt sind, gibt es bisher keine Methode, die langfristige Folgen für Seevogelpopulationen vorhersagen kann.

Weil die Populationsgrößen von Seevögeln der Maßstab sind, an denen die Auswirkungen von Eingriffen zu messen sind, müssen mögliche Einflüsse von Offshore-Windparks kumulativ betrachtet werden. Der kumulative Ansatz darf sich dabei nicht nur auf andere Windparks beschränken, sondern muss auch andere Eingriffe, die auf Seevogelpopulationen einwirken, einschließen (z. B. Störung und Vertreibung durch Schiffsverkehr, Lebensraumverlust durch Sand- und Kiesabbau).

Offene Fragen bestehen hinsichtlich des Verhaltens der Seevogelarten, die bei den dänischen und schwedischen Studien nicht berücksichtigt wurden bzw. dort nicht vorkommen, aber auch zur bislang völlig unbekannten Situation bei schlechtem Wetter (z. B. Sturm), wenn Sicht und Manövrierfähigkeit der Vögel stark beeinträchtigt sind. Ganz allgemein sollten zukünftig mehr direkte Beobachtungen (z. B. von Schiffen aus) unternommen werden, um das Verhalten sowohl bei Meidereaktionen als auch bei der Nahrungssuche innerhalb von Windparks genauer zu untersuchen. Zusätzlich könnte ein Monitoring der Beutearten ein sehr viel besseres Verständnis der Seevogelverteilung in und um Windparks fördern. Um allerdings mehr über die Einflüsse von Lebensraumverlust und Barrierewirkung auf die Populationsgröße von Seevögeln zu erfahren, sind grundlegende Studien zu Dichteeffekten bei überwinternden Seevögeln unerlässlich.

3 Introduction

Seabirds play an important role in the assessment of the possible impacts of offshore wind farms on the marine environment. Despite numerous studies of the consequences of on-shore wind turbines for birds (most recently reviewed by HÖTKER *et al*. 2004 and PERCIVAL 2005), the in many respects different biology of seabirds generally limits the extend to which results from studies at land can be applied to offshore wind farms. Seabirds include breeding birds from coastal areas and islands which undertake foraging flights to the open sea as well as birds living there to overwinter, moult or stop over during migration. Habitat loss (displacement due to disturbance by operating turbines and associated ship and helicopter traffic, or habitat alteration by artificial creation of hard-bottom substrate), habitat fragmentation due to barrier effects during flight (disturbance by operating turbines) and additional mortality (collision with turbines) are regarded as the most important possible impact factors (GARTHE 2000, NOER *et al*. 2000, EXO *et al*. 2002).

To date, fairly few of the offshore wind farms built since the early 1990s have been studied with respect to their effects on seabirds. This review intends to summarise the knowledge of seabird reactions to operating offshore turbines, and to discuss the universality of the results of published impact studies. As similar effects may arise from related impacts, relevant studies of offshore platforms, ship traffic and aggregate extraction are likewise considered. The general focus of this review is on the 35 seabird species which regularly live in the German parts of North and Baltic Seas – the 12-mile zone plus the Exclusive Economic Zone (GARTHE *et al*. 2003a, see also Table 2).

Several methods for the assessment of possible impacts of offshore wind farms on seabirds have been proposed (e.g. NERI 2000, PERCIVAL 2001, DIERSCHKE *et al*. 2003, GARTHE & HÜPPOP 2004). Of special interest is the question as to whether the results from studies at existing turbines correlate with the assumptions included in these methods, and whether modifications and a review of these methods appears necessary. Furthermore, the possible consequences of the observed effects on the population dynamics of the respective seabird species are discussed.

4 Methodology

This report summarises the results of studies on seabirds at offshore wind farms in construction and operation. Some of the studies are still in progress, and results were only considered here if published before 30 June 2005. Despite of the fact that a considerable number of offshore wind farms (Fig. 1) exists, only few of them were studied with regard to effects on seabirds during construction and/or operation. This report therefore mainly relies on results obtained at five offshore wind farms (for technical details see Table 1):

- **Tunø Knob** (Århus Bay, Baltic Sea, Denmark, operating since autumn 1995, GUILLEMETTE *et al*. 1998),
- **Utgrunden** (Kalmar Sound, Baltic Sea, Sweden, operating since December 2000, PETTERSSON & STALIN 2002),
- **Yttre Stengrund** (Kalmar Sound, Baltic Sea, Sweden, operating since September 2001, PETTERSSON & STALIN 2002),
- **Horns Rev** (west of Jutland, North Sea, Denmark, operating since the last quarter of 2002, PETERSEN *et al*. 2004),
- **Nysted** (south of Lolland, Baltic Sea, Denmark, operating since August 2003, KAHLERT *et al*. 2004b).

In addition, observations at the semi-offshore Lely wind farm in the IJsselmeer, in the Netherlands were included (DIRKSEN *et al*. 1998c). Finally, effects of wind turbines on seabirds were studied at some wind farms which were built directly at the coastline or close to it. Results obtained there can also give indications on the effects that can be expected from offshore wind farms, especially with respect to flight behaviour, potential barrier effects and collision risk.

Table 1: Technical details of the five offshore wind farms, at which the majority of information about seabirds was gained (data from various reports and websites).

	Tunø Knob	Utgrunden	Yttre Stengrund	Horns Rev	Nysted
location	Århus Bay, DK	Kalmar Sound, S	Kalmar Sound, S	W of Jutland, DK	S. of Lolland, DK
wind farm area	0.3 km²	–	–	20 km²	24 km²
wind farm extension	0.8 km	2.2 km	1.5 km	5.0 km	6.0 km
water depth (m)	3 - 5 m	7 - 10 m	6 - 10 m	6.5 - 13.5 m	6 - 9.5 m
closest distance from coast	3 km	8 km	5 km	14 km	10.5 km
closest distance between turbines	200 m	?	?	560 m	480 m
number of turbines	10	7	5	80	72
power per turbine	0.5 MW	1.5 MW	2 MW	2 MW	2.3 MW
total height	60 m	101 m	96 m	110 m	110 m
Hub height	40.5 m	65 m	60 m	70 m	69 m
rotor diameter	39 m	70.5 m	72 m	80 m	82 m

In general, the results (e.g. figures and values) were taken as shown in the reports on seabird studies. Sometimes, additional values had to be worked out from figures listed in the reports. For example, in the reports about seabirds at the Horns Rev and Nysted wind farms, bird numbers are given for three partial areas in comparison to the whole area surveyed: wind farm; wind farm plus 2 km radius; and wind farm plus 4 km radius.

In order to compare the development of bird numbers in the 2-km-zone (not counting the wind farm) and the 4-km-zone (not counting the wind farm or 2 km zone), the respective values were calculated from the data shown in the reports.

A systematic list of species mentioned in this report is shown in Appendix I.

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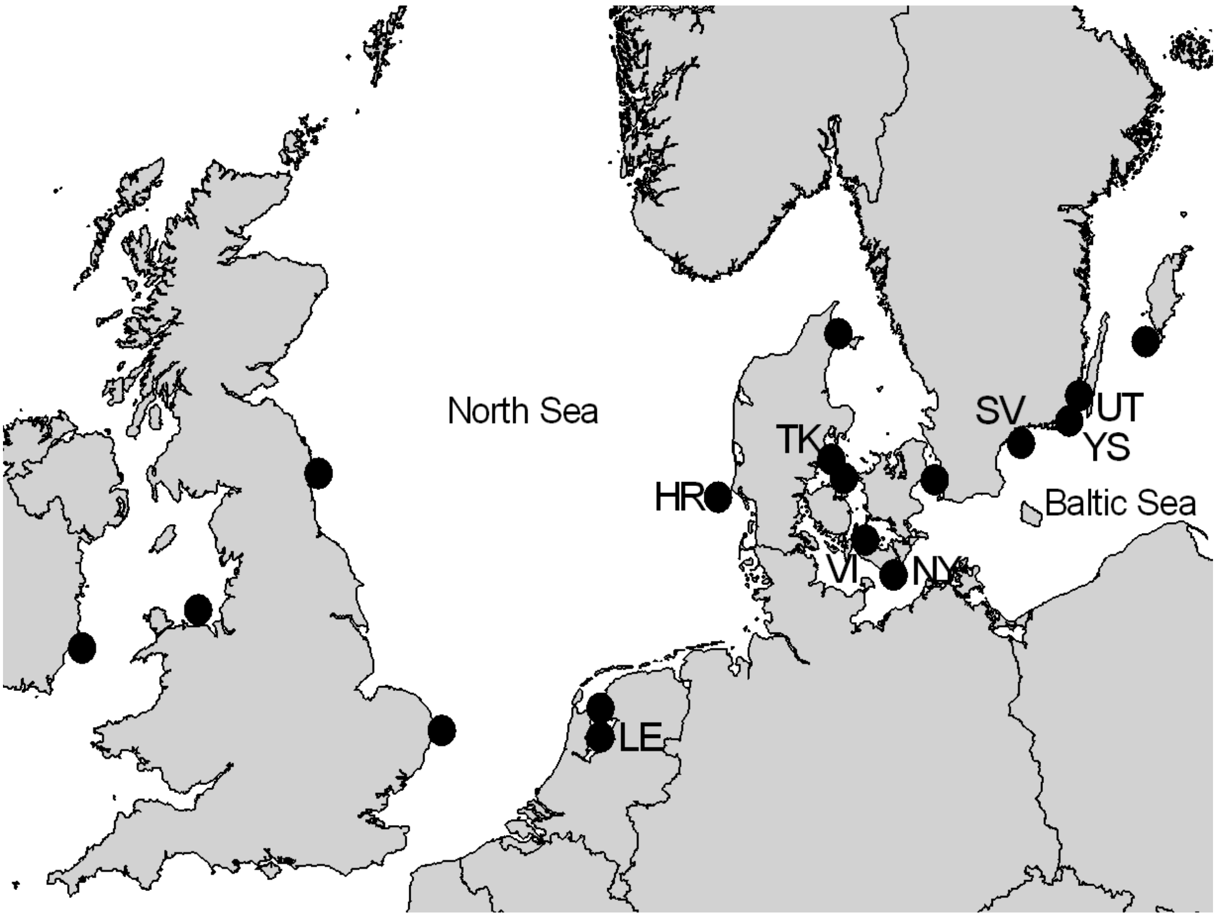

Fig. 1: Offshore and semi-offshore wind farms operating as of June 2005. Wind farms mentioned in this report are indicated as follows: SV Svante, VI Vindeby, TK Tunø Knob, LE Lely, UT Utgrunden, YS Yttre Stengrund, NY Nysted, HR Horns Rev.

Table 2: Overview of seabirds (35 species regularly occurring in German waters, GARTHE *et al*. 2003a) covered by studies on barrier effects (B), collision risk (C) and habitat loss (H) at offshore wind farms. Species listed in Annex I of the EU Birds Directive are printed bold. Coast: relevant studies from coastal wind farms (<5 km inland; C only with respect to proved collisions).* Species only considered as part of a species group; [1] only migrating birds (no local movements); in brackets: small sample size or fragmentary information. Note that a notification does not necessarily mean that there are appropriate results, because insigfnificant information was often provided.

	Tunø Knob	Utgrunden	Yttre Stengrund	Horns Rev	Nysted	Coast
Red-throated Diver		(B*[1]) (H*)	(H*)	B*[1] H*		B C
Black-throated Diver		(B[1]) (H*)	(H*)	B*[1] H*		
Great crested Grebe						
Red-necked Grebe				(B[1])		
Slavonian Grebe		(B[1])	(B[1])			
Fulmar				(B[1])		B C
Sooty Shearwater				(B[1])		
Gannet				B H		
Cormorant	(H)	B (C[1]) (H)	B[1] (C[1]) (H)	B[1] C[1] H	B H	B C
Greater Scaup		(B[1]) (H*)	(B[1]) (H*)			B*
Eider	B H	B C[1] H	B[1] C[1] (H)	B[1] (H)	B H	B C
Long-tailed Duck		(B) H			B H	
Common Scoter	(H)	H		B C H		
Velvet Scoter		(B[1])	(B[1]) (H)	B[1]		
Red-breasted Merganser		(B[1]) H	B[1] (H)	B[1]	B	
Pomarine Skua						
Arctic Skua		(B[1])		B C		
Great Skua				(B[1])		
Little Gull				B[1] H	B*[1]	
Black-headed Gull				B[1] C*[1]	B*[1]	B C
Common Gull				B[1] C*[1]	B*[1]	B* C
Lesser Black-backed Gull		(B[1])	(B[1])	B[1] C*[1]	B*[1]	B C
Herring Gull				B C H	B*[1] H	B C
Great black-backed Gull				B C H	B*[1]	B C
Kittiwake		(B[1])	(B[1])	B[1] C*[1] H		B C
Caspian Tern		(B[1])	(B[1])			
Sandwich Tern				B C*[1]	B[1]	B
Common Tern			C*[1]	B* C*[1] H*		B C
Arctic Tern			C*[1]	B* C*[1] H*		
Black Tern						B C
Guillemot				B*[1] H*		C
Razorbill				B*[1] H*		
Black Guillemot		(B[1])				
Little Auk						
Puffin						

5 Results

5.1 Effects of Offshore Wind Farms on Seabirds

5.1.1 Barrier Effects for Flying Seabirds

Except for the Tunø Knob wind farm, the question of barrier effects at offshore wind farms was studied only for migrating birds (including seabirds). However, results about avoidance reactions shown by seabirds during flight at Utgrunden, Yttre Stengrund, Nysted and Horns Rev may in part be valid for non-migratory flights of seabirds as well. For instance, high proportions of seabirds flying southwards in spring and northwards in autumn suggest that observations at Horns Rev in some cases involve staging birds. This is especially true for the Common Scoter which is present around the wind farm area in very large numbers. The behaviour of seabirds observed at coastal wind farms may also be transferred to offshore situations, hence the respective studies are considered here as well. Despite the inclusion of the latter studies, no information on possible barrier effects is available for a number of species (Table 2). Consequences of detours and changes in flight altitude of affected birds on the energy budget are dealt with not here, but in a parallel study on migrating birds (HÜPPOP *et al*. 2005).

Tunø Knob, Denmark

The flight activity of Eiders (locally wintering birds) was observed with radar at night and during twilight from December 1998 to April 1999 (TULP *et al*. 1999). As for the observations concerned wintering and staging birds, the flights can be regarded as local movements within a staging area. High flight activity was noted especially at dawn (flights to display areas) and on moonlit nights, but was much lower on dark nights. Nocturnal flight activity was low within a distance of 1000-1500 m from the wind farm, but higher than expected at a distance of 1500 m, probably due to a concentration of evading birds. Such an effect was already observable at 1200 m distance at dusk, but was absent (or below 200 m distance) at dawn. The avoidance reactions occurred on all sides of the wind farm and were therefore independent of the location of the areas used for resting and foraging, respectively. Not only the wind farm area (0.3 km²), but also a large area around the wind farm (approx. 12.9 km²) was avoided by Eiders.

Flights within a distance of 500 m around the wind farm were analysed more precisely. With increasing darkness, fewer flights occurred between the turbines. Eiders much more often entered the wind farm parallel to the two rows of turbines (mostly through the 400 m wide gaps between the rows) than perpendicular to the turbine rows, between the 200 m wide gaps. Irrespective of light conditions and flight direction, more flocks flew outside than inside the wind farm. A directional change was observed in 6.5-7.5% of the flocks observed, and more often on moonlit than on dark nights.

The authors conclude from their results that with regard to nocturnal movements of local Eiders, the wind farm acts as a barrier, which is actively avoided. In daytime, such avoidance seemed to be restricted to a distance of about 100 m from the wind farm (GUILLEMETTE *et al*. 1998, see 5.1.3).

Utgrunden, Sweden

Observations of flying birds nearly exclusively refer to migration, which takes many seabirds along the 20 km wide Kalmar Sound in the spring and autumn. Diurnal migration was monitored visually during parts of the spring seasons of 1999 (pre-construction), 2001, 2002 and 2003 (operation); and during parts of the autumn seasons of 2000 (construction) and 2002 (operation), from the mainland and Öland coastlines as well as from the lighthouse located in the middle of the Sound. Using data from a nearby military radar station, the flight paths of migrating bird flocks were recorded during daytime and nighttime hours, but the calibration of the radar allowed only the tracking of large and/or high flying bird flocks (at least 45-100 Eiders, PETTERSSON 2005). All results mentioned refer to the reports by PETTERSSON (2001, 2002, 2003, 2005).

During visual observations, the Kalmar Sound was divided into four zones with widths of 5 km each (A, B, C, D from west to east). The outer zones were observed from the respective coastlines, and the inner two zones from the lighthouse. During spring migration, Eiders were by far the most abundant seabirds (e.g. Table 3). In the pre-construction phase (spring 1999), Zone C was preferred by Eiders (37% of all birds), but the same zone was strongly avoided after seven turbines had been built there parallel to the direction of flight (7% in 2001 and 6% in 2002-2003 of all birds observed, see Fig. 2 and Table 3: decreases in Zone C and increases in Zone D significant). Within Zone C, the spring migration of Eiders was distributed evenly over five 1 km wide sub-zones before construction, but the three sub-zones in which turbines were located were clearly avoided during operation, and the sub-zone closest to the turbines was also used to a much lesser degree (Fig. 3). Compared to the first post-construction spring (2001), a slight increase in the number of Eiders passing between or over the turbines (sub-zones 3-5) was noted. Eiders usually detoured the wind farm, altering their course by 1-2 km in front of the turbines and keeping a distance of at least 500 m from them (of the total 10,654 waterbird flocks observed during spring migration, only 3.1% approached closer than 500 m to a turbine, and only 0.3% passed at approximately 100 m distance). Detours ranged between 1.2 and 2.9 additional kilometres flown. Of those Eider flocks which came close to the wind farm, some crossed between the turbines, preferably at those temporarily not operating (Fig. 4). On a day on which Eider migration proceeded perpendicularly to the row of turbines, 6% of the flocks passed in between and 9% above the turbines; all the other flocks flew around the wind farm. No Eider approached a turbine more closely than 100 m.

Autumn migration of Eiders took place along the mainland coast during construction and operation of the wind farm. It seems that this was the commonly used route, even before construction. Eiders heading towards the wind farm in autumn already changed their flight direction 3-4 km in front of the turbines and kept a distance of about 1 km from them, with detours of a few hundred metres to 1 km flown additionally. As in the spring, the few birds flying in Zone C avoided the three sub-zones containing the wind farm. Radar observation in daylight confirmed the long detours flown by Eiders in the spring and autumn.

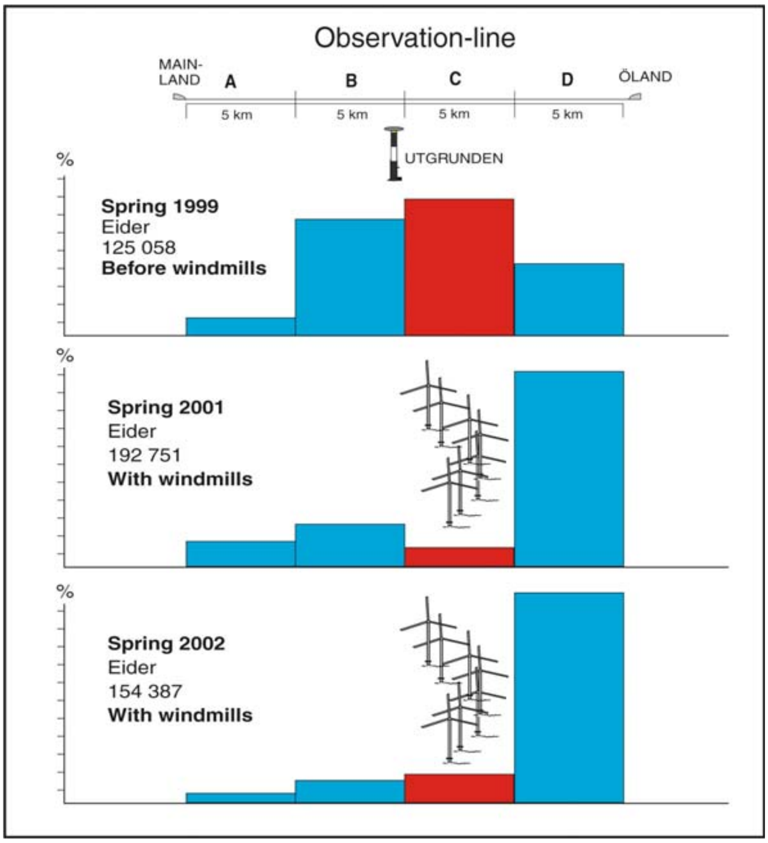

Fig. 2: Distribution of spring-migrating Eiders over four 5 km wide zones in the Kalmar Sound between Öland and the Swedish mainland coast, before and after construction of the Utgrunden wind farm (seven turbines) in Zone C in December 2000. From PETTERSSON & STALIN 2002.

Table 3: Distribution of spring migrating seabirds on four 5 km wide zones of Kalmar Sound before (1999) and after (2001) construction of the Utgrunden wind farm. The turbines were built in Zone C (printed bold for comparison), for the location of the four zones see Fig. 2. Data from PETTERSSON (2002), but birds migrating over land were omitted from the analysis. The differences between the yearly proportions in Zone C are significant for all species (χ^2 tests calculated with data from PETTERSSON 2002).

	Spring 1999 (pre-construction)					Spring 2001 (operation)				
	A	B	**C**	D	n	A	B	**C**	D	n
Divers	1%	72%	**16%**	11%	580	3%	87%	**4%**	5%	705
Cormorant	46%	23%	**22%**	9%	807	57%	13%	**14%***	17%	1819
Eider	5%	34%	**40%**	21%	120087	8%	14%	**6%**	72%	179341
Red-breasted Merganser	22%	19%	**18%**	41%	754	18%	22%	**4%**	56%	1532

* PETTERSSON (2005) states an increase to 25% for Cormorants in Zone C in the spring seasons 2001-2003. However, the data in his Table 16 suggest that only some 10-11% of the Cormorants were recorded in this zone.

Compared to Eiders, the pooled results obtained for other large birds (with Cormorant and Red-breasted Merganser reported as being the most abundant) are very much the same. Details of the distribution over the four zones of Kalmar Sound are given for divers, Cormorant and Red-breasted Merganser, which all showed decreased proportions of birds migrating in Zone C in spring after the wind farm had been built (Table 3). Before construction, 28% of all waterbirds (except Eiders) migrated in Zone C, but many switched to zone D during operation, with only 6% recorded in Zone C in 2001, and 17% in 2002-2003.

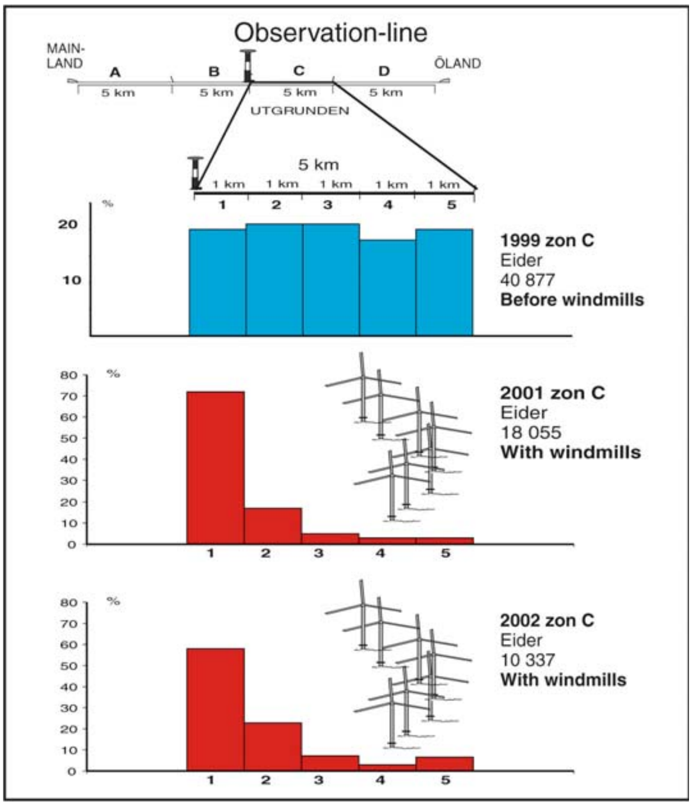

Fig. 3: Distribution of spring migrating Eiders over five 1 km wide sub-zones of zone C in the Kalmar Sound (compare Fig. 2) before and after the construction of seven turbines in the sub-zones 3, 4 and 5 in December 2000. Taken from PETTERSSON & STALIN 2002.

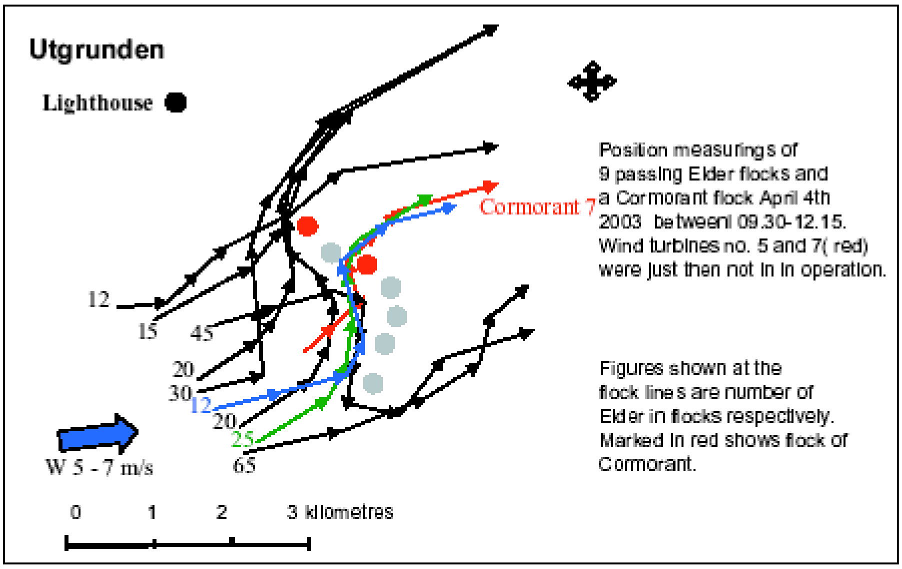

Fig. 4: Flight paths of Eiders and Cormorants tracked by optical rangefinder at the Utgrunden wind farm in Spring 2003 (taken from Petterson 2005).

In autumn, divers (mostly Black-throated Divers), scoters, auks and Arctic Skuas preferred to fly in the middle of the Sound, but avoided getting close to the wind farm. Cormorants and Red-breasted Mergansers crossed the wind farm more often than other seabirds. Bird flocks tracked by radar revealed flights round the wind farm at daytime and nighttime, and during both good and poor visibility, indicating that birds are able to detect wind turbines even in darkness and fog. However, an increased rate of flight paths passing straight through the wind farm was observed during fog during daytime. The species involved were unknown in these cases. Regarding the distribution of migrating birds over the sub-zones of Zone C, data are presented for some rare species (but unfortunately not for the common ones). Accordingly, it appears that Velvet Scoters and Black Guillemots avoid the wind farm area, whereas Greater Scaups were flying in the sub-zones containing the turbines (Table 4).

With respect to local wintering birds, the general statement is that Eiders, Long-tailed Ducks and Cormorants which forage in the shallow water around the wind farm area commonly fly back and forth between the turbines. However, quantitative data are not available for staging birds, because the vast majority of results mentioned above refer to actively migrating birds. The question as to the extent to which a barrier effect for staging birds can be deduced from the visual and radar observations at Utgrunden remains open.

Table 4: Number of seabirds migrating through sub-zones outside (1, 2) and inside (3, 4, 5) the Utgrunden wind farm before and after the construction of the turbines. S spring, A autumn.

	Season	Pre-Construction		Operation	
		outside WF	WF sub- zone	outside WF	WF sub-zone
Slavonian Grebe	S + A	0	0	4	0
Greater Scaup	A	0	0	0	14
Velvet Scoter	S + A	11	21	41	0
Lesser Black-backed Gull	S	2	2	3	0
Kittiwake	A	0	0	1	0
Caspian Tern	S	0	0	1	0
Black Guillemot	S + A	8	4	34	0

Yttre Stengrund, Sweden

Due to the proximity to the Utgrunden wind farm, visual observations of diurnal migration and radar tracking were conducted for both wind farms combined. As at Utgrunden, flying birds at Yttre Stengrund were for the most part actively migrating birds, and the area is hardly used by staging seabirds (see 5.1.3). Observations of bird migration were carried out during the pre-construction period (autumn 2000, spring 2001) and the operational period (autumn 2001, spring and autumn 2002, spring 2003). All results are from PETTERSSON (2002, 2003, 2005).

In the southern Kalmar Sound, observations were carried out only from the mainland coast. Migrating birds in zone A (mainland side, see Utgrunden) were assigned to four sub-zones with a width of 1-1.5 km each (1, 2, 3, 4). During the autumn of 2000, Eiders and other seabirds (species composition not given) were distributed equally over the four sub-zones. After the five turbines were built in sub-zone 3, this sub-zone was avoided nearly completely by Eiders (2000: approx. 20% of all flocks, 2001: no flocks at all, 2002: three flocks only; see also Table 5). Not a single flock crossed the wind farm; instead the birds evaded it, shifting to sub-zones 2 (2001) and 4 (2002). In doing so, they only exceptionally came closer to the turbines than 500 m. Detours started at about 800-1000 m in front of the wind farm and caused prolonged flights of 1.2-3 km. Seven (out of 756) Eider flocks behaved indecisively before passing. During the spring, the proportion of Eider flocks flying in the wind farm sub-zone decreased as well, from 13% before construction (2001) to only 2% during operation (2002). Detours tracked by radar during the spring revealed flight paths approximately 2 km longer.

Other seabirds also avoided sub-zone 3 during autumn migration (after construction, only 3% of all flocks, compared to 9% before construction) and flew around the wind farm on both the eastern and western sides. Red-breasted Mergansers are reported as flying through the wind farm, and migrating Common/Arctic Terns were found to fly close to and between turbines without showing "great deviation manoeuvres". Although Cormorants were scarce in sub-zone 3 before construction, the proportion of birds using this section decreased from 2.5% to 0.3% (Table 5). A much stronger decrease in sub-zone 3 was noted for Velvet Scoters (from 22.6% during pre-construction to 5.4% during operation), but 20.3% of Greater Scaups migrated in this zone with operating turbines (Table 5). During spring migration, sub-zone 3 was generally used by only few birds (approx. 3% of all flocks) before construction, and this proportion was even smaller during operation (approx. 1%). According to radar observations, seabirds (most probably including Eiders) were flying around the wind farm even at night (mostly on the eastern side) and on foggy days (on both sides).

Table 5: Number of seabirds migrating through sub-zones outside (1, 2, 4) and inside (3) the Yttre Stengrund wind farm before and after the construction of the turbines. S spring, A autumn.

	Season	Pre-construction Outside WF	Pre-construction WF sub-zone	Operation Outside WF	Operation WF sub-zone
Slavonian Grebe	S + A	2	0	5	0
Cormorant	A	1383	35	3290	11
Greater Scaup	S + A	60	0	121	31
Eider	A	42290	2611	122512	647
Velvet Scoter	S + A	188	55	353	20
Lesser Black-backed Gull	A	3	0	17	0
Kittiwake	A	0	0	1	0
Caspian Tern	S + A	1	0	3	0
Black Guillemot	S	1	0	0	0

Nysted, Denmark

Radar tracking of birds flying at the Nysted wind farm is available from the pre-construction period (1999-2002), during construction (spring 2003), and from the operational period (autumn 2003, spring 2004; KAHLERT *et al.*2004a, 2004b). The radar equipment was based on an observation tower 5 km northeast of the wind farm. The results presented in the reports mostly refer to actively migrating waterbirds, including species not considered seabirds in this review, because the radar tracks were assigned to this group due to their flight speed. The migration of waterbirds generally took place along an east-west axis. During the spring, Eiders made up 48% of all flocks during operation (61-90% in the preceding years), and their share was 45% in the autumn (all years combined). A large proportion (31%) of autumn flocks involved foraging flights by Cormorants, which rested on the nearby Rødsand; local staging Red-breasted Mergansers were also involved. The analysis of radar data concentrated on directional changes of flight paths and the proportions of flocks crossing the eastern border of the wind farm.

During **autumn migration**, the general route of migrating waterbirds turns westward after passing the southern tip of Falster and brings birds towards the wind farm area in a broad front. Before construction, they crossed this area in a straight line, but during construction and operation they have flown around the wind farm (Fig. 5). Because detours to the north and to the south occurred concurrently, the average flight direction remained the same, but the response to the turbines could be measured as an increasing standard deviation when approaching the wind farm. Accordingly, directional changes started mainly at a 1 km distance at night and at a 3 km distance during daytime. The probability of crossing the eastern border when approaching from the east varied between 23.9% and 48.1% during the pre-construction period, but fell to 8.9% (daytime: 4-7%; nighttime: 11-24%) during operation. The difference between the two periods is significant, even when accounting for side winds, time of day and the position of flocks during the approach. The migration intensity (length of all flight paths measured in a monitoring area divided by the number of flocks flying in across the eastern border) decreased from pre-construction to operation within the wind farm, but remained the same in a control area outside the wind farm. Visual observations at the radar station northeast of the wind farm showed that 3% of Eider flocks were heading back towards the east during operation, almost the same as in the years prior to construction.

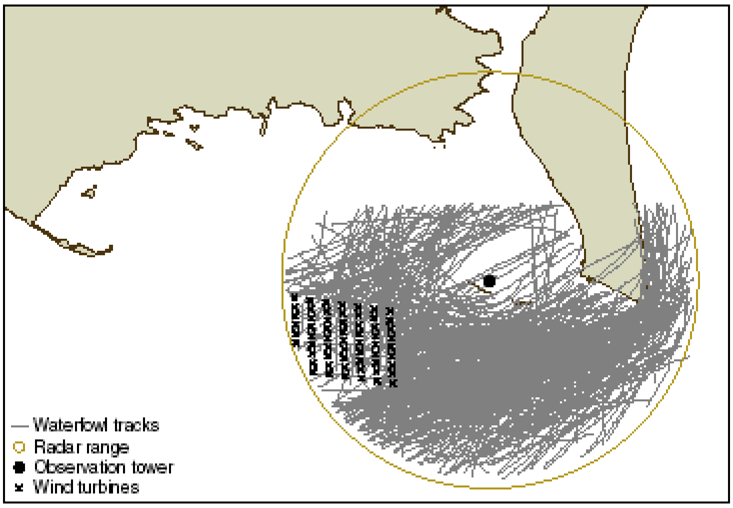

Fig. 5: Radar registration of 508 waterbird flocks visually ascertained at the Nysted wind farm during the autumn of 2003 (operational period). From KAHLERT *et al.* 2004b.

Spring migration usually takes place closer to the south coast of Lolland, and thus mainly north of the wind farm area. However, during the pre-construction period, 16% (2001) and 25% (2002) of waterbird flocks crossed the eastern border of the wind farm. This proportion was lower during construction (11%) and operation (11%), and it can be assumed that these birds flew through the wind farm. Differences between the pre-construction period and the construction or operational periods, respectively, are significant only for nocturnal migration.

From statements in the reports, it can be concluded that the results refer mainly to migrating birds, but also include local staging birds (Cormorant, Eider, Long-tailed Duck, Red-breasted Merganser and gulls are mentioned). Radar tracking was only considered in the analysis when it could be followed for at least 5 km. This suggests that an even lower proportion of staging birds is included in the results. It could not be ascertained whether staging birds behaved similarly to migrating birds. Therefore, a general transfer of the results to barrier effects on staging birds is not possible, except for foraging flights by Cormorants (see 5.1.3).

Horns Rev, Denmark

According to the published reports (CHRISTENSEN *et al*. 2004, CHRISTENSEN & HOUNISEN 2004, 2005), movements of birds were recorded from a transformer station at the northeastern edge of the wind farm, using both radar (August 2003 to May 2004, total of 195 hours, both daytime and nighttime) and visual equipment (August 2002 to May 2004, total of 169 hours). Visual observations during the daylight period were conducted along four transect lines, of which one ran along the easternmost row of turbines, one across the wind farm, and two outside the wind farm (Fig. 6); the birds crossing the transect lines were counted.

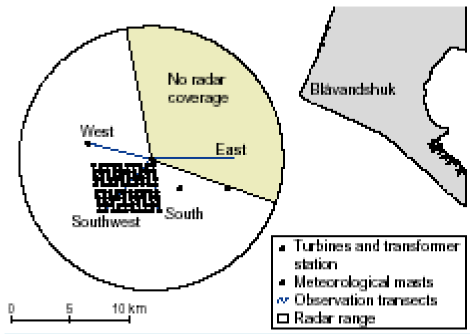

Fig. 6: Transect lines observed visually from the transformer station at the Horns Rev wind farm (from CHRISTENSEN *et al*. 2004).

Radar observations during the autumn demonstrated that birds approaching the wind farm significantly altered their flight direction. When approaching the northern edge of the wind farm, they changed their flight direction from SW to S (with the most apparent point of deflection at a distance of 400 m from the wind farm) and when heading towards the eastern edge of the wind farm, they changed their flight direction from SW to W. These manoeuvres resulted in detours around the southeastern and northwestern corners of the wind farm, as well as in entering the wind farm perpendicular to the turbine rows. Thus, the few flocks which actually entered the wind farm (13.9% of approaches from the north and 21.9% of approaches from the east) chose to fly through the centre between the rows of turbines. Entrance to the wind farm occurred independently of wind conditions and time of the day (day/night). During the spring of 2004, directional changes of birds flying southwards mainly occurred 400-500 m in front of the wind farm. With much less data than in 2003, the proportion of flight paths leading into the wind farm was 0% from the north and 29% from the east. Northbound spring migration was also found to be deflected well before the wind farm, tentatively estimated at a 4-6 km distance.

During visual observation, none of the 70 divers recorded crossed those two transect lines, which indicate flights through the wind farm. The two single divers tracked by radar passed at a distance of 900 m or made a U-turn 1 km before the wind farm, respectively. Very low proportions of individuals flying within the wind farm were also observed for Gannets (1.1%), Common Scoters (1.1%), Velvet Scoters (0.6%) and Guillemots/Razorbills (3.8%). While flight paths of 16 individuals or flocks of Gannets tracked by radar confirmed avoidance of the wind farm, Common Scoter flight paths were also recorded between the turbines. However, more flight paths were found outside the wind farm (where many birds were staging during the spring of 2004); within the wind farm, unexpected turns occurred (Fig. 7). In addition, in a sample of 20 flocks approaching the wind farm, all birds reacted to the turbines by changing their flight directions (mostly at 200-500 m distance). Large proportions of individuals flying in or into the wind farm were obserbed for Arctic Skuas and most species of gulls and terns (24-51%), with the exception of Little Gulls (13%, Table 6). Flight paths of gulls and terns recorded by radar confirm frequent entry to the wind farm.

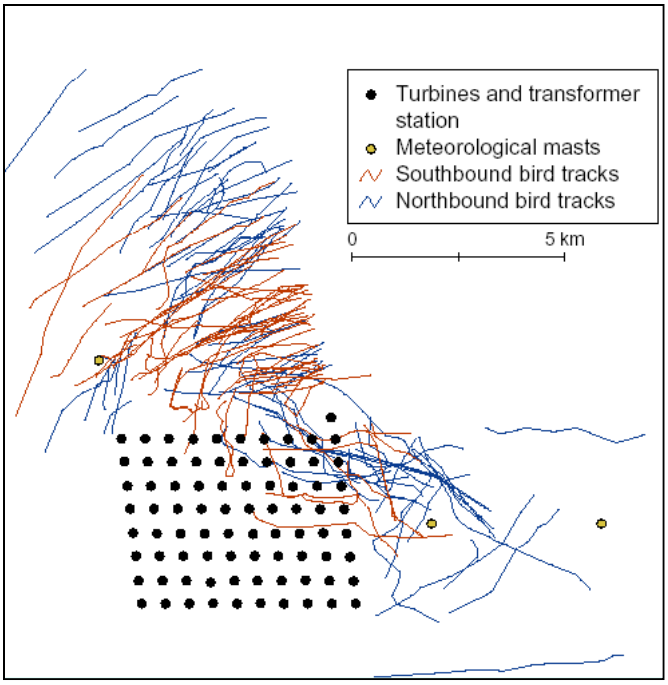

Fig. 7: Radar tracking of Common Scoters (n = 138 individuals/flocks) at the Horns Rev wind farm during the spring of 2004 (from CHRISTENSEN & HOUNISEN 2005).

In some of the flights across the transect lines the observers recorded the reaction of seabirds to the turbines. None of 13 divers and 28 Gannets entered the wind farm; all turned west and flew southwards again only after passing the wind farm. The same was observed for approaching Fulmars. A total of 28 Common Scoters did not fly into the wind farm, but detoured to the east or west. Common Scoters which were present in ”many thousands” (spring of 2003) or “in large numbers” (spring of 2004) north and northwest of the wind farm avoided the turbines at a distance of 300-1000 m and often turned back when disturbed by ships. Short panic reactions during flights between the turbines were observed among Red-necked Grebes, Cormorants and one Great Black-backed Gull. In general, gulls, Arctic Skuas and Sandwich Terns seemed to enter the wind farm without fear, whereas Common/Arctic Terns often left the wind farm only a short time after entering it.

Table 6: Numbers of seabirds observed visually crossing four transect lines at the Horns Rev wind farm during the spring of 2003 and 2004 and the autumn of 2003; data from CHRISTENSEN *et al*. 2003, CHRISTENSEN & HOUNISEN 2004, 2005. For the direction of the transect lines, see Fig. 6. Birds crossing transect lines S and SW are considered to be flying within the wind farm (flying in or out, and flying inside, respectively).

	Spring				Autumn				Total	% S+SW
	E	W	S	SW	E	W	S	SW		(in wind farm)
Divers	28	3	0	0	39	14	0	0	84	0.0
Red-necked Grebe	0	0	0	0	6	0	0	0	6	
Fulmar	0	0	0	0	2	1	0	0	3	
Sooty Shearwater	0	0	0	0	1	0	0	0	1	
Storm Petrel	0	0	0	0	1	0	0	0	1	
Gannet	155	39	1	0	52	16	1	1	265	1.1
Cormorant	1	9	0	0	134	3	3	5	155	5.2
Shag	0	0	1	0	0	0	0	0	1	
Eider	0	0	2	0	5	0	0	0	7	
Common Scoter	36012	20786	114	522	558	334	6	2	58334	1,1
Velvet Scoter	160	0	0	0	0	2	1	0	163	0.6
Red-breasted Merganser	2	0	0	0	0	0	0	0	2	
Great Skua	0	0	0	0	2	0	0	0	2	
Arctic Skua	44	27	18	8	7	0	1	0	105	25.7
Common Gull	94	81	85	39	15	23	22	34	393	45.8
Herring Gull	148	221	122	83	183	80	95	67	999	36.7
Lesser Black-backed Gull	49	12	11	16	14	23	10	10	145	32.4
Great Black-backed Gull	80	63	31	20	237	201	139	121	892	34.9
Black-headed Gull	10	21	9	32	29	11	4	3	119	40.3
Little Gull	46	143	22	2	61	50	1	20	345	13.0
Sabine's Gull	0	0	0	0	1	0	0	0	1	
Kittiwake	78	141	46	29	61	93	12	33	441	24.3
Arctic/Common Tern	250	84	182	3	183	36	32	21	791	30.1
Sandwich Tern	545	938	1132	499	69	135	52	43	3413	50.6
Guillemot/Razorbill	6	1	0	0	37	7	1	1	53	3.8

In summary, some seabirds (divers, Gannet, scoters, auks) actively avoided the wind farm, suggesting the occurrence of a barrier effect during changes of location within an area of sea used by them. In the case of the Common Scoter, the observations in fact referred to local movements. A quite large proportion of gulls and especially terns entered the wind farm from the east and left it on the same side. As flights into and out of the wind farm were of the same magnitude, CHRISTENSEN *et al*. (2004) assume that these birds use the wind farm as a landmark on foraging flights starting at the coast.

Coastal Wind Farms

Information from five coastal wind farms may help assess possible barrier effects from offshore wind farms for seabirds. Three of these wind farms are located directly at the shore on piers or seawalls (Blyth Harbour, Maasvlakte, Zeebrugge). One single turbine was built close to the IJsselmeer Dam (Den Oever) and one wind farm operates close to the shore in the IJsselmeer (Lely).

Nine turbines (rotor diameter 25 m, total height 38 m) were built at intervals of 200 m on the outer pier of **Blyth Harbour** in northeastern England. During a seven-year study

(STILL *et al*. 1996, PAINTER *et al*. 1999), considerable numbers of Cormorants, Eiders, Black-headed Gulls, Herring Gulls and Great Black-backed Gulls were present for several months or all year. When flying to and from their roosts in the harbour, Cormorants regularly crossed the row of turbines, with 10% of the birds flying at rotor height and all the others below it. During the first years of the study, some of the Eiders present outside the harbour flew into the harbour between the turbines, but later entered that area only by swimming. Large gulls made up 80% of all flights between the turbines, but many more flew along the row of turbines (20-300 flights per 10 min) than perpendicular to them (0.7-1.5 flights per 10 min). 16% (Great Black-backed Gulls) and 13% (Herring Gulls) of the crossings occurred at rotor height, but the greater share occurred below that height, and rarely above it. According to anecdotal reports, Fulmars, Black-headed Gulls, Kittiwakes and Sandwich Terns also passed through the wind farm.

Two rows of nine and 13 turbines, respectively, operate directly at or on the seawall of **Maasvlakte,** The Netherlands. The turbines (total height: 56.5 m, rotor diameter: 35 m) have been built at intervals of 130 m and are located between breeding colonies of gulls (mostly Lesser Black-backed and Herring Gulls, but also Black-headed and Common Gulls) and Common Terns and the offshore feeding grounds of these birds. In July 2001, VAN DEN BERGH *et al*. (2002) observed the flight activity of breeding seabirds in the wind farm. At both rows of turbines, most seabirds crossed below the rotor tips (92% and 62%, respectively). Of the birds passing below the rotor tip, 3.1% of gull flocks and 5.3% of Common Tern flocks showed behavioural reactions, but only one gull turned back. The rate of reaction was much the same amongst gulls flying above total turbine height (3.0%). The authors exclude a barrier effect for the foraging flights of the seabirds investigated and see their results as showing reduced sensitivity in breeding birds or rapid habituation during the breeding season.

A total of 23 turbines are in operation on the eastern pier of **Zeebrugge** harbour in Belgium. Turbine size varies: ten have a total height of 29 m (rotor diameter: 14 m), 12 a total height of 50 m (rotor diameter: 34 m), and one has a tip height of 79 m (rotor diameter: 48 m). Thirteen of the turbines are located directly at the shoreline, of which four are very close to a tern colony. The terns as well as gulls breeding elsewhere in the harbour regularly cross the wind farm in order to forage at sea (EVERAERT 2003). The majority of birds (54-82%) of all of the abundant species passed below rotor height and only a small fraction (1-14%) above total turbine height (Table 7). Depending on species and flight altitude, part of the passing seabirds showed avoidance reactions (deviations, changes of flight altitude, turning back) to the turbines (Table 7). Because most birds eventually passed the wind farm, a barrier effect was not assumed. The proportion of reacting birds was correlated with wing span, i.e. larger birds reacted in larger proportions (cf. Table 7).

Table 7: Proportions of seabirds showing avoidance reactions (deviation, change of flight altitude, turning back) when crossing the wind farm on the Oostdam of Zeebrugge harbour below rotor height (0-15 m), at rotor height (16-50 m) and above rotor height (51-65 m). The proportions referring to total turbine height (0-50 m) are given as well (all data from EVERAERT 2003).

Species	Flight altitude	N	Percentage of all birds passing	Number of birds showing reaction	Percentage of birds showing reaction
Herring Gull	0-15 m	85	62.5%	8	9.4%
	16-50 m	34	25.0%	13	38.2%
	51-65 m	17	12.5%	7	41.2%
	0-50 m	119	87.5%	21	17.6%
Lesser Black-backed Gull	0-15 m	44	54.3%	6	13.6%
	16-50 m	26	32.1%	7	26.9%
	51-65 m	11	13.6%	7	63.6%
	0-50 m	70	86.4%	13	18.6%
Black-headed Gull	0-50 m	15	88.2%	2	13.3%
Common Tern	0-15 m	408	81.9%	15	3.7%
	16-50 m	35	7.0%	11	31.4%
	51-65 m	55	11.0%	6	10.9%
	0-50 m	443	89.0%	26	5.9%
Little Tern	0-15 m	1010	54.3%	0	0.0%
	16-50 m	828	44.5%	4	0.5 %
	51-65 m	22	1.2%	1	4.5%
	0-50 m	1838	98.8%	4	0.2%

At the western end of the IJsselmeer dam, one 72 m high turbine with a rotor diameter of 44 m has been built in **Den Oever,** The Netherlands, exactly in the flight path of the morning and evening flights of Black Terns (according to a 1997 study, up to 15,000 birds) and Common Terns (1997: up to 6500 birds) in the post-breeding period. The results from the visual and radar observations showed that the terns deviated to both sides and kept a distance of 50-100 m from the turbine. Therefore, the direct vicinity of the turbine was used less than adjacent areas (DIRKSEN *et al*. 1998a).

The **Lely** wind farm, The Netherlands, consists of a row of four turbines (total height 60 m, rotor diameter 41 m) at intervals of 200 m. Because it is located 800 m offshore in the IJsselmeer, it is often referred to as a “semi-offshore wind farm”. The row of turbines intersects the flight paths of Pochards and Tufted Ducks during their flights between diurnal roosts and nocturnal feeding grounds. According to radar observations (DIRKSEN *et al*. 1998c), the behaviour of ducks during nocturnal flights differed between moonlit and dark nights. On moonlit nights, a higher proportion of ducks flew close to the wind farm. Moreover, flights between the turbines occurred; turning back did not. Nevertheless, the overall rate of flocks crossing was low, whereas detours were the common reaction to the wind farm. The authors assume that ducks can see the turbines (or perceive them in some way) on moonlit nights, but avoid approaches on dark nights by flying parallel to the wind farm. They further conclude that long-staying birds (in contrast to migrants stopping over) are habituated to the presence of turbines, even if they constitute a barrier to their regular movements. As during a second study with the same results 2500 Greater Scaups were present temporarily (DIRKSEN *et al*. 2000, VAN DER WINDEN *et al*. 2000), the conclusions seem to apply for this species as well.

5.1.2 Collision Risk to Flying Seabirds

While elaborate methods have been developed at onshore wind farms to extrapolate from casualties found near the turbines to the total number of birds collided (WINKELMAN 1992a, GRÜNKORN *et al*. 2005), it is impossible even to try to search for collision victims at sea. Real collision rates can therefore be obtained only by direct observation. With the exception of one pilot study, in which nocturnal bird flights are automatically recorded at a turbine at the Nysted wind farm (DESHOLM 2003), no such attempt has been made at offshore wind farms. Although evidence about collisions at offshore turbines is largely lacking, this question will be discussed with the help of observed behaviour of flying (mostly migrating) birds (see 5.1.1.) and by considering seabird species found as collision victims at coastal wind farms.

The only collision ever witnessed at an offshore wind farm happened at Yttre Stengrund: At dawn on 29 September 2003, the rear end of a flock of 310 Eiders migrating at an altitude of 60 m was hit by a rotor blade. One Eider fell into the water, and three others were forced to alight on the water, of which at least two managed to resume flight. In addition to this collision, five near-accidents were observed at the Utgrunden and Yttre Stengrund wind farms (PETTERSSON 2005). Extrapolating from the only observation of collision with a flock and including information on horizontal and vertical distribution of waterbird migration through the Kalmar Sound, PETTERSSON (2005) estimated the number of migrating waterbirds killed by collisions annually as 1-4 birds during the spring and ten birds during the autumn (i.e. 0.0002-0.0008% and 0.0016%, respectively, of all birds passing through the Kalmar Sound). The collision rate in spring may be twice as high because the fate of one of the four Eiders included in the accident was not clear.

5.1.2.1 Seabird Collisions at Coastal Wind Farms

Some of the 35 seabird species regularly living in German marine areas (e.g. all tubenoses and auks) occur only rarely close to the coast. Hence, even studies at coastal wind farms cannot sufficiently establish the collision risk for seabirds at sea. However, some species do live in coastal areas, and for others, a comparison with closely related species may be of interest. Altogether, 13 seabird species were found to include collision victims at coastal wind turbines up to 4 km inland (Table 8). This does not exclude the possibility that further species are at risk of collision, but evidence is lacking so far. It is obvious that especially gulls are vulnerable to collisions.

Based on figures from the Netherlands, Belgium, Spain, Sweden, Austria, Britain, Denmark and Germany, HÖTKER *et al*. (2004) summarise the number of fatal seabird collisions as follows: Red-throated Diver (1), Cormorant (2), Black-headed Gull (87), Kittiwake (1), Common Gull (14), Herring Gull (189), Great Black-backed Gull (7), Common Tern (8), Guillemot (1). Since e.g. Fulmar and Eider are not included here, this compilation appears to be incomplete (cf. Table 8).

Table 8: Number of seabirds and related species found as collision victims at coastal wind farms. Species regularly occurring offshore in the German parts of North Sea and Baltic Sea are printed bold. Species belonging to the same systematic families are included for comparison. For Zeebrugge no numbers are reported. References: 1 BÖTTGER *et al*. 1990, 2 SCHERNER 1999, 3 WINKELMAN 1989, 4 MUSTERS *et al*. 1996, 5 WINKELMAN 1992a, 6 EVERAERT *et al*. 2002, 7 STILL *et al*. 1996, 8 PAINTER *et al*. 1999, 9 MEEK *et al*. 1993, 10 GRÜNKORN *et al*. 2005.

	Hooksiel	Jadewindpark Wilhelmshaven	Bremerhaven-Fischereihafen	Nordholz	Westküste, Dithmarschen	Klärwerk Westerland	Friedrich-Wilhelm-Lübke-Koog	Marienkoog	Reußenköge	Simonsberger Koog	Helgoland	Urk	Kreekrak	Oosterbierum	Oostdam Zeebrugge	Blyth Harbour	Burgar Hill
Reference	1	1	2	1	1	1	10	10	10	10	1	3	4	5	6	7,8	9
Country	D	D	D	D	D	D	D	D	D	D	D	NL	NL	NL	B	GB	GB
No. of turbines	1	3	2	25	32	1	13	15	17	13	1	25	5	18	23	9	3
Hub height (m)	27	60	32	20-22	15-23	24	?	?	?	?	50	30	30	35	22-55	25	?
Rotor diameter (m)	17	56	35	15-16	10-25	21	?	?	?	?	60	25	25	30	14-48	25	?
Distance to coast (km)	3	?	85	0,4	1	<1	2	1	1	2	<0.5	0.06	dike	3	dike	pier	?
Red-throated Diver			1														
Fulmar																1	
Cormorant			2													1	
Brent Goose													1				
Shelduck			1														
Gadwall													1				
Teal			1														
Mallard			2		2	2	2					2	2	2			
Shoveler												1					
Tufted Duck	1											1					
Greater Scaup												1					
Eider																12	
Common Gull			2	1	1		1			1		1			x		
Herring Gull	1	1	1			1			2		3	1	1	1	x	24	
Lesser Black-b. Gull															x	1	
Great Black-b. Gull															x	29	
Black-headed Gull	1		2		1	1	1	1		2		4	1	2	x	4	3
Kittiwake															x	1	
Black Tern										1							
Common Tern															x		
Little Tern															x		
Guillemot			1														

Most of the studies at coastal wind farms listed in Table 8 give no information about the situation, in which collisions may have occurred. From gulls at Oosterbierum, it is known that both migration and flights to night roosts take place through the wind farm, including flights at rotor height (WINKELMAN 1992c). At Zeebrugge, it can be assumed that at least some of the seabirds that collided belonged to the local breeding populations and were hit during foraging flights. Eiders at Blyth Harbour collided when moving between the harbour and the adjacent sea across the pier through the row of turbines. No casualties were found after Eiders changed their mode of movement from flying to swimming. Other collisions victims like Cormorants and most of the gulls probably were also birds which roost regularly in the harbour.

At the Zeebrugge wind farm, the annual rate of fatal collisions in a ten-year study was calculated to range between 11 and 29 birds per turbine (EVERAERT *et al*. 2002). According to results from 2001, these rates mainly refer to seabirds, for in that year the total of 55 birds actually found included 44 gulls (mainly Herring Gulls, Lesser Black-backed Gulls, Great Black-backed Gulls and Kittiwakes) and five terns (three Common Terns and two Little Terns). The annual collision rate was higher along the turbine row perpendicular to the main flight direction of birds (22-58 collision victims per year and turbine), with a maximum of 120 collision victims per year at one turbine (EVERAERT *et al*. 2002). In September 2001, the rate of collisions per birds passing the turbines was investigated. For seabirds, the risk varied depending on flight altitude and time of day, and was highest for flights of Common Terns at rotor height (1:600, Table 9). At an inland wind farm (Boudewijn Canal), the overall collision risk for Herring Gulls was estimated to be 1:2200, but 1:750 if only flights at rotor height were considered (EVERAERT *et al*. 2002).

Table 9: Calculated collision risk per bird crossing the Zeebrugge wind farm at different times of day and flight altitudes in September 2001, based on the estimated number of collision victims and the observed number of passing birds (from EVERAERT *et al*. 2002).

Flight altitude	Day and night All altitudes	Day and night Rotor height	Night All altitudes	Night Rotor height
Gulls	1:3700	1:2100	1:1900	1:1000
Common Tern	1:3000	1:600	?	?
Little Tern	1:27,000	1:12,000	?	?

At a comparable wind farm on the pier of Blyth Harbour, the annual collision rate during a six-year study was six birds per year and turbine (corrected for recovery probability), of which 97% were seabirds (PAINTER *et al*. 1999). The annual additional mortality due to fatal collisions was 0.8% of the local wintering population of Eiders (up to 3200 birds) in the winter of 1992/93, 1.3% in 1993/94, 0.2% in 1994/95, 0.1% in 1995/96, 0% in 1996/97 and 0.1% in 1997/98 (STILL *et al*. 1996, PAINTER *et al*. 1999).

5.1.2.2 Flight Behaviour of Seabirds at Offshore Wind Farms

Tunø Knob, Denmark

A nocturnal radar study of staging Eiders and Common Scoters (December to April) showed both species with increased flight activity in the staging area on moonlit nights over dark nights. TULP *et al*. (1999) conclude that collision risk is reduced by relatively low flight activity on dark nights.

Utgrunden, Sweden

Visual and radar observations of migrating seabirds showed that in general the wind farm is detoured at daytime, at night and even during fog (PETTERSSON 2005). Only 0.3% of all diurnally migrating Eider flocks passed less than 200 m away from or less than 50 m above a turbine. In spring, only five of 20 flocks observed in the wind farm area passed at rotor height; all the other flocks were flying higher than 100 m or even above 200 m. Thus, the collision risk seems small for migrating Eiders; no collisions were recorded by visual observation. Radar observation showed flights through or above the wind farm occasionally occurring at night and during fog (PETTERSSON 2002), which could indicate a higher collision risk. If staging birds also avoid turbines, their collision risk would be equally low.

During spring migration, Eider flocks which did not start detours well in front of the wind farm but headed towards it, were tracked by optical rangefinder from 1 km in front of to 1 km behind the turbines (PETTERSSON 2005). These Eiders either flew around the turbines or passed between them. The distance kept from turbines was usually more than 200 m, and only four of 331 flocks tracked approached to about 100 m. Flights between turbines usually occurred when turbines were not operating. Comparing 1 km in front of and 1 km behind the wind farm, average flight altitude increased from 10-20 m to 30-40 m at 300 m in front of the turbines, to 30-50 m between the turbines, with some flocks flying at 150 m (PETTERSSON 2003, 2005). This behaviour near the turbines was modified by wind direction. This indicates that despite horizontal manoeuvres near the turbines, increased flight altitude brings more birds to the dangerous rotor height of approx. 30-100 m.

Yttre Stengrund, Sweden

Detours around the wind farm were common among migrating Eiders and other seabirds, both in spring and autumn, and daytime and nighttime, and also during fog (PETTERSSON 2002, 2003, 2005). Flight altitudes of autumn migrating Eiders measured by optical rangefinder were mostly below 20 m, but increased when approaching the wind farm. This was more pronounced when flying close to the wind farm, and those Eiders flying over the turbines did so well above rotor height (Fig. 8). Similar behaviour was exhibited by other seabirds (flight paths of Cormorants shown by PETTERSSON 2005). Migrating Common/Arctic Terns maintained their flight altitude of approximately 10 m, even when very close to the turbines, and flew along or between them. Therefore, terns were at much less danger from collision than Eiders, which increased their risk due to climbs to rotor height. However, as most seabirds fly around or over the wind farm (only 0.3% of all Eider flocks passed as close as 100 m from turbines), the collision risk seems to be low, at least during daytime (measurements of flight altitude are not available for nighttime), but the only collision ever witnessed at an offshore wind farm happened at Yttre Stengrund in daylight. If local movements of staging birds are similar in terms of distances from the turbines, collision risk would be low for them as well.

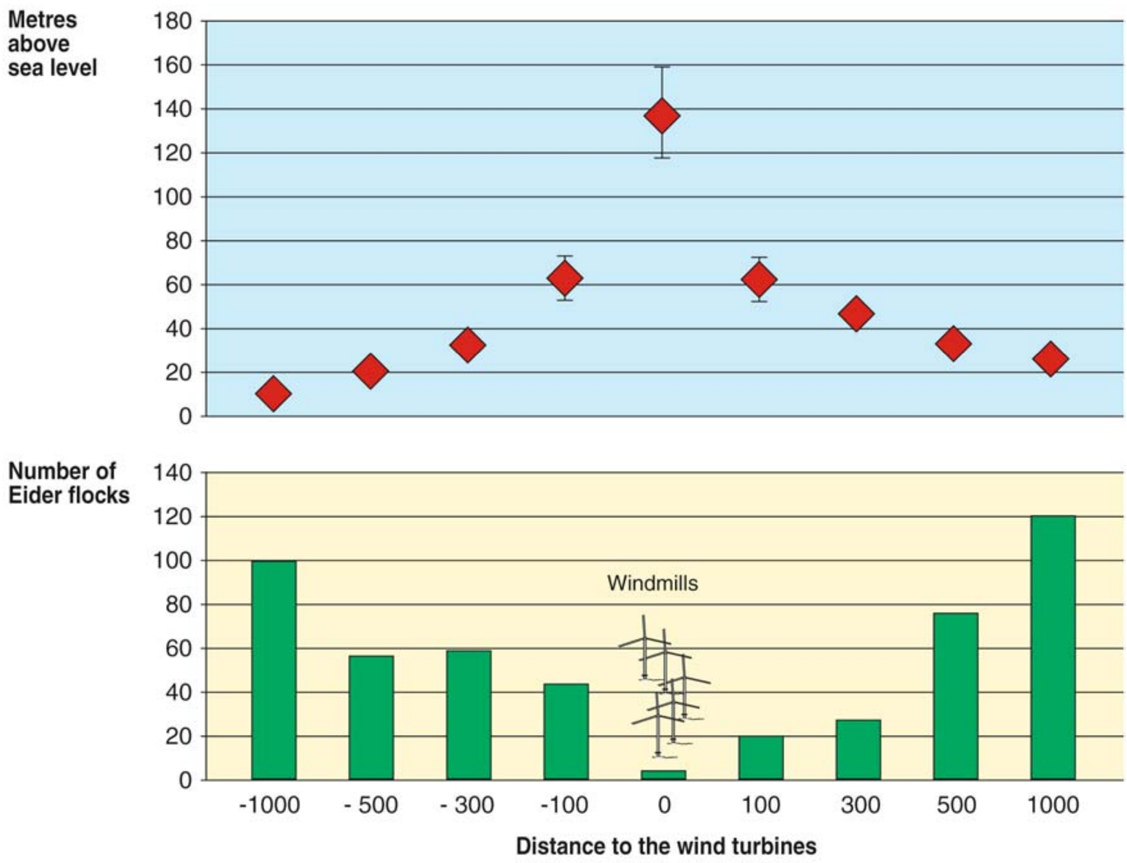

Fig. 8: Flight altitudes (top; mean and standard deviation) and number of flocks (bottom) recorded at various distances from Yttre Stengrund wind farm during autumn migration of Eiders (September 2002). Total turbine height is 96 m; from PETTERSSON & STALIN 2002.

Nysted, Denmark

Radar observations showed a high proportion of detours in the seabirds heading towards the wind farm during migration (KAHLERT *et al*.2004a, 2004b, DESHOLM & KAHLERT 2005): in the autumn of 2003, only 13.8% (nighttime) and 4.5% (daytime) of all migrating flocks of Eiders and geese entered the wind farm, which substantially lowered the risk of collision. However, according to DESHOLM & KAHLERT (2005), a relatively large proportion of the entering flocks (6.5% at night, 12.3% in daytime) flew closer than 50 m to turbines (compared to the very low proportion in Kalmar Sound, with a minimum distance of 100 m there). Because the flight altitude in the wind farm area is not known, the risk cannot be quantified. Compared to the wind farms in Kalmar Sound (much lower proportions approaching the wind farms and a minimum distance of 100 m), the risk at Nysted appears to be high.

Horns Rev, Denmark

Radar and visual observations revealed that detours were flown by seabirds migrating or moving locally (CHRISTENSEN *et al*. 2004, CHRISTENSEN & HOUNISEN 2004, 2005). Birds entering the wind farm changed their flight direction and adjusted their flight path parallel to the rows of turbines. This behaviour was more pronounced in daytime than at night, when flight paths were more likely to cross several rows of turbines, probably leading to higher collision risk. The same can be assumed during low visibility (e.g. fog), when detection of the turbines is probably reduced. Although some of the flight paths of

Common Scoters, gulls and terns shown in the figures by CHRISTENSEN & HOUNISEN (2005) pass quite close to turbines, it seemed that close proximity to the turbines was largely avoided, leading to lower general collision risk than with unaltered flights straight through the wind farm. Because the radar was oriented only horizontally, the birds tracked may also have crossed the wind farm above rotor height. The few published measurements of flight altitude at Horns Rev showed that all Cormorants and 61% of gulls, but only 9% of terns flew at rotor height (the remaining terns flew below rotor height, but the remaining gulls flew both lower and higher than rotor height).Hence, terns have lower collision risk than other birds which commonly fly between the turbines, such as gulls.

5.1.3 Habitat Loss for Seabirds

5.1.3.1 Disturbance and Avoidance

Studies on possible habitat loss for seabirds caused by disturbance from offshore turbines and avoidance reactions were conducted at four wind farms in the Baltic Sea (Tunø Knob, Utgrunden, Yttre Stengrund, Nysted) and one in the North Sea (Horns Rev). They cover only part of the 35 seabird species regularly living in marine areas of Germany (Table 2). Notably little information is available for species usually living far offshore in the North Sea (such as Fulmar, Sooty Shearwater, skuas etc.).

Tunø Knob, Denmark

Possible habitat loss was investigated via three approaches: comparison of bird densities in the wind farm area with a reference area 14 km distant; distribution of birds within the wind farm area; and two experiments (unless otherwise stated, all information is from GUILLEMETTE *et al*. 1998). Basically, the study was designed as a BACI-study (before-after-control-impact, GREEN 1979), i.e. data were collected before and after construction in the impact area and in an unaffected reference area. Since no other species was sufficiently abundant, the study focused on Eiders (90% of staging birds) and in part on Common Scoters (8%). Bird data were collected only in winter (November to April). The data from the baseline study were even more limited, only covering the period from mid February to mid April.

Pre-construction aerial surveys in the whole Århus Bay revealed significant correlations between total number of Eiders and the subsamples at Tunø Knob (the 5000 ha wind farm area) and Ringebjerg Sand (the 4700 ha reference area). These correlations were maintained during operation, but in Tunø Knob, the regression curve flattened, i.e. the proportion of Eiders there decreased. This was confirmed by a 32% decrease in their total number, although the difference to numbers before construction was not significant. The relation between Eider numbers there and at Ringebjerg Sand remained unchanged. Counts from the ground verified the decline at Tunø Knob, while numbers in the reference area did not fall below the pre-construction level. The changes in Eider numbers were concomitant with a strongly fluctuating November supply of the size classes of blue mussels (*Mytilus edulis*) which are profitable prey for Eiders. These classes were lacking during the first two years of operation at Tunø Knob, which was probably the reason for the low numbers of Eiders. This was supported by the results from an additional study period in the third year of operation, when profitable size classes of mussels as well as large numbers of Eiders were present (GUILLEMETTE *et al*. 1999). Thus, the authors regard the fluctuating Eider numbers as a reaction to the available food supply and classify it as natural variation. They conclude that spatial distribution was not affected by the wind turbines (GUILLEMETTE *et al*. 1998, 1999). The connection between food supply – the biomass of the bivalves *Cardium* spp. and *Spisula subtruncata* – and spatial distribution of Eiders was studied in greater detail the second year after the turbines were taken into operation, in four 200 x 200 m plots at distances of 0, 300, 320 and 600 m from the turbines. A strong correlation between bivalve biomass and Eider numbers was found. As these factors explained 93-98% of the variation, the impact of the turbines seemed negligible.

Within the four parts of the Tunø Knob area studied, Eider numbers showed a similar variation compared to the total wind farm area. During the baseline period, the four plots showed a stronger correlation with each other than during the first two years of operation. The authors conclude that this too is due to natural variation (GUILLEMETTE *et al*. 1998). On a smaller scale (1 ha plots), much variation occurred among seasons and years. Even a short time after the construction, Eiders were seen between the turbines. In the third year of operation, many Eiders were present in the wind farm, at less distance to the turbines than in the two preceding years, with a distribution much like that of the baseline year (GUILLEMETTE *et al*. 1999).

To investigate the effect of operation (motion, noise) on spatial distribution, Eiders were counted on successive days with moving and non-moving rotors, respectively. In the two observed zones, 200 m and 200-600 m around the wind farm, no significant difference was noted between operational and non-operational days. Not even the spatial distribution within the zones changed. When the rotors were turned on again, none of the ten Eider flocks observed (1-10 birds) took off, and their swimming movements varied: During the first 5 minutes, some approached to as close as 60 m, while others withdrew up to 35 m.

Decoy Eiders put out at different distances to the turbines were used to induce flying Eiders to land on the water. The attractive effect of the decoys increased with the distance to the turbines, i.e. fewer Eiders landed at 100 m distance than at 300 m and 500 m distance. This can be explained only in part by fewer Eiders flying close to the turbines.

Compared to the baseline year, Common Scoters sharply decreased at Tunø Knob in the first year of operation, nearly disappeared the second year, but were abundant the third year (GUILLEMETTE *et al*. 1999). In the Ringebjerg Sand reference area they initially stayed constant, but completely disappeared the second year. This shows that fluctuating numbers also occur in species other than Eider, but the role of wind farms remains unclear in this case. Cormorant droppings found on turbine foundations during a study of Eiders indicate that cormorants may rest on the foundations (TULP *et al*. 1999).

Utgrunden, Sweden

In Kalmar Sound, staging and wintering birds were counted during construction and operation of the wind farm in two adjacent plots: one containing seven turbines (UT1, 60 km², calculated from Fig. 3 in PETTERSSON 2001) and the other serving as a non-manipulated reference area (UT2, 41 km²). Counts were conducted from the lighthouse in the middle of the Sound, but sometimes also from ships or aircraft. Before construction, birds were counted only twice (spring 1998, spring 1999; PETTERSSON 2001), but results of both plots were lumped together and are given only for four species. Considerably more counts are available for the operational period and details are given for nine species. Due to the lack of additional information needed for the interpretation of the spatial distribution (e.g. food supply, disturbance) and because natural fluctuation seems to occur in this part of the Kalmar Sound (PETTERSSON 2005), these data are hardly useful for the assessment of wind farm impacts. Furthermore, it must be considered that the wind farm consists only of a single row of turbines, probably limiting comparability to wind farms with several rows.

Staging and wintering birds were also counted from the lighthouse in parts of UT1 (UT10, in wind farm area) and UT2 (UT20, in reference area) in the spring seasons of 1999 (pre-construction) and 2001 (operation; PETTERSSON 2002). From 1999 to 2001, stocks of most species increased, but Long-tailed Ducks decreased to only about half of their former numbers (both in UT10 and UT20, Table 10). Bird numbers for UT10 and UT20 partially contradict the results reported from the same day for UT1 and UT2. For example, divers are completely absent in UT1, despite being mentioned as occurring in relatively high numbers in UT10, which is located within UT1. Such contradictions can also be found for counts in other seasons (again, especially for divers), for which no comparative data are available for the pre-construction period (PETTERSSON 2002). However, possible natural fluctuation prevents detection of wind farm impacts on bird numbers in this short-term study.

Table 10: Minimum and maximum numbers of seabirds counted in parts of the study plots UT1 and UT2 near the Utgrunden wind farm in the Kalmar Sound (from PETTERSSON 2002).

Study plot	UT10 (wind farm)	UT10 (wind farm)	UT20 (reference area)	UT20 (reference area)
Period	30 March – 2 April 1999 (pre-construction)	26 March – 4 April 2001 (operation)	30 March – 2 April 1999 (pre-construction)	26 March – 4 April 2001 (operation)
Number of counts	2	4	2	4
Divers	0-2	3-15	2-12	2-22
Cormorant	0-6	12-35	0	3-22
Eider	220-350	55-650	350-400	200-700
Long-tailed Duck	770-900	350-500	650-700	100-450
Common Scoter	15-70	0-12	0-45	0-10
Red-breasted Merganser	0-5	0-25	0	0-20

From the lighthouse, the observer mapped the exact locations of roosting and foraging Eiders and Long-tailed Ducks within UT10 and UT20. In the spring of 1999, positions were estimated according to the location of buoys, but in 2001, 2002 and 2003 a compass and rangefinder were used. Although the numbers partially changed, Long-tailed Ducks were seen in exactly the same places. Even foraging areas in close proximity to the turbines were retained, with Long-tailed Ducks diving less than 100 m from turbines and flying back and forth between them (PETTERSSON 2002, 2003, 2005). As in the pre-construction period, Eiders remained in the area north of the wind farm, but were seen at distances below 1 km from the northernmost turbine (PETTERSSON 2005). The same applies to Common Scoters, whereas flocks of Red-breasted Mergansers were also present south of the northernmost turbines and less than 1 km away from them (PETTERSSON 2005). Foraging Cormorants were also observed near turbines (PETTERSSON 2002).

At least in part, seabird distribution around the Utgrunden wind farm can be explained by food supply and disturbance caused by service boats (PETTERSSON 2005). Basic investigations of blue mussels revealed high densities just north of the turbines and lower densities in the centre of the wind farm. Accordingly, their predators (staging Eiders and Long-tailed Ducks) concentrated in the area of high prey density north of the turbines. Observations of bird behaviour and the diurnal rhythm of abundance in the study plots showed that Long-tailed Ducks and Red-breasted Mergansers (and perhaps also Common Scoters, but not Eiders) were displaced by service boats operating in the wind farm. Individuals of the two species mentioned first returned to their foraging sites only 21-30 minutes after the service boat had left the area.

Yttre Stengrund, Sweden

Aerial, ship-based and land-based surveys in the wind farm area were conducted ten times before construction and eighteen times during operation. A reference area was counted ten and twenty times, respectively (PETTERSSON 2005). As in the parallel study at Utgrunden, the significance of the data for ten species is limited. Again, the lack of information on biotic and abiotic factors other than wind turbines prevents the detection of wind farm effects on seabird numbers. Also, the presence of only one turbine row restricts extrapolation of the results to larger wind farms.

Nysted, Denmark

Aerial surveys along transects were used to describe the spatial distribution of staging and wintering birds in a 1350 km² large area of the Baltic Sea south of the islands Lolland and Falster. Twenty surveys took place before the construction of the wind farm (August 1999 to March 2002), four during construction (August 2002, January, March and April 2003; Kahlert *et al*. 2004b) and five during operation (December 2003, January, 2x March, April 2004; PETERSEN 2004).

Based on the bird densities in the total study area, avoidance or preference was investigated by using the selectivity index of JACOBS (1974) for three areas: the wind farm (WF, approx. 23 km²), the wind farm plus a 2 km zone around it (WF+2-zone) and the wind farm plus a 4 km zone around it (WF+4-zone). To date, selectivity indices for pre-construction, construction and operational periods for March and April have been compared, both for numbers of individuals and numbers of flocks. Most seabird species only occur in shallow waters near the coast, and only three species proved to be abundant in the wind farm area and its surroundings. The three periods are compared only for those species.

Before construction, **Eiders** avoided the wind farm area, but in the WF+2 and WF+4 zones, their density resembled that of the total area (Table 11). During construction, the wind farm was abandoned completely, and index values became negative in the zones around it. Compared to the total study area, the wind farm was still mostly avoided during operation (in total 16 birds in three surveys), and in the surrounding the index values further declined (Tables 11 and 12). Derived from data given by KAHLERT *et al*. (2004b) and PETERSEN (2004), during operation the relative number of Eiders increased by 48% compared to the situation before construction in the wind farm, but decreased by 88% in the WF+2 zone and 44% in the WF+4 zone (Table 13).

Table 11: Selectivity index D (after JACOBS 1974) of seabirds in the Nysted wind farm and the 2 km and 4 km buffer zones, during the baseline period (4 April and 26 April 2000, 16 March and 20 April 2001, 26 March 2002), during construction (4 March and 24 April 2004) and during operation (5 March, 24 March and 15 April 2004). Positive values (maximum +1) indicate preference and negative ones (minimum –1) avoidance of the tested area compared to the whole study area (0: bird density in tested area is equal to whole study area). Taken from KAHLERT *et al*. 2004b and PETERSEN 2004 (levels of significance are not given).

		Bird numbers				Flock numbers			
		WF	WF+2	WF+4		WF	WF+2	WF+4	
		D	D	D	n	D	D	D	n
Eider	baseline	-0.81	-0.13	0.04	21020	-0.14	0.13	0.24	1154
	construction	-1.00	-0.58	-0.16	2573	-1.00	-0.24	-0.07	282
	operation	-0.73	-0.77	-0.42	5116	-0.16	-0.25	-0.01	552
Long-tailed Duck	baseline	0.46	0.46	0.40	5966	0.64	0.68	0.65	939
	construction	-0.91	-0.13	-0.10	1794	-0.64	0.13	0.24	399
	operation	-0.20	-0.12	-0.09	4474	0.29	0.35	0.29	782
Herring Gull	baseline	-0.64	-0.65	-0.38	4779	-0.29	-0.28	-0.15	1416
	construction	-0.52	-0.66	-0.05	824	-0.21	-0.40	-0.26	403
	operation	-0.71	-0.78	-0.75	9428	-0.14	-0.24	-0.33	1655

Table 12: Changes in selectivity index D (bird numbers) for seabirds at the Nysted wind farm, and in the 2 km and 4 km buffer zones, from the baseline period to the construction and operational periods, (calculated from KAHLERT *et al*. 2004b and PETERSEN 2004; levels of significance are not given).

	construction			operation		
	WF	WF+2	WF+4	WF	WF+2	WF+4
Eider	-0.19	-0.45	-0.20	+0.08	-0.64	-0.46
Long-tailed Duck	-1.37	-0.59	-0.50	-0.66	-0.58	-0.49
Herring Gull	+0.12	-0.01	+0.33	-0.07	-0.13	-0.37

Table 13: Proportion of seabirds present in the Nysted wind farm (WF) and the 2 km and 4 km buffer zones, during the operational period compared to the baseline period (calculated from KAHLERT *et al*. 2004b and PETERSEN 2004).

	WF	0-2 km distance	2-4 km distance
Eider	+48.0%	-87.8%	-45.2%
Long-tailed Duck	-74.4%	-65.0%	-41.6%
Herring Gull	-22.1%	-47.9%	-75.2%

For **Long-tailed Ducks**, the wind farm and its surrounding area were among the clearly preferred areas south of Lolland and Falster islands. During construction, the wind farm was almost completely avoided, and the surrounding zones were distinctly less attractive (Table 11). Considering numbers of birds, selectivity indices were still low during operation, but increased slightly compared with the construction period. However, the whole area seemed to be avoided. Considering flocks, the wind farm and surrounding zones belonged to the preferred areas within the whole study area, but these also showed lower selectivity indices than in the baseline years. From pre-construction to operation, bird numbers decreased by 74% in the wind farm, by 65% in the 0-2 km zone and by 42% in the 2-4 km zone (Table 13). When plotting the numbers of Long-tailed Ducks within 4 km against their distance from the wind farm, the curve is flattest in the year of construction (2003); in the operational period (2004), it resembles those of the three pre-construction years. Hence, avoidance of the wind farm was greatest during construction and was within the natural range during operation. The three spring surveys during the operational period recorded a total of 60 Long-tailed Ducks in the wind farm.

During all periods, **Herring Gulls** visited the wind farm and its surrounding area in lesser densities than in the total study area. Based on bird numbers, this avoidance was strongest during operation and weakest in the baseline period. However, the differences were small compared to the two duck species. A similar result was obtained for the number of flocks, but the avoidance of the wind farm was more pronounced before construction than afterwards. (Table 11). Compared to the pre-construction period, Herring Gulls decreased by 22% (WF), 48% (0-2 km zone) and 75% (2-4 km zone) during operation (Table 13). A total of 32 Herring Gulls was counted within the wind farm during the three spring surveys. It is worth noting that the distribution of Herring Gulls in the study area is strongly influenced by the distribution of active fishing vessels (KAHLERT *et al*. 2004b).

Anecdotal information is available for other seabirds, which are less abundant in the wind farm area (KAHLERT *et al*. 2004a, 2004b, PETERSEN 2004). All divers observed during construction were at least 1400 m away from the turbines. During operation, one diver was seen inside and another 200 m outside the wind farm. The study area was visited by only a few **Common Scoters** (maximum number: 133 birds). During the surveys, a flock of 12 birds was seen within the wind farm (construction). A total of 14 **Red-breasted Mergansers** was observed within or close to the wind farm during operation. During radar observation of bird movements, three large flocks of foraging **Cormorants** (1500, 2150 and 3700 birds) were detected within the wind farm or less than 1 km away. Workers reported that Cormorants were diving in the wind farm area and resting on the foundations.

Horns Rev, Denmark

With the same methods and by the same researchers as in the Nysted wind farm, the spatial distribution of seabirds in the Horns Rev area was monitored by aerial surveys. The study area of 1846 km² extends to the Danish coastline from Blåvandshuk to Fanø. Sixteen surveys were conducted during the baseline period (April 1999 to August 2001), five during construction (September 2001 to August 2002; CHRISTENSEN *et al*. 2003), and ten (to date) during operation (February to December 2003, PETERSEN *et al*. 2004; February to September 2004, PETERSEN 2005). As two surveys (7 January and 12 March 2002) took place during the construction period, but at times with no turbines built and no construction in progress (see CHRISTENSEN *et al*. 2003), it seems that they were later on treated as baseline data, while the first two surveys (20 April and 4 May 1999) were no longer considered in the most recent reports (PETERSEN *et al*. 2004, PETERSEN 2005).

In relation to the bird density in the total study area, avoidance and preference of three areas was identified by means of the selectivity index of JACOBS (1974): the wind farm itself (approx. 20 km²), the wind farm plus 2 km around it (WF+2-zone) and the wind farm plus 4 km around it (WF+4-zone). The indices were compared for all months, grouped into pre-construction, construction and operational periods for both the number of individuals and the number of flocks (CHRISTENSEN *et al*. 2003, PETERSEN *et al*. 2004). Most recently, the same approach was used for the spring season (February to May) only, but including two years of operation (PETERSEN 2005). Therefore, post-construction results are presented two-fold, for the whole year and for spring only. No survey results have been reported from the period when the rotors were taken down temporarily due to technical problems (summer and autumn 2004). The procedure outlined above was applied only to species regularly occurring in the offshore parts of the study area, but not for species restricted to coastal areas. Bird numbers in the wind farm and the zones around it were tested for significant differences between the two baseline years (1999 and 2000) and the construction period. Such a test was not applied during the operational period.

In the baseline period, divers were present in the wind farm area in approximately the same density as in the total study area, and in the WF+2- and WF+4-zones densities were only slightly lower. In contrast to this, these areas were strongly avoided in the construction period and nearly completely abandoned during operation (with no birds within the wind farm area itself; Table 14 and 15). The decline in the wind farm during construction is not significant, because only a single diver was observed, which was in fact 2.5 km away from the only active ship (at that time no turbine had been built). However, when including the surrounding zones, the decline is significant. During heavy construction work in April 2002, no diver came closer than 2 km to the wind farm area. Compared to the baseline period, divers decreased by 100% (wind farm), 97% (0-2 km distance from WF) and 77% (2-4 km distance from WF) during the operational period (Table 17). Visual observations of flying birds once revealed a diver foraging at the edge of the operating wind farm, and several others at distances of 100-800 m from the next turbine (CHRISTENSEN *et al*. 2004).

Gannets were never recorded in the wind farm area (even during the baseline period), but when the surrounding zones are included, the selectivity indices declined from the baseline to the operational period (Table 14). Furthermore, many fewer Gannets were observed there during operation than expected from the baseline surveys (Table 17). Aerial surveys revealed no **Cormorants** in the wind farm. Changes in the selectivity indices (Tables 14 and 16) can be explained by a single observation of a Cormorant during the baseline period in the WF+4-zone, while the only Cormorant seen during the operational period was in the WF+2-zone. During visual observations from the transformer station, a Cormorant was once seen resting on the fence of a foundation of a turbine with rotating blades (CHRISTENSEN *et al*. 2004). During the spring of 2004, a number of observations referred to 2-3 **Shags** resting on the meteorological mast east of the wind farm, and at least one bird foraged between the turbines (CHRISTENSEN & HOUNISEN 2004).

Eiders were among the three most abundant species in the study area, but were concentrated close to the coast and usually did not occur in the wind farm and surrounding areas (Table 14). Inside the wind farm, only one Eider was seen during the baseline surveys; none were recorded during operation.

With up to 381,000 individuals (March 2003), **Common Scoters** were by far the most abundant seabirds in the total study area, but numbers and distribution varied greatly among the years studied. Compared to the total study area, the wind farm area and WF+2-zone appeared to be avoided during the pre-construction period, but the large numbers of Common Scoters in the WF+4-zone resulted in a nearly balanced D-value (Table 14). During construction, the proportions of Common Scoters in the wind farm and WF+2-zone increased (Tables 14 and 16). However, the increase compared to the first baseline year was significant as was the decrease compared to the second baseline year. During operation, the wind farm and the WF+2-zone were completely abandoned and the WF+4-zone was strongly avoided (Table 14). This avoidance was less pronounced when including data from the spring of 2004 (Table 15), as large numbers were present in the vicinity of the northwestern corner of the wind farm at that time. That Common Scoters usually do not forage or rest between the turbines may at least in part be due to reluctance to fly into the wind farm. In a sample of 96 flocks approaching the wind farm in the spring of 2004, 76 landed on the water (mostly more than 500 m from the nearest turbine); the remaining 20 flocks changed flight direction (CHRISTENSEN & HOUNISEN 2005).

Arctic Skuas were not seen in any considerable numbers during the aerial surveys, but some of them were observed within the wind farm from the transformer station (CHRISTENSEN *et al*. 2003, Table 6). As they seemed to be attracted by gulls, these birds can be regarded as foraging birds and therefore fall into the category of species which do not generally avoid wind farms.

On the basis of their presence in the entire study area, **Herring Gulls** avoided the wind farm area in the baseline period, but were more abundant there during operation and especially during construction (Tables 14, 15 and 16, significant increase for the construction period). The authors attribute this shift to the attractive effect of ship traffic. In addition, the foundations may have been used for resting. The latter was noted four times during systematic observations from the transformer station (once at an operating turbine, CHRISTENSEN *et al*. 2004).

Changing preferences were even more pronounced in **Great Black-backed Gulls**, which initially strongly avoided the wind farm and its surroundings (baseline period), but obviously preferred this area during operation (Tables 14 and 16). The situation was not so clear during the construction period (strong avoidance of the wind farm, but increased selectivity indices in the surrounding zones plus the wind farm, Table 14). Systematic observations from the transformer station showed Great Black-backed Gulls eight times resting on turbines, three of which were operating (CHRISTENSEN *et al*. 2004).

In the total study area, numbers of **Little Gulls** showed great variability between years. They avoided the wind farm area before and especially during construction. By contrast, the area was clearly preferred during the operational period (Tables 14 and 16). Considering only spring data (2003 and 2004), the wind farm itself was still avoided (Table 15). During the survey in December 2003, the majority of the Little Gulls observed were foraging between the turbines.

Many **Kittiwakes** were present in the study area in the baseline and construction periods, but the wind farm area and zones around it were avoided (more so during the construction period than during the baseline period, Table 14). This decrease was significant only in the WF+2 and WF+4 zones. In the first year of operation, the species occurred in much lower numbers in the study area as a whole. Eight birds were seen within the wind farm area and another three in the surrounding zones, but due to the low total number, the increased D-values (Table 14) have low significance. Including data from the second year of operation (2004), the wind farm is still an avoided area, whereas this effect seems to be less pronounced in the surrounding zones (Table 15). Without giving more details, CHRISTENSEN *et al*. (2004) mention that Kittiwakes were observed resting on fences of the turbine foundations.

Table 14: Selectivity index D (from JACOBS 1974) of seabirds in the Horns Rev wind farm and the 2 km and 4 km buffer zones, during the baseline (August 1999 to March 2002), construction (September 2001 to August 2002) and operational periods (February to December 2003). Data obtained from the entire year. Positive values (maximum +1) indicate preference and negative values (minimum –1) avoidance of the tested area compared to the entire study area (0: bird density in tested area equals that of entire study area). Values are printed bold if based on significantly different proportions (χ^2 tests). Note that the counts on 7 January and 12 March 2002 are included in both the baseline and the construction period because of different classification in CHRISTENSEN *et al*. (2003) and PETERSEN *et al*. (2004).

		Bird numbers				Flock numbers			
		WF	WF+2	WF+4		WF	WF+2	WF+4	
		D	D	D	n	D	D	D	n
Divers	baseline	0.00	-0.01	**-0.13**	1331	0.10	0.02	-0.10	926
	construction	-0.66	**-0.78**	**-0.46**	322				
	operation	**-1.00**	**-0.96**	**-0.87**	1036	**-1.00**	**-0.93**	**-0.76**	548
Gannet	baseline	**-1.00**	**-0.45**	-0.02	515	-1.00	-0.27	-0.15	241
	construction								
	operation	-1.00	**-0.77**	**-0.68**	149	-1.00	-0.68	**-0.57**	103
Cormorant	baseline	-1.00	**-1.00**	**-0.90**	168	-1.00	-1.00	-0.65	45
	construction								
	operation	-1.00	-0.57	**-0.77**	73	-1.00	0.37	0.01	10
Eider	baseline	**-0.99**	**-1.00**	**-1.00**	12,600	**-0.81**	**-0.94**	**-0.94**	593
	construction	**-1.00**	**-1.00**	-1.00	1349				
	operation	**-1.00**	**-0.98**	**-0.96**	5018	**-1.00**	**-0.91**	**-0.83**	396
Common Scoter	baseline	**-0.60**	**-0.35**	**-0.07**	128,786	**-0.73**	**-0.61**	**-0.45**	3977
	construction	**-0.33**	**-0.21**	**-0.33**	49,823				
	operation	**-1.00**	**-1.00**	**-0.87**	574,988	**-1.00**	**-0.98**	**-0.80**	3792
Herring Gull	baseline	**-0.93**	**-0.86**	**-0.76**	18,005	**-0.75**	**-0.63**	**-0.48**	3828
	construction	**-0.47**	**0.12**	**0.25**	4131				
	operation	**-0.65**	**-0.57**	**-0.53**	11,064	0.04	-0.01	0.03	1753
Great Black-backed Gull	baseline	**-0.80**	**-0.56**	**-0.43**	556	**-0.74**	**-0.45**	**-0.37**	417
	construction	-1.00	-0.29	0.03	108				
	operation	**0.62**	**0.44**	**0.45**	95	0.50	0.33	**0.41**	87
Little Gull	baseline	-0.34	-0.23	-0.12	127	-0.22	-0.09	0.03	97
	construction	-1.00	**-0.66**	**-0.45**	286				
	operation	**0.46**	**0.40**	**0.37**	822	0.31	**0.37**	**0.44**	410
Kittiwake	baseline	**-0.34**	**-0.30**	**-0.22**	2520	-0.24	-0.13	0.03	1118
	construction	**-0-56**	**-0.80**	**-0.64**	700				
	operation	**0.65**	**0.20**	0.00	113	-0.04	-0.55	-0.27	68
Arctic/Common Tern	baseline	**-0.23**	**-0.41**	**-0.28**	2400	-0.05	**-0.20**	-0.07	1042
	construction								
	operation	**-1.00**	**0.33**	**0.21**	378	-1.00	0.23	0.20	185
Guillemot/Razorbill	baseline	-0.28	**-0.32**	**-0.13**	1104	-0.15	-0.17	-0.07	590
	construction	-1.00	**-1.00**	**-1.00**	207				
	operation	**-1.00**	**-0.55**	**-0.44**	415	-1.00	-0.38	**-0.32**	224

Table 15: Selectivity index D (after JACOBS 1974) of seabirds in the Horns Rev wind farm (WF) and the 2 km and 4 km buffer zones, during the baseline period (seven surveys 2000 to 2001) and during operation (six surveys 2003 and 2004). Only spring data (February to May) are considered (after PETERSEN 2005). Note that baseline values are different from Table 14, because they are based on a different selection of surveys. Positive values (maximum +1) indicate preference and negative ones (minimum –1) avoidance of the tested area compared to the whole study area (0: bird density in tested area is equal to whole study area). Values are printed bold if based on significantly different proportions (χ² tests).

		bird numbers				flock numbers			
		WF	WF+2	WF+4		WF	WF+2	WF+4	
		D	D	D	n	D	D	D	n
Divers	baseline	-0.01	0.02	**-0.16**	1106	0.10	0.04	-0.13	734
	operation	**-1.00**	**-0.95**	**-0.81**	1611	**-1.00**	**-0.91**	**-0.69**	924
Gannet	baseline	-1.00	-1.00	**-0.77**	74	-1.00	-1.00	-0.59	38
	operation	**-1.00**	**-1.00**	**-0.87**	450	-1.00	**-1.00**	**-0.73**	134
Eider	baseline	**-0.99**	**-1.00**	**-0.99**	9168	-0.69	**-0.89**	**-0.89**	345
	operation	**-1.00**	**-0.96**	**-0.94**	4730	**-1.00**	**-0.67**	**-0.68**	334
Common Scoter	baseline	**-0.38**	**-0.06**	**0.26**	71,978	**-0.45**	**-0.16**	0.06	1327
	operation	**-0.93**	**-0.56**	**-0.58**	578,233	**-0.57**	-0.03	**-0.15**	4885
Herring Gull	baseline	**-0.94**	**-0.88**	**-0.81**	13,027	**-0.66**	**-0.63**	**-0.41**	1529
	operation	**-0.74**	**-0.61**	**-0.59**	13,298	0.04	-0.04	0.00	1680
Little Gull	baseline	-1.00	-1.00	-0.30	37	-1.00	-1.00	0.06	19
	operation	**-0.71**	**0.24**	**0.27**	826	-0.48	**0.25**	**0.35**	394
Kittiwake	baseline	-0.63	-0.27	-0.11	283	-0.38	-0.16	0.02	141
	operation	**-1.00**	0.06	**-0.25**	366	-1.00	-0.25	-0.39	148
Arctic/Common Tern	baseline	-0.21	**-0.35**	**-0.31**	586	-0.01	-0.17	-0.07	261
	operation	**-1.00**	0.14	**0.16**	575	-1.00	-0.04	-0.07	295
Guillemot/Razorbill	baseline	-0.07	-0.08	**-0.33**	219	-0.12	-0.14	-0.34	164
	operation	-1.00	**-0.65**	**-0.66**	309	-1.00	**-0.61**	**-0.62**	182

Table 16: Changes in selectivity index D (bird numbers) for seabirds in Horns Rev wind farm (WF) as well as including 2 km and 4 km buffer zones from the baseline period to the construction and operation period, respectively (calculated from CHRISTENSEN *et al*. 2003, PETERSEN *et al*. 2004 and PETERSEN 2005). Values are printed bold if derived from pairs of D-values, which both are based on significantly different proportions (χ² tests). Discrepancies to Table 14 are owing to different classifications of two counts (7 January and 12 March 2003) by the two authors.

	Construction (all year, 2001-2002)			Operation (all year, 2003 only)			Operation (spring only, 2003-2004)		
	WF	WF+2 km	WF+4 km	WF	WF+2 km	WF+4 km	WF	WF+2 km	WF+4 km
Divers	-0.66	-0.79	**-0.29**	-1.00	-0.95	**-0.74**	-0.99	-0.97	**-0.65**
Gannet				-	**-0.32**	-0.66	0.00	0.00	**-0.10**
Cormorant				-	+0.43	**+0.13**			
Eider	**-0.01**	**0.00**	0.00	**-0.01**	**+0.02**	**+0.04**	**-0.01**	**+0.04**	**+0.05**
Common Scoter	**+0.17**	**-0.01**	**-0.40**	**-0.40**	**-0.65**	**-0.80**	**-0.55**	**-0.50**	**-0.32**
Herring Gull	**+0.47**	**+1.00**	**+0.99**	**+0.28**	**+0.29**	**+0.23**	**+0.20**	**+0.27**	**+0.22**
Great Black-backed Gull	0.00	+0.26	+0.52	**+1.42**	**+1.00**	**+0.88**			
Little Gull	0.00	-0.22	-0.19	+0.80	+0.63	+0.49	+0.29	+1.24	+0.57
Kittiwake	**-0.18**	**-0.55**	**-0.49**	**+0.99**	+0.50	+0.22	-0.37	+0.33	-0.14
Common/Arctic Tern				**-0.77**	**+0.74**	**+0.49**	-0.79	+0.49	**+0.47**
Guillemot/Razorbill	-0.77	**-0.70**	**-0.96**	-0.72	**-0.23**	**-0.31**	-0.93	-0.57	**-0.33**

The wind farm and its surrounding were avoided by **Common and Arctic Terns** before construction. During operation, the zones around the wind farm became preferred areas, whereas no tern had been seen within the wind farm during the aerial surveys (Tables 14, 15 and 17). However, as the terns observed in the operational period were aggregated into a few flocks, the significance of these data appears to be low. Without giving more details CHRISTENSEN *et al*. (2004) report that Common/Arctic Terns were seen resting on fences of the turbine foundations.

Guillemots and Razorbills were already underrepresented in the wind farm and the surrounding area during the baseline surveys, but they completely avoided this area during construction (no auk occurred within 4 km of the wind farm, see Table 14; significant decrease). In the operational period auks kept away from the wind farm as well. In the WF+2 and WF+4 zones, the selectivity indices decreased compared to the baseline period, with auks occurring 14% and 49%, respectively, less than expected in the zones around the wind farm (Table 14, 15, 16 and 17).

In summary, it was shown that during the baseline years the wind farm and its surrounding area did not belong to the preferred sites within the study area as a whole for most species. Only Common Scoters were present in the WF+2- and WF+4-zones in densities above average. Divers, Common/Arctic Terns and Guillemots/Razorbills occurred in more or less expected densities. During construction, most species (divers, Great Black-backed Gull, Little Gull, Kittiwake, Guillemot/Razorbill) avoided the wind farm area; to some extent, this also applies to the surrounding zones. Common Scoters and especially Herring Gulls increased during this period. From the fact that in most species (except Kittiwakes) decreases in the construction period were based on non-significant D-values in the baseline period and that changes of the D-values were more pronounced in the surrounding zones than in the wind farm itself, CHRISTENSEN *et al*. (2003) conclude that an effect of the turbines and/or construction cannot be verified. Low sample sizes limited the possibility of direct comparison between bird numbers in the wind farm down to five species/groups. A significant decline was found only in auks, whereas Herring Gulls increased significantly; Common Scoters increased or decreased significantly, depending on which baseline year is chosen. Changes of diver and Kittiwake numbers were not significant.

Tab. 17: Proportion of seabirds present in the Horns Rev wind farm (WF) and in the 0-2 km and the 2-4 km zones during the operational period, compared with the baseline period (calculated from PETERSEN *et al*. 2004).

	WF	0-2 km zone	2-4 km zone
Divers	-100..0%	-96.8%	-77.0%
Gannet	-	-65.0%	-82.4%
Common Scoter	-100.0%	-100.0%	-88.0%
Herring Gull	+470.3%	+223.8%	+71.6%
Great Black-backed Gull	+3433.3%	+324.0%	+287.1%
Little Gull	+427.4%	+177.6%	+78.8%
Kittiwake	+801.9%	-100.0%	-31.1%
Common/Arctic Tern	-100.0%	+737.2%	+37.8%
Guillemot/Razorbill	-100.0%	-14.1%	-49.0%

During the operational period, divers, Common Scoters, Common/Arctic Terns and Guillemots/Razorbills did not occur in the wind farm at all, and except for the terns, they also declined in the zones to 4 km. Compared to the baseline period, Herring Gulls showed reduced avoidance of the wind farm. Great Black-backed Gulls avoided the wind farm before construction, but preferred it during operation. The same was true for Little Gulls over the entire year, but not for the spring. Changed preference was also observed for Common/Arctic Terns, but only in the surrounding zones. From notes by CHRISTENSEN *et al*. (2004) it appears that birds only rarely use the foundations for resting, and then mostly at the edge of the wind farm and when the rotors are not moving.

The authors of the reports (last by PETERSEN 2005) stressed that avoidance should not only be attributed to the physical presence of the turbines, but possibly also to service boat traffic (on approx. 150 days per year).

5.1.3.2 Habitat Alteration

Since offshore wind farms are commonly built on soft subtrate, the construction of turbines introduces a new type of habitat for benthic organisms. The settlement of sessile invertebrates and algae as well as the subsequent attraction of mobile invertebrates and fish are known as the “reef effect”. It was argued that seabirds may benefit from this increase in biomass, especially if fish stocks increase because of the absence of fisheries (PERCIVAL 2001). Results from studies at operating wind farms – even if only very preliminary – confirmed the assumed development of hard bottom communities, but their utilisation by seabirds remains to be proven. Physical habitat loss, i.e. the replacement of soft by hard substrate, can be regarded as being of little significance. The area of soft bottom and the respective amount of infauna lost is far below 1% in large wind farms and thus seems to be negligible. Initial results from Horns Rev also indicate that the benthic community and sandeels (an important prey species for seabirds) are not negatively affected.

Svante, Sweden

Fish studies were conducted at this single wind turbine, which was built 250 m offshore at Nogersund in southeastern Sweden in 1990. In up to 200 m distance from the turbine, more fish were caught when the rotor did not move compared to periods of operation. However, it remained unclear whether this was due to the fact that the catchability of the fish was being measured, or because fish were attracted during non-operation (reef effect), or disturbed during operation (WESTERBERG 2000).

Vindeby, Denmark

This wind farm with 11 turbines was built in 1991 in the Baltic Sea 1.5 km off the north coast of Lolland. It was thought that an artificial reef habitat including blue mussels (*Mytilus edulis*) developed on the turbine foundations. Fish stocks increased after the construction of the wind farm (LEMMING 1999, cited in PERCIVAL 2001).

Horns Rev, Denmark

Due to the construction of the wind turbines hard subtrate was introduced to the Horns Rev area. Each turbine is surrounded by a scour protection of stones, with a diameter of about 20 m. Therefore, about 0.025 km² of soft bottom seabed (0.1% of the total wind farm area) are replaced by hard substrate. In addition, the turbines themselves (4 m diameter of the monopile foundation) present habitat for epifouling organisms. In 2003, the year after the construction of the wind farm, seaweed and dense aggregations of blue mussels were growing on the hard substrate introduced (controlled by the starfish *Asterias rubens*), with mobile organisms occurring increasingly towards the sea bottom. Stable communities are expected to occur only 5-6 years after construction. Compared to the normal soft bottom seabed fauna, the food availability for fish was estimated to increase by eight times. Close to the new hard bottom fauna, a total of 14 fish species were observed, with some of them present in shoals and probably attracted by the increased food supply (LEONHARD & PEDERSEN 2004).

Compared to the pre-construction period (sampling in September 2001), the soft bottom benthos fauna in the wind farm area changed significantly during the operational period (sampling in September 2003). However, no difference was detected between the wind farm area and a reference area, indicating that natural variation rather than the operating turbines was responsible for the change, to which an increase in the particle size of the sediment seems to have contributed. The authors of the report on the infauna (BECH *et al*. 2004) stress that the Horns Rev area is a highly dynamic environment with migrating bedforms. When comparing a pre-construction survey (February/March 2002) with a survey during operation (March 2004), no negative impact from the wind farm could be detected for sandeels (JENSEN *et al*. 2004), an important prey for seabirds.

Nysted, Denmark

The concrete foundations and the scour protection of stones (total diameter: 25 m) introduced about 0.04 km² of hard substrate into the wind farm area, i.e. 0.17% of its total area. In October 2003, 19-49 weeks after the deployment of the foundations and 16-28 weeks after the placement of stones into and around the foundation, a fouling community of mussels, barnacles and macroalgae had started to develop. The thick layer of mussels at a monitoring mast in the wind farm six years after its construction demonstrates that this community is in its first stages and further development can be expected (BIRKLUND & PETERSEN 2004).

5.1.4 Habituation

Due to the short time the offshore wind farms have been in operation and because of relatively short durations of the environmental studies, it has so far not been possible to draw conclusions about habituation of seabirds to turbines at sea. The presence and behaviour of some species within wind farms suggests that they became accustomed to the turbines, but this is difficult to judge for species avoiding wind farms, at least in the first years of their presence. However, the quite obvious avoidance of the Horns Rev wind farm by divers and auks was maintained during the second year of operation (PETERSEN 2005). This is partially true, too, for the Common Scoter, but its avoidance decreased in the surrounding zones compared to the first year of operation (PETERSEN 2005). This may have been an effect of local food distribution (which has not been investigated). That habituation can occur has been demonstrated in the case of several small wind farms located at coastlines, which are regularly crossed by Cormorants, ducks, gulls and terns on flights between breeding colonies, roosts and offshore foraging areas (STILL *et al*. 1996, DIRKSEN *et al*. 1998a, 1998c, PAINTER *et al*. 1999, VAN

DEN BERGH *et al*. 2002, EVERAERT 2003). Birds flying close to turbines still show changed flight paths or even panic reactions (DIRKSEN *et al*. 1998a, VAN DEN BERGH *et al*. 2002, EVERAERT 2003). This was also observed in the evening flights of gulls to their night roosts at the Oosterbierum wind farm (2 km inland), where habituation was found to lead to calmer reactions instead of a reduced number of reactions (WINKELMAN 1992c). However, lacking barrier effects in flights to and from roosts or breeding colonies do not necessarily mean that wind farms are used as foraging or resting areas, i.e. habitat loss cannot be excluded on the basis of flights observed in a wind farm.

5.1.5 Summary of Species-Specific Effects of Offshore Wind Turbines on Seabirds

In this section, the results of studies from operating offshore wind farms and relevant results from onshore wind farms (Sections 3.1.1. to 3.1.3.) are summarised for the 35 seabird species regularly occuring in the German parts of the North and Baltic Seas (GARTHE *et al*. 2003a).

Red-throated Diver and Black-throated Diver: Although single divers were seen close to and even within the Nysted wind farm, the results from aerial surveys at Horns Rev and Nysted suggest that divers strictly avoid swimming or flying within wind farms. Low densities of divers were found at Horns Rev even in the WF+2 and WF+4 zones, indicating a typical avoidance distance of at least 2-4 km. Based on much less data, the same tendencies were recognised in Utgrunden. The strong avoidance of wind farms corresponds to the large escape distances observed in divers when encountering approaching ships. Since one collision victim was found at a coastal wind farm, divers must be considered as vulnerable to collision.

Great Crested Grebe: No information available.

Slavobian Grebe: The only information refers to four and five birds which migrated in the sub-zones without turbines near the wind farms Utgrunden and Yttre Stengrund, respectively, but this small sample size does not allow any conlusions to be drawn (Tables 4 and 5).

Red-necked Grebe: The only information about red-necked grebes and offshore wind farms refers to a flock showing panic reaction when crossing the Horns Rev wind farm.

Fulmar: The scarce information on this species refers to one bird heading south towards the Horns Rev wind farm, which deviated westward instead of flying into the wind farm. Three birds seen there during transect observations were flying outside the wind farm area. One casualty found at the onshore wind farm Blyth Harbour shows that even this usually low-flying species is at risk of collision.

Sooty Shearwater: The only bird seen during transect observations at Horns Rev was flying outside the wind farm, but no other information is available.

Gannet: No Gannets were recorded within the wind farm during aerial surveys at Horns Rev, and decreasing Jacobs indices in the surrounding zones suggest that this species avoids the wind farm area. This is underscored by the facts that only 1% of all Gannets were observed within the wind farm area via transect observations, and all flight paths recorded by radar kept their distance from the turbines.

Cormorant: This species does not generally avoid offshore wind farms. Cormorants resting on the foundations of turbines were reported from the Horns Rev, Tunø Knob and Nysted wind farms, and within the latter, large feeding flocks were observed. Foraging close to turbines was also seen at Utgrunden (and in Horns Rev the closely related Shag did so). Locally staging Cormorants regularly fly through rows of turbines (Utgrunden, Blyth Harbour), but on the other hand a large fraction of radar observations at Nysted can be attributed to this species, indicating that flying around the wind farm is common. The existence of a barrier effect is also clear from Horns Rev, where only 5% of all observed cormorants crossed transect lines concomitant with flights through the wind farm. Also at Utgrunden, the zones and sub-zones of the Kalmar Sound which include the turbines were used to a significantly lower extent by migrating Cormorants during operation than during the pre-construction period. Whereas in Horns Rev all Cormorants were flying at rotor height, only 10% did so at the onshore wind farm Blyth Harbour. Collisions victims were found at two coastal wind farms.

Greater Scaup: Although the results on nocturnal flight paths of diving ducks at the "semi-offshore" wind farm at Lely on the IJsselmeer primarily refer to Tufted Ducks, the temporary presence of Greater Scaups at this site sheds light on this species as well. The row of turbines, which intersects the diving ducks' flight path between foraging and resting areas, was generally avoided, but on moonlit nights some birds flew through instead of around the wind farm. Migration along sub-zones containing the turbines at Utgrunden and Yttre Stengrund further indicates that offshore wind farms do not act as barriers for Greater Scaups. Near the IJsselmeer seawall, the Greater Scaup has been found as a collision victim.

Eider: By far the most thoroughly investigated species in connection with offshore wind farms. Foraging Eiders occured at all sites between the turbines or close-by, but numbers were quite low before construction and during operation at Horns Rev, Nysted and Yttre Stengrund. Eiders were most present in the Tunø Knob wind farm, where the detailed study found that fluctuation of bird numbers was mostly due to changes in food supply. With respect to flight behaviour when approaching offshore turbines, there seem to be differences between migrating birds and those making local movements. Based on very large sample sizes, especially at Utgrunden, Yttre Stengrund and Nysted, it can be concluded that most migrating Eiders avoid flying through wind farms and rather fly around them. Such a barrier effect was also found for local movements at Tunø Knob at night, in particular on dark nights. In the daytime, there is a general statement from the Utgrunden study that foraging Eiders fly back and forth between the turbines. The row of turbines on the pier of Blyth Harbour was regularly passed by Eiders flying into the harbour or back during the first 2.5 years of the study. This seemed to be dangerous, for at least 12 birds collided with turbines. At offshore wind farms, detouring lowered collision risk considerably, although some flocks were reported to migrate between the turbines. According to data from Utgrunden and Yttre Stengrund, collision risk was on the one hand decreased by increasing flight altitude above rotor level when crossing the turbine rows. On the other hand, Eiders migrating near turbines increased flight altitude into the range of rotor height in the same wind farms, but the proportion of flocks involved in such high risk situations is very low. As a result, only one daylight collision was observed during the studies at the two Swedish wind farms, which included several hundred thousand birds. By contrast, a relatively large proportion of migrating Eiders (0.9% at night, 0.6% at daytime, including some geese) approached to less than 50 m from the Nysted turbines.

Long-tailed Duck: Although Long-tailed Ducks are not generally scared away by wind farms, their numbers were found to decrease after the construction of wind farms. At Nysted, the wind farm area changed from a preferred site (pre-construction phase) to an avoided site (construction and operational phase). At Utgrunden, Long-tailed Ducks remained in their foraging sites after the construction of turbines, but numbers were lower than before. In both studies it is unknown whether changes in the food supply contributed to the decline, but at Utgrunden, displacements appeared to be caused by service boats rather than by the turbines themselves. Based on a general statement it can be assumed that birds foraging at Utgrunden fly back and forth between turbines during daylight hours.

Common Scoter: Although Common Scoters are very abundant in the Horns Rev area, high year-to-year variation in numbers and distribution and lack of supplementary information on food supply make the interpretation of the results obtained by aerial surveys complicated. However, because only about one tenth the number of Common Scoters expected according to the baseline studies actually occurred within the wind farm and their numbers also dropped in the WF+2 and WF+4 zones, they seem to avoid operating wind farms strongly. It is noted that Common Scoters have been reported to occur in the areas of other offshore wind farms (and perhaps close to the turbines), but these reports provide no usable data, except for one observation of a flock of 12 birds within the Nysted wind farm and a map from Utgrunden with flocks less than 1 km from turbines. At Horns Rev, most Common Scoters seen flying were local staging birds. Those disturbed by ships in the vicinity of the wind farm flew around the turbines at a distance of 300-1000 m or even turned back. This strong avoidance is confirmed by only a very small fraction (1.1%) of birds flying inside the wind farm during transect observations. In a sub-sample of flocks observed visually, all birds either landed on the water well in front of the wind farm or changed their flight direction without entering. However, radar tracking has confirmed that Common Scoters actually do cross this wind farm.

Velvet Scoter: Like Common Scoters, only a very small share (0.6%) of the few observed Velvet Scoters passed the transect lines through the Horns Rev wind farm. By contrast to the pre-construction period, this species was not seen to migrate through the sub-zones with turbines at Utgrunden, and only a few did so at Yttre Stengrund. A barrier effect for flying Velvet Scoters can thus be assumed.

Red-breasted Merganser: At Utgrunden, Red-breasted Mergansers were present less than 1 km from the turbines. From occasional observations and the diurnal pattern of presence, it was concluded that service boats displace the birds temporarily, whereas operating turbines do not cause major disturbance. A total of 14 birds were seen in or near the Nysted wind farm during aerial surveys. At the Utgrunden and Yttre Stengrund wind farms, Red-breasted Mergansers have been recorded crossing the rows of turbines more often than other seabirds.

Pomarine Skua: No information available.

Arctic Skua: The only skua species commonly occurring at Horns Rev seems to fly into the wind farm without being disturbed; it is probably attracted by the gulls foraging between the turbines. During the transect observations, 26% of all birds crossed the transect lines which represent flights within the wind farm area. By contrast, it was assumed that Arctic Skuas avoided the Utgrunden wind farm because of the low share of that species migrating in the respective zone of the Kalmar Sound.

Great Skua: As only two birds were seen on transect lines outside the Horns Rev wind farm, no significant information is available on this species.

Little Gull: The Horns Rev wind farm area was avoided by Little Gulls before and during construction, but information for the operational period is contradictory. Data obtained throughout the first year of operation indicate preference for the wind farm area, whereas data from two spring seasons suggest avoidance. During one aerial survey (December 2003), the majority of all Little Gulls observed were foraging between the turbines. That the wind farm is not generally avoided is further confirmed by visual observations, in which 13% of the birds where seen to cross transect lines, which represent flying into or within the wind farm. However, as flight altitudes were unknown, no assessment of collision risk is yet possible.

Black-headed Gull: There are no data to date permitting assessment of potential habitat loss for this species at offshore wind farms. At coastal wind farms (Maasvlakte, Blyth Harbour), regular movements between breeding colonies, roosts and foraging sites cross rows of turbines. From Horns Rev, it is known that large shares (40% of observed birds crossing transect lines) fly through the wind farm. As the majority of gulls at this site fly at rotor height, Black-headed Gulls appear vulnerable to collision risk. In fact, the species was noted as a collision victim at 13 wind farms at or near the coast.

Common Gull: Although information about potential habitat loss is lacking, commonly occurring flights through the Horns Rev wind farm (46% of all birds crossing transect lines) suggest that there is at least no barrier effect for this species. As stated for gulls as a whole at Horns Rev, high percentages of birds flying at rotor height may indicate increased collision risk. At seven coastal wind farms, Common Gulls were found to collide with turbines.

Lesser Black-backed Gull: No information on potential habitat loss is available for this offshore-foraging species. For birds on flights between breeding colonies and foraging areas, it was observed that wind farms at the coastline do not act as a barrier. However, different degrees of reaction (detouring manoeuvres, turns) were observed for gulls, including large shares of Lesser Black-backed Gulls, at Zeebrugge (14-64% showing reaction) and Maasvlakte (3%) when flying through rows of turbines. The absence of a barrier effect was also observed at Horns Rev, where 32% of all birds crossing transect lines were flying within or into the wind farm. At Horns Rev and Maasvlakte, most gulls (including this species) were passing at rotor height, but in Zeebrugge only 32% did so. That this species is at risk of collision is shown by collision casualties found at Zeebrugge.

Herring Gull: Offshore turbines are not generally avoided by Herring Gulls, which were regularly seen in the Nysted and Horns Rev wind farm areas. At Horns Rev, Herring Gulls became more abundant during the operational phase and especially during construction. It was assumed that this was caused by attraction to slowly moving ships or the possibility of roosting outside the water; Herring Gulls were occasionally seen to rest on foundations. At the same site, 37% of the birds flew within the wind farm during transect observation. The lack of a barrier effect is known from coastal wind farms as well, although up to 42% of passing birds still show detouring manoeuvres or turns. Whereas at Horns Rev most gulls (including Herring Gulls) flew at rotor height, most birds were found to fly at altitudes below the rotor at coastal wind farms. Nevertheless, Herring Gulls were reported as collision victims at 11 onshore wind farms.

Great Black-backed Gull: At Horns Rev, Great Black-backed Gulls changed from strong avoidance during pre-construction to strong preference during operation. Like Herring Gulls, the attractive effects of ship traffic and resting places on foundations can be assumed as the reasons for the increase (the latter is proven by visual observations). No barrier effect appears to exist, as 35% of all birds seen in transect observations were flying within the wind farm. This corresponds to the observation that Great Black-backed Gulls commonly cross the row of turbines at Blyth Harbour. High percentages of gulls flying at rotor height at Horns Rev (but only 13% at Blyth Harbour) and collision victims found at Blyth Harbour and Zeebrugge indicate high vulnerability to collisions.

Kittiwake: Despite their low numbers recorded during aerial suryevs, Kittiwakes do not seem to avoid the Horns Rev wind farm: 24% of the birds observed crossing transect lines were within the wind farm, and resting on the foundations was reported. Casualties at two coastal wind farms provide evidence of vulnerability to collisions.

Caspian Tern: Little or nothing is known about Caspian Terns at wind farms, except that four birds were observed flying in sub-zones with no turbines at Utgrunden and Yttre Stengrund (Tables 4 & 5).

Sandwich Tern: According to transect observations at Horns Rev, Sandwich Terns commonly fly within the wind farm (51% of birds seen). Observations of flight altitude showed the great majority of terns flying low, and only 9% at rotor height; hence, vulnerability to collision may be relatively low.

Common Tern and Arctic Tern: The authors of the Horns Rev study do not consider the lack of these species within the operating wind farm to be of great importance, because the sample size was low and the birds (which actually preferred the zones around the wind farm) were concentrated in a few flocks. Because Common/Arctic Terns have been seen resting on the railings of the foundations, but on the other hand often left the area between the turbines soon after flying in, the results involving potential habitat loss are contradictory. The observed proportion of 30% of flying birds crossing the transect lines representing flights within the wind farm demonstrate that there is no general avoidance reaction to offshore turbines. Like at Horns Rev (9% of all terns), it was noted at Zeebrugge that only few birds (7%, Common Terns) fly at rotor height and pass below the rotor – just as at Yttre Stengrund, where migrating Common/Arctic Terns maintained their flight altitude of approximately 10 m even close to the turbines and did not deviate from their course. Common Terns flying to a night roost at Den Oever evaded a single turbine laterally, and evasive behaviour was noted in 4-31% (Zeebrugge) and 5% (Maasvlakte) of passing Common Terns. However, collisions can still occur, as casualties have been reported from Zeebrugge.

Black Tern: Information about Black Terns is restricted to their behaviour at a single coastal turbine at Den Oever, where they evaded laterally during flights to the night roost. One casualty was found at a coastal wind farm in Germany.

Guillemot and Razorbill: The Horns Rev wind farm seems to be avoided strictly by both auk species. Aerial surveys failed to record any bird within the wind farm during either construction or operation, and reduction in numbers was also noted in the WF+2 and WF+4 zones during operation (with no record there at all during construction). Furthermore, only two out of 53 birds (4%) flying across transect lines during visual observations were within the wind farm. Avoidance of wind farms is also indicated by a low proportion of auks migrating in the zone of the Kalmar Sound, in which the Utgrunden wind farm is located. Despite the general low flight altitude, a Guillemot was found as a collision victim at a coastal wind farm.

Black Guillemot: Before the Utgrunden turbines had been built, four out of 12 Black Guillemots migrating through zone C were seen in the sub-zones which later contained the wind farm. During operation, all 34 birds of zone C kept away from the wind farm sub-zones (Table 4), perhaps indicating avoidance.

Little Auk and Puffin: No information available.

5.2 Quality of Studies and Results

When discussing the quality of the studies on seabirds conducted at operating offshore wind farms, it is important to differentiate between the design and coverage of the studies on the one hand and how and to which extent the results are reported on the other hand. It must be stressed for all studies that the harsh marine environment restricts investigations to calm weather conditions, which are not representative, especially for autumn and winter. The researchers cannot be blamed for this shortcoming, because the methods applied cannot be used, e.g. during storms or high waves.

Tunø Knob, Denmark

A well-designed BACI study was conducted at Tunø Knob, some aspects of which lasted up to four years. However, a major point of criticism is that the baseline period for bird counts lasted only two months (mid-February to mid-April 1995), and largely addressed only one species, the Eider, with fragmentary results for one more, the Common Scoter. Moreover, the study was restricted to the winter and therefore failed to include: i) possible offshore foraging trips of breeding birds; ii) the moulting period of seaducks as a period of high sensitivity; and iii) migration periods with turnover of individuals which bring relatively high proportions of populations into contact with the wind farm.

The authors of the Tunø Knob study proposed that the high annual and spatial variation in Eider numbers was mainly caused by variations in the availability of profitable size classes of mussels. However, earlier comments raised the question as to whether the construction of the wind farm might have influenced the mussel abundance by sediment disturbance (TINGLEY 2003). Even when taking into account annually fluctuating numbers, Eider numbers increased in the fourth year of the study by 300% in the sector containing the turbines, but on average by 1900% in adjacent sectors. While the authors refer this to natural variation, TINGLEY (2003) pointed out that it is “more likely that these data indicate short-distance disturbance effects caused by the wind farm.” Detection of natural variation was impeded by the fact that only one baseline year was included in the study.

The radar studies on the nocturnal flight behaviour of Eiders are of high value, because in contrast to other wind farms, staging birds were observed during their local movements. In addition they show, how important it is to consider the conditions under which seabirds fly, especially visibility.

When assessing the results from Tunø Knob in the context of the general effects of offshore wind farms on seabirds, the fact that the farm has relatively few and – more importantly – relatively small turbines, which are not illuminated at night, should be considered. It is unclear how the findings from Tunø Knob can be transferred to large wind farms with turbines more than twice as high.

Utgrunden and Yttre Stengrund, Sweden

Compared to other studies, the investigation of the effects of the two wind farms on staging seabirds in the Kalmar Sound appeared to be less thorough and are based on a qualitative rather than a quantitative or systematic approach. First of all, counting methods did not include those used for seabirds in offshore areas for many years (TASKER *et al*. 1984, GARTHE *et al*. 2002) or developed recently (NOER *et al*. 2000, DIEDERICHS *et al*. 2002). Secondly, methods used, study plots and results are poorly documented and allow assessment only after some of the data has been recalculated. The results are only qualitative and only include some species in winter and spring, but not during the summer months. The decline in bird numbers found in several species after the construction of the wind farms are difficult to relate to the presence of the turbines. Natural variation cannot be excluded, especially because no information is available on food supply and related subjects. Finally, some results presented in different tables are contradictory, as mentioned above concerning divers. For these reasons, the seabird studies from Utgrunden and Yttre Stengrund have contributed relatively little to our understanding of seabird reactions to offshore wind farms as far as staging birds are concerned. One positive contribution has, however, been the description of the effects of service boats on the seabirds.

Much better documentation is available for flying seabirds. However, these results mainly refer to migrating birds, rather than flights of staging birds. The type of radar used did not allow detection of small flocks (e.g. smaller than 45-100 Eiders), which is why all local movements are probably excluded. Furthermore, the majority of birds observed were Eiders, and results of other species are often summarised without naming the species involved. Study periods were restricted to the peak periods of Eider migration, which also restricts the number of species included in the observations. A highlight of the studies is the use of an optical rangefinder, which allowed following the flights of seabirds close to turbines in 3-D. Regarding the focus of this report, the results of migrating seabirds from Kalmar Sound can provide some indication as to their behaviour, but in general, these results cannot be transferred to local flights of staging birds.

For the first time, Pettersson (2005) gave an estimate of collision risk for migrating waterbirds at the two offshore wind farms in the Kalmar Sound. He arrived at a value between one 20th and one 150th of those arrived at in calculations for a coastal wind farm in Belgium (see Table 9). It is important to realise that this estimate is based mainly on observations during good visibility and was extrapolated from only one witnessed collision. Furthermore, the great majority of data comes from Eiders, which are known to generally detour around wind farms. Hence, the low rate of collisions reported is not representative for seabirds in general and cannot be applied to staging seabirds.

Horns Rev and Nysted, Denmark

The bird studies at Horns Rev and Nysted followed a shared design and are therefore well comparable. They focused on the distribution of seabirds (aerial surveys) and the flight paths of birds (radar studies). The latter mostly referred to migrating birds, which were in fact the object of these studies. Hence, general answers to the question as to the flight behaviour of staging seabirds or of those conducting foraging flights could not be obtained. However, visual observations from the transformer station at Horns Rev gave valuable insight into the reactions of birds approaching the wind farm, and these observations to some extent involve local movements. Unfortunately, such observations are lacking from Nysted, where they might have been conducted from shipboard.

In order to investigate the distribution of seabirds in a large study area, the researchers chose aerial surveys rather than ship-based counts. Regarding the species of interest and those actually occurring in the area, this was certainly the right decision, because for most of these species aerial surveys are suitable or even recommended (CAMPHUYSEN *et al*. 2003, GARTHE *et al*. 2004). The standardised surveys made it possible to apply the selectivity index of Jacobs (1974) which is independent of the fluctuations in the numbers of seabirds present. Unfortunately, no surveys took place in late May, June or July, which prevented assessment of the effects on foraging seabirds during the breeding season. However, the inclusion of approx. three years of the pre-construction period provided a good basis for the detection of effects from the later construction and operation of the wind farm.

A major shortcoming of the seabird surveys is the lack of information on food supply. The objective of the benthos studies carried out at Horns Rev was to examine the effects on benthic organisms, not to provide e.g. a picture of their large-scale distribution or their annual variation. Especially the strong numerical and distributional fluctuations of the Common Scoter, one of the key species in the environmental impact assessment, could have been much better explained and might have led to a more accurate estimate of wind farm effects. The same is true of Long-tailed Ducks at Nysted.

Finally, the large number of turbines inevitably leads to frequent ship traffic for service and maintainance. Unfortunately, the amount of ship traffic in the wind farm area was not recorded during the aerial surveys. Therefore, effects ascribed to wind turbines may at least in part be due to disturbance by ship traffic (PETERSEN *et al*. 2004). At Horns Rev however, three of the four surveys conducted during the operational period of 2003 – all except the September survey – took place in periods of low ship traffic, as indicated by the logbook of a small vessel (TOUGAARD *et al*. 2004).

Despite some of the problems addressed above, the two Danish studies have substantially enhanced the knowledge of seabirds at offshore wind farms.

5.3 Effects of Other Technical Impact Factors on Seabirds in Offshore Areas

5.3.1 Offshore Platforms

As to habitat loss and barrier effects for seabirds, only little information is available from offshore installations, most of it from oil drilling platforms. Drilling platforms generally attract seabirds, leading to higher bird densities around them than in the adjacent sea areas (HAUGE & FOLKEDAL 1980, TASKER *et al*. 1986, WIESE *et al*. 2001). Apart from the opportunity for resting, the most important reason for such seabird concentrations seems to be the improved food supply due to waste, exhausted migrating landbirds, and zooplankton and small fish which are attracted at night by the lights (BOURNE 1979, JONES 1980, TASKER *et al*. 1986, WIESE *et al*. 2001). In addition, epibenthic organisms growing on the foundations may alter feeding conditions, as they can be preyed upon directly or attract other potential food organisms like fish (reef effect; CARLISLE *et al*. 1964, ORTEGO 1978, WOLFSON *et al*. 1979, JONES 1980, BAIRD 1990).

In Europe, attraction by artificial lights from offshore platforms, which occasionally causes collisions or burning in gas flares, is mostly reported for passerine migrants (SAGE 1979, HELBIG *et al*. 1979, HAUGE & FOLKEDAL 1980, JONES 1980, MÜLLER 1981, WALLIS 1981, DIERSCHKE 2004). In the Canadian Atlantic, it does not seem uncommon for Leach's Storm-petrels and Little Auks to be attracted by drilling platforms at night, with thousands of the latter species circling around a platform for hours (WIESE at al. 2001), but there is only one report of several hundreds supposed Storm Petrels being incinerated in the gas flare of a drilling rig in the North Sea (SAGE 1979). Seabirds that feed nocturnally on bioluminiscent zooplankton, especially juveniles just after fledging, seem instinctively attracted by artificial light sources in their search for prey (IMBER 1975).

5.3.2 Sand and Gravel Extraction

There are no studies directly related to the effects of aggregate extraction on seabirds. However, in addition to disturbance caused by human activity above the sea surface, the consequences of the deterioration of the benthic communities certainly have an impact on the food supply, and thus on the suitability of feeding areas for seabirds. For seabirds feeding on bivalves (e.g. scoters) which live in the upper layers of the sediment, resources are removed. Disturbance can also be expected for sandeels, especially if the preferred grain size of the sediment (WRIGHT *et al*. 2000) is changed. Sandeels are a key factor in marine food webs and of particular importance to seabirds, including such species listed in Annex I of the EU Birds Directive as the Red-throated Diver, the Sandwich Tern, the Common Tern and the Arctic Tern (FURNESS & TASKER 2000). Reduced availability of sandeels was found to reduce the breeding success of seabirds (FURNESS & TASKER 2000, FURNESS 2003). Therefore, it is likely that areas used for sand and gravel extraction will be of less value to seabirds for an indefininite period.

5.3.3 Ship Traffic

Behaviour of seabirds in relation to ships can be linked directly to the question of the environmental impacts of offshore wind farms. Not only the construction, but also the operation of wind turbines causes increased ship traffic for maintainance and service. While especially gulls are often associated with ships (e.g. GARTHE & HÜPPOP 1994), other seabird species are disturbed by them. However, information about habitat loss caused by ship traffic is scarce. During ship-based surveys in northern Europe it was noted that flushing distance varies among seabird species. Strong escape/avoidance behaviour and/or large flushing distances have been noted for divers, Slavonian Grebes, Long-tailed Ducks, scoters and Cormorants, while the opposite is true of Gannets, skuas, gulls and terns (intermediate behaviour in Great Crested Grebes, Red-necked Grebes, Eiders, Red-breasted Mergansers and auks; GARTHE & HÜPPOP 2004, GARTHE *et al*. 2004). Nearly the same assessment was made by CAMPHUYSEN *et al*. (1999), who included "escape behaviour" in a "traffic disturbance index". Compared to the above, these authors saw escape behaviour caused by ships as more pronounced in Eiders, but less so in Slavonian Grebes, Long-tailed Ducks and Red-breasted Mergansers.

It was discussed earlier that areas with much ship traffic tend to be avoided by the more sensitive species, especially divers and scoters (HÜPPOP *et al*. 1994, MITSCHKE *et al*. 2001). For example, densities of wintering divers were observed to be considerably lower in the Elbe shipping lane compared to the sea area just north of it (HÜPPOP *et al*. 1994). In the Pomeranian Bay, Long-tailed Ducks avoided the shipping lane despite of the high biomass of harvestable prey in part of this zone. This was probably due to an unfavourable energy balance caused by frequent flushing and diving when ships are passing (KUBE 1996).

The flushing distance of Common Scoters was examined experimentally in Liverpool Bay in the Irish Sea (KAISER 2004). With combined visual and radar observation, the distance between a ship cruising at 10 knots and flocks taking off for flight was estimated. Although no correlation between flock size and flushing distance was found, flocks flushing below 1 km distance were significantly smaller than those taking off at distances of 1-2 km from the approaching ship. Therefore, 1 km is the critical flushing distance at which flock size increased dramatically. The vast majority of large flocks took off at distances greater than 1 km. Smaller flocks (<15 birds) let vessels approach more closely, but showed alert postures before flying away. In addition, the observers noted wave effects, i.e. flushed flocks at closer distances prompted flocks further away (even >2 km) to take off as well.

6 Discussion

Compared to only a few years ago, the results of studies at offshore wind farms now provide improved insight into the reactions of seabirds towards these obstacles. While it is still difficult to give even rough estimates of additional mortality due to fatal collisions, it is possible for a number of species to estimate habitat loss and fragmentation – despite the lack of information on long-term habituation.

6.1 Collision Risk

Since several seabird species were observed entering offshore wind farms, a general collision risk can be assumed for them. This must be kept in mind when disussing the possible impact on protected species. For example, four species listed in Annex 1 of the EU Birds Directive (Little Gull, Sandwich Tern, Common Tern and Arctic Tern) are known to fly between offshore turbines. Unfortunately, knowledge related to collision risk is very limited and mainly refers to migrating birds rather than to local movements of staging birds or seabirds foraging offshore in the breeding season. To date, only one fatal collision has been observed (migrating Eiders, PETTERSSON 2005), and very few flight altitude measurements have been carried out near offshore wind farms (mostly for migrating seabirds). Hence, most information on collision risk of seabirds comes from coastal wind farms.

Observations at coastal wind farms are helpful when estimating the collision risk for seabirds. According to casualties recorded at turbines up to 4 km inland, at least 13 of 35 seabird species regularly occurring in German waters are affected by collisions. Primarily, gulls were reported as colliding with turbines, which indicates that birds which commonly fly into wind farms are most affected. This is underscored by the fact that the rate of collision calculated for gulls and terns at a coastal wind farm (EVERAERT *et al*. 2002) is many times higher than that estimated for migrating Eiders, which generally detour around wind farms (PETTERSSON 2005). The general risk is underlined by the fact that many birds pass turbines at rotor height (STILL *et al*. 1996, VAN DEN BERGH *et al*. 2002, EVERAERT 2003). In addition, the study at Zeebrugge has shown that the direction of turbine rows compared to the flight direction of seabirds is an important factor determining collision risk (more collisions when turbines are perpendicular to the flight paths, EVERAERT *et al*. 2002).

The studies conducted at both coastal and offshore wind farms came to the result that seabirds mostly avoid collisions by either flying detours around wind farms and turbines (e.g. DIRKSEN *et al*. 1998c, TULP *et al*. 1999, KAHLERT *et al*. 2004b, PETTERSSON 2005, CHRISTENSEN & HOUNISEN 2005) or by conducting swerves when ultimately confronted with the rotor (e.g. WINKELMAN 1992c, EVERAERT *et al*. 2002, PETTERSSON 2005). However, the detectability of the turbines seems to have an effect on the actual risk. In poor visibility – at night or under foggy conditions – migrating birds reacted to turbines to a lesser degree and at closer distances than under better conditions in daylight (KAHLERT *et al*. 2004b, CHRISTENSEN & HOUNISEN 2005, PETTERSSON 2005), but at Nysted a higher percentage of those Eiders and geese entering the wind farm came closer than 50 m to the turbines during daytime. Furthermore, radar tracking of nocturnal flights at the Horns Rev wind farm illustrated that adjustments of flight paths are less effective in avoiding turbines (CHRISTENSEN & HOUNISEN 2005). This implies that turbines, even when illuminated, are more difficult to detect by flying birds in darkness.

In fact, in a coastal wind farm in the Netherlands, a higher collision rate for birds flying through the rotating blades was observed at night (28%) than in daytime (7%) – although this study does not refer only to seabirds (WINKELMAN 1992b). In addition, STILL *et al*. (1996) pointed out that four of the 12 Eider collisions recorded at Blyth Harbour occurred within only one week, at poor visibility. In contrast to the findings of migrating birds, nocturnal flights of staging birds approached the wind farms at Lely (diving ducks) and Tunø Knob (Eiders) less during dark nights than on moonlit nights (DIRKSEN *et al*. 1998c, TULP *et al*. 1999). It is possible that staging birds are aware of the turbines within their home range and keep away from them under poor visibility conditions, but do not mind crossing the wind farm when they can detect obstacles.

Finally, regarding the nocturnal illumination of offshore turbines, it is unknown whether seabirds are attracted by artificial lights, which would increase collision risk. In the North Sea, there is only one uncertain report about Storm Petrels which had been attracted by the gas flare of a drilling rig (SAGE 1979; cf. also reports from the Canadian Atlantic in WIESE *et al*. 2001). This lack of information highlights the importance of future studies on mortality caused by offshore wind farms.

6.2 Habitat Loss

Physical habitat loss caused by the introduction of hard subtrate into a soft bottom environment seems negligible, because the proportion of soft bottom area lost is low (far below 1%) and the benthos as a food resource for seabirds appears hardly affected. For habitat loss due to displacement, studies in Denmark and Sweden have shown that at least in the first year after construction six seabird species (Red-throated Diver, Black-throated Diver, Gannet, Common Scoter, Guillemot and Razorbill) strongly avoided offshore wind farms (Table 18). In addition, Long-tailed Ducks did not generally keep away from them, but were present in reduced numbers. Another seven species occurred within wind farms and showed few obvious effects (Table 18). The numbers of three species (Little Gull, Herring Gull and Great Black-backed Gull) increased, and at least for the large gulls, an attraction effect by ship traffic and/or by resting opportunities on the foundations of the turbines can be assumed (CHRISTENSEN *et al*. 2003). For the remaining 18 species (including Fulmar, Velvet Scoter and Lesser Black-backed Gull) nothing is known on possible displacement.

Although some species appear unaffected by offshore turbines or may even gain increased food resources from invading hard bottom fauna, avoidance behaviour by other species may lead to displacement from habitats used prior to wind farm construction. The role of bird density at sea in the population dynamics of seabirds is unknown. For many species, mobile food resources such as fish stocks or discards from fishery make determination of areas of special importance difficult. The distribution of seabirds as a result of food distribution is better understood for sea ducks, which mainly rely on benthic bivalves. Prey density and water depth determine the importance of some marine areas and exclude others because food is either lacking or is too deep to allow profitable diving. Although bivalve consumption rates by sea ducks were found to be low in German waters (LEIPE 1985, NEHLS 1989, KUBE 1996), density may impact the mortality and reproduction of these and other species.

Table 18: Summary of the effects of offshore wind farms on the 35 seabird species regularly occurring in German marine areas (North and Baltic Seas). Species listed in Annex I of the EU Birds Directive are printed bold. Categories: Habitat loss – 00 strong avoidance, 0 reduced numbers, + occurring with no or only few effects, ++ increased numbers. Barrier effect – 00 strong avoidance, 0 detours occurring, + (commonly) flying through wind farms (* including information from coastal wind farms). Fatal collisions – 00 casualties at offshore and coastal wind farms, 0 casualties at coastal wind farms.

	Habitat loss	Barrier effect	Fatal collisions
Red-throated Diver	00	00*	0
Black-throated Diver	00	00	?
Great Crested Grebe	?	?	?
Red-necked Grebe	?	+	?
Slavonian Grebe	?	?	?
Fulmar	?	0	0
Sooty Shearwater	?	?	?
Gannet	00	00	?
Cormorant	+	0*	0
Greater Scaup	?	0*	?
Eider	+	0*	00
Long-tailed Duck	0	+	?
Common Scoter	00	00	?
Velvet Scoter	?	00	?
Red-breasted Merganser	+	+	?
Pomarine Skua	?	?	?
Arctic Skua	+	+	?
Great Skua	?	?	?
Little Gull	++	+	?
Black-headed Gull	?	+*	0
Common Gull	?	+*	0
Lesser Black-backed Gull	?	+*	0
Herring Gull	++	+*	0
Great Black-backed Gull	++	+*	0
Kittiwake	+	+	0
Caspian Tern	?	?	?
Sandwich Tern	?	+*	?
Common Tern	+	+*	0
Arctic Tern	+	+	?
Black Tern	?	+*	0
Guillemot	00	00	0
Razorbill	00	00	?
Black Guillemot	?	00	?
Little Auk	?	?	?
Puffin	?	?	?

As density effects have not been studied in seabirds, mechanisms of habitat loss known from other birds must serve as examples. A large number of waders, many of which breed in the Arctic, spend the non-breeding season in intertidal areas along the coastlines of all continents. Like sea ducks, they feed on benthic prey. The huge amount of data on foraging, food exploitation and bird movement of coastal waders has made the effect of habitat loss well known for them: Generally, wader density correlates with prey density in estuaries, with increased bird density leading to higher mortality rates or movement to other estuaries. Mortality increases due to lower intake rates caused by increased interference competition and more rapid exploitation of prey. Displacement to less favourable estuaries (or less favourable parts of the same estuary) usually occurs in young and subdominant individuals and also leads to lower intake rates in these individuals (GOSS-CUSTARD 1979, 1985, EVANS 1981, LAMBECK 1991, SUTHERLAND & GOSS-Custard 1991). As displaced individuals cause the same effect in the new estuary, habitat loss in one site can have an impact even on birds which never use this site ("knock-on effect", DOLMAN & SUTHERLAND 1995). If density-dependent mortality also occurs in seabirds during the non-breeding season, habitat loss caused by offshore wind farms may have effects similar to those which loss of estuarine habitats, e.g. by reclamation, has for waders.

Displacement may also impact the reproduction of seabirds. Lower intake rates due to density effects may reduce body condition at departure from wintering areas and/or spring staging sites, and hence lead to arrival at breeding areas in worse condition and/or at a later time. Carry-over effects which link events (e.g. disturbance) in winter and spring with reproductive output in summer have been found in several bird species. In five populations of geese, breeding success was lower when body condition before or during spring staging was poor (Pink-footed Goose: MADSEN 1995; Greater Snow Goose: BÊTY *et al*. 2003; Lesser Snow Goose: ANKNEY & MACINNES 1978; Barnacle Goose: PROP *et al*. 2003; Brent Goose: EBBINGE & SPAANS 1995, GANTER *et al*. 1997, STOCK & HOFEDITZ 1997). Pink-footed Geese and Brent Geese exposed to human disturbance during spring staging in Norway and the Wadden Sea, respectively, showed poor body condition and reduced breeding success (MADSEN 1995, STOCK & HOFEDITZ 1997). Also, after loosing habitat in reclaimed salt marshes in the Wadden Sea, displaced male Brent Geese were significantly less successful in breeding than control birds from other parts of the Wadden Sea (recalculated data from GANTER *et al*. 1997). The high connectivity between events in the annual cycle of birds was also shown by studies of the Mallard (KRAPU 1981) and a North American passerine, the American Redstart (SMITH & MOORE 2003). In the latter, early arrival of females increased the number of offspring (SMITH & MOORE 2005), indicating that right arrival time also affects breeding success. This is especially true for Arctic breeding birds, including seabirds, which must fit their breeding into a short period with no snow or ice.

If it occurs in a bottleneck situation, habitat loss can have a dramatic impact on a bird population. On their way to their Arctic breeding area, nearly all Red Knots wintering in southern South America stop over at Delaware Bay on the east coast of the USA, where they lay on fuel for the last stage of their flight, feeding nearly exclusively on the eggs of the horseshoe crab (*Limulus polyphemus*). After only a few spring seasons of shortage of prey, Red Knots faced both high adult mortality and low breeding success, leading to a dramatic population drop to nearly half the former size within only three years and a high risk of extinction of this subspecies (BAKER *et al*. 2004). If comparable bottlenecks also exist in seabirds, habitat loss would have a negative impact on their population sizes as well. It should be noted that bottlenecks for seabirds in northern Europe may occur either within an annual cycle (e.g. during the winter or spring staging), or over the course of several annual cycles, for example when most of the Baltic Sea is ice-covered in severe winters and seabirds have to move to the North Sea.

Because of the precautionary principle, the worst-case scenario where species completely avoid offshore wind farms and thus experience habitat loss should be taken into consideration. However, three open questions prevent generalisation:

First, it is still not known whether habituation will occur. Published results from the large Danish wind farms Horns Rev and Nysted cover only a short period of operation and thus as yet provide no information on habituation over a longer time scale. To date, avoidance of the Horns Rev wind farm by divers and auks was maintained during the second year of operation. The three-year study at the operating Tunø Knob wind farm overlapped strong fluctuations in both prey and bird densities; it, too cannot answer the question as to habituation. In an analysis of studies at terrestrial wind farms over several years, HÖTKER *et al*. (2004) found no general trend towards habituation, because according to the various studies, distances kept from turbines either increased or decreased over time.

Second, the size of wind farms and turbines may not be representative of future facilities, which will be larger than those built recently. For terrestrial wind farms, HÖTKER *et al*. (2004) tested the relationship between tower height and the distance birds kept during the non-breeding season. In most species, they found a positive correlation, although this was significant in only one species (the Lapwing). Therefore, taller turbines may have more pronounced effects on seabirds as well. On the other hand, distances between the turbines will also increase with turbine size and thus may offer enough space to move and forage in between them.

Third, there are indications that some of the displacements occurring in seabirds at operating offshore wind farms are caused by the traffic of service boats and even helicopters rather than by the turbines themselves (e.g. PETTERSSON 2005, PETERSEN 2005). Unless wind farms are completely free of such traffic, it will be difficult to assign reactions of birds to any source of disturbance. However, it became clear from several observations that the turbines themselves lead to avoidance by seabirds. At least some surveys at Horns Rev took place during periods of reduced or even no ship traffic (see 5.3.3). Furthermore, it was shown at the two wind farms in Kalmar Sound that flying Eiders are more likely to pass turbines when they are not operating (PETTERSSON 2005). However, the question of the respective roles of ship traffic and turbines appears to be negligible, since operating wind farms will always have some service and maintainance work. Nevertheless, future bird surveys at offshore wind farms should always include the monitoring of ship traffic in order to estimate its effect on seabirds.

6.3 Habitat fragmentation

Flights of seabirds can be attributed to two categories, flights between different areas used in an annual cycle (migration) and flights within areas (foraging flights, change of foraging sites, flights to roosts etc.; see below). When discussing the effects of offshore wind farms, these categories have to be reviewed separately. Whereas migrating seabirds are confronted with a wind farm only once or twice per year, frequent movements of seabirds within a staging area containing a wind farm bring seabirds close to turbines much more often (probably several times per day), and there are indications that birds are aware of the presence of the turbines (DIRKSEN *et al*. 1998c, TULP *et al*. 1999). However, knowledge about local movements of individual seabirds is scarce in some ways:

It is known that all seabirds breeding at the coast or on islands and foraging offshore regularly fly to and from their colonies; some species do so several times a day. This is most pronounced during chick rearing (e.g. Gannet, NELSON 2002; Lesser Black-backed Gull, GARTHE *et al*. 1999; Sandwich Tern, PEARSON 1968; Guillemot, GRUNSKY-

SCHÖNEBERG 1998). If wind farms present a barrier, foraging flights could last longer and cost more energy, and some foraging areas might become unprofitable.

Habitat fragmentation may also affect seabirds moving back and forth within staging areas for any reason. Outside the breeding season, seabirds feeding on discards concentrate at fishing vessels (e.g. CAMPHUYSEN *et al*. 1995) and therefore must be as mobile as fishing fleets are versatile. Other species such as divers fly in order to compensate drift (MELTOFTE & KIØRBOE 1973, NOER *et al*. 2000). Land-based observations also indicate that especially sea ducks change foraging areas within their winter quarters (e.g. BERNDT & BUSCHE 1993, HELBIG *et al*. 1996, GARTHE *et al*. 2003b). Common Scoters passing Helgoland in different directions throughout the year (DIERSCHKE *et al*. 2005) suggest movements across the German Bight between staging areas in the northern and southern parts of the Wadden Sea. Such movements even occur during the night, as recorded at the Tunø Knob wind farm (TULP *et al*. 1999). More regular flights include those between diurnal offshore foraging sites and nocturnal roosts at or near land (e.g. Red-breasted Merganser, DIERSCHKE 1987; Little Gull, SCHIRMEISTER 2001, 2002) – or the other way round as in nocturnally foraging Greater Scaups and other diving ducks (DIRKSEN *et al*. 1998b). We have the least information on such flights.

The effects of wind turbines on local movements of seabirds have been poorly investigated at sea, but additional information on this topic is available from coastal wind farms. Although migration is outside the scope of this study, the reactions of migrating birds may also help understand their behaviour when a wind farm is present in their staging or foraging area. Nevertheless, no information about their flight behaviour at wind farms is available for eight of the 35 German seabird species, and for some of the other species such information is very scarce. However, there is evidence that eight species commonly fly detours instead of crossing offshore wind farms (Table 18). This barrier effect suggests that their marine habitat can become fragmented through the establishment of wind farms, which would imply either higher energy costs due to frequent detours, or even loss of certain foraging areas, if reaching them came to be too energy-consuming. Interestingly, species showing avoidance during flight are the same as those listed in the category for habitat loss (the Velvet Scoter and the Black Guillemot are not mentioned, because information is lacking; Table 18).

Detours were also noted in another four species, but it is not clear whether this is a common phenomenon (Fulmar) or why it only occurs sometimes (Cormorant). In the case of nocturnal flights of Greater Scaups and Eiders, it was observed that the degree of darkness affects the level of detouring (DIRKSEN *et al*. 1998c, TULP *et al*. 1999). During migration, nearly all Eiders seem to fly around wind farms, but local movements also take place between turbines (TULP *et al*. 1999, PETTERSSON 2002).

Fifteen seabird species (Table 18) are known to fly through wind farms or rows of coastal turbines. Although for some species (e.g. Red-necked Grebe) it remains unclear whether this is common, most gulls and terns were observed to cross coastal wind farms on the way between offshore foraging areas and breeding colonies or roosts. It appears that these birds are familiar with the obstacles with which they are regularly confronted, but according to studies from Belgium and the Netherlands they still show avoidance behaviour (VAN DEN Bergh *et al*. 2001, EVERAERT 2003). Therefore, habituation seems to occur in breeding birds, which are more or less forced to fly through the wind farms. Observations from Horns Rev confirm that the same species do not avoid offshore wind farms. As in the section on habitat loss, the question as to whether habituation will ever occur among those species that have detoured around wind farms during the first year of operation remains open.

Regular detours and habitat loss due to fragmentation will have the same consequences as outlined in Section 4.2, i.e. reduced body condition may have an impact on mortality and reproduction. For Eiders detouring the single rows of turbines at Utgrunden and Yttre Stengrund, PETTERSSON (2005) calculated extra flight distances of 1.2-2.9 km, equivalent to 2-4 minutes extra flight time. This is only 0.2-0.5% of the 800 km long migratory journey in spring and autumn, but would be a larger proportion of smaller-scale diurnal movements. Much larger distances and times can be expected when Eiders and other seabirds are confronted with large wind farms several kilometres wide. However, it is possible that birds can compensate at least for the higher energy consumption by prolonging foraging time. Brent Geese were found to increase the duration of foraging when energy is lost due to flights caused by disturbance (STOCK & HOFEDITZ 1996). Such an adjustment of the time budget would appear easier for those seabirds which feed on a few large prey compared with those feeding on many smaller ones.

6.4 Assessment Methods

Until recently, commissioning of offshore wind farms presented a difficult challenge for the responsible authorities. Although most wind farm projects in offshore areas were preceded by environmental impact assessments, the impact that construction and operation would really have on seabirds living in the respective areas remained unknown.

In a basic approach, the NERI (2000) proposed that a wind farm should not affect protected areas such as SPAs. It was concluded that the distance between wind farms and protected areas should not fall below the escape distance shown by seabirds towards wind turbines. Meanwhile, and especially as a result of the studies at Horns Rev and Nysted wind farms, such distances are roughly known for a number of seabird species. While no measure at all is necessary for some species, others seem to require a safety margin of at least 1-2 km or even more. Thus, this assessment method seems applicable, although once again, the question of habituation remains an open one, and the size of safety margins will have to be adjusted when knowledge increases. The NERI (2000) further proposed that annual mortality rates should not increase by more than 5% due to collisions with turbines. Apart from the fact that such an increase would be critical for some seabird species – an additive mortality rate of only 0.3% for the Red-throated Diver or of 3% for the Herring Gull would negatively affect their population sizes (REBKE 2005, see also DIERSCHKE *et al*. 2003) – no such assessment is yet possible, because data on collision mortality at sea are lacking. Even for transferring increased mortality data to habitat loss and habitat fragmentation, this method cannot be applied, because density-dependent mortality and carry-over effects on reproduction rates have not been investigated in seabirds.

The Scottish Natural Heritage (SNH) and the British Wind Energy Association (BWEA) have developed a methodology for impact assessment which combines the sensitivity of the seabird species occurring with the magnitude of the disturbing effects. The sensitivity refers to the legal status of the species (e.g. listed in Annex I of EU Birds Directive or cited interest of SPAs) and the proportion of the national population which will be affected. The magnitude of likely effects is determined by the proportion of the local population which will loose habitat (PERCIVAL 2001). In a matrix combining both factors, the significance of an impact results in “unacceptable” or “acceptable”, with borderline cases needing more detailed consideration (Table 19). This approach has commonly been used by the German Marine and Hydrographic Agency (BSH) in the commissioning process for offshore wind farms in the Exclusive Economic Zone. However, the question as to which reference population area should be selected when determining the proportion of affected birds is still under discussion. Apart from this problem, recent results from seabird studies at operating offshore wind farms allow a much better assessment of the magnitude factor in this methodology. Furthermore, it is much better known which species must be considered, because some species experience no habitat loss. For those species which avoid wind farms, habitat loss can be estimated more precisely than before.

Table 19: Matrix of magnitude and sensitivity used to determine the significance of effects (see text for details). Very high and high significance indicate unacceptable impacts, whereas low and very low stand for acceptable impacts. Medium represents borderline cases, which may require mitigation measures. From PERCIVAL (2001).

		SENSITIYITY			
		very high	**high**	**medium**	**low**
MAGNITUDE	**very high**	very high	very high	high	medium
	high	very high	very high	medium	low
	medium	very high	high	low	very low
	low	medium	low	low	very low
	negligible	low	very low	very low	very low

An estimate of the importance of an area of sea can be the proportion of a population living in that area. Based on the Ramsar Convention of 1971, wetlands are of international importance when 1% of a biogeographical population occurs there regularly (at least once per year) (ATKINSON-WILLES 1972). This criterion is commonly applied in order to assess the importance of wetlands (e.g. HÖLZINGER *et al*. 1972, BERNDT *et al*. 1979, STRUWE-JUHL 2000). Although the value of 1% cannot be derived from population biology, it was proposed to apply this approximation be applied, too, for offshore areas insofar as habitat loss caused by offshore wind farms should not affect more than 1% of a population (DIERSCHKE *et al*. 2003). This criterion should be applied cumulatively, i.e. 1% refers either to the biogeograpic population and all offshore wind farms along the flyway, or to the national population and only the wind farms within the waters of one country (DIERSCHKE *et al*. 2003). Apart from which threshold level is used, the recent results from studies at offshore wind farms again give a much better impression as to which species must be addressed and how large the buffer zone around a wind farm should be. It should be noted that due to a high turnover of individuals, areas used during migration may provide refuelling resources for many more birds and thus a higher proportion of the respective population than indicated by averaged counting data.

GARTHE & HÜPPOP (2004) have developed a vulnerability index for seabirds, based on their behaviour and status. Specific sensitivity indices (SSI) can be combined for all species occurring in a given area to a value representing the sensitivity of a proposed wind farm area (windfarm senitivity index, WSI). To calculate the SSI, each species is scored on a scale of 1 through 5, according to assumed interaction with wind turbines, for nine factors: Flight manoeuvrability; Flight altitude; Proportion of time spent flying; Nocturnal flight activity; Disturbance by ships/helicopters, Habitat use flexibility; Adult survival rate; Biogeographical population size; and European threat/conservation status. The WSI includes the densities and SSIs of all species and indicates the vulnerability of the local seabird community to wind farms. As no factors contributing to the SSI/WSI are directly related to wind turbines, but only provide parameters for assessing potential effects, the results from recent studies at operating wind farms have not been included as yet. If more data becomes available, an improvement would be to consider alteration of flight altitude when facing offshore turbines. The only known example to date is the increase of flight altitude to rotor height by migrating Eiders when approaching offshore wind farms in the Kalmar Sound (PETTERSSON 2005), which increases collision risk considerably. Further updates of SSI and WSI may become necessary if certain parameters (e.g. population size, threat) change. However, it seems worth looking at the SSI values for the species and their behaviour at offshore wind farms. Although there is much overlap, those species which avoid wind farms have higher average SSI values than those which do not (Table 20). When deleting the part of the SSI referring to collision risk (the first four factors mentioned above), it is even clearer that the vulnerable species tend to avoid offshore wind farms (Table 20). Thus, the WSI can still give a very good impression of the vulnerability of marine areas. In future, if relevant data become available for all seabird species, this index could be improved by including factors directly related to offshore wind farms such as the degree of reluctance to entering wind farms or to foraging between turbines.

Table 20: Specific sensitivity indices of seabirds (after GARTHE & HÜPPOP 2004) with known reaction to offshore wind farms. The right column gives the SSI without reference to flight behaviour. Higher values indicate higher vulnerability to offshore turbines.

Species	Avoidance of wind farms	SSI	SSI without flight (rank)
Black-throated Diver	yes	44.0	16.0 (2)
Red-throated Diver	yes	43.3	17.3 (1)
Velvet Scoter	yes	27.0	12.0 (3)
Sandwich Tern	no	25.0	10.0 (4)
Cormorant	yes/no	23.3	9.3 (5)
Eider	yes/no	20.4	8.2 (7)
Great Black-backed Gull	no	18.3	7.3 (9)
Common Scoter	yes	16.9	7.5 (8)
Gannet	yes	16.5	6.0 (13)
Razorbill	yes	15.8	9.0 (6)
Common Tern	no	15.0	6.7 (11)
Lesser Black-backed Gull	no	13.8	5.5 (15)
Arctic Tern	no	13.3	6.7 (11)
Little Gull	no	12.8	7.3 (9)
Guillemot	yes	12.0	6.0 (13)
Herring Gull	no	11.0	4.0 (16)
Arctic Skua	no	10.0	4.0 (16)
Black-headed Gull	no	7.5	3.3 (18)
Kittiwake	no	7.5	3.3 (18)

6.5 Cumulative Effects

According to the definition in the United States' National Environmental Policy Act, cumulative effects are "the impact on the environment which results from the incremental impact of an action when added to other past, present, and reasonably foreseeable future actions" (COUNCIL ON ENVIRONMENTAL QUALITY 1997). Therefore, effects of a single offshore wind farm should not be assessed in isolation from other actions, but rather other causes of disturbance, regardless of quality, must be considered. This seems reasonable for two reasons.

First, effects from offshore wind farms on seabirds will impact their population dynamics as soon as mortality rates and reproduction rates are affected. However, single and relatively small disturbances, such as a small offshore wind farm, will fail to have detectable impacts on a population level in most cases, but the interaction of several small disturbances may do so. This applies to all kinds of possible effects combined, i.e. habitat lost in wind farm areas directly and habitat lost indirectly due to barrier effects (both influencing mortality and reproduction), as well as direct mortality from collisions.

Second, if density-dependent mortality occurs in seabirds, it will of course be necessary to consider not only all habitats lost by all offshore wind farms combined which reduce the entire habitat available for a given species, but in addition other sources of habitat loss as well. For example, marine areas disturbed by sand and gravel extraction cannot serve as replacement habitats for seabirds displaced from wind farm areas. How cumulative effects on seabirds can be assessed was demonstrated by the example of Common Scoters in Liverpool Bay (Irish Sea), where in a total area of nearly 5000 km² this species faces impacts from fishery, shipping, wind farms and related cable routes, oil/gas platforms and related pipelines, dumping, aggregate extraction and human recreation (OAKWOOD ENVIRONMENTAL LTD 2002).

6.6 Gaps in Knowledge and Need for Further Studies

Although knowledge of the effects of offshore wind farms on seabirds has increased recently, there are still large gaps which prevent detailed assessment. First of all, information is very scarce or even completely lacking for a number of seabird species (see Table 18). Some, such as the Fulmar, shearwaters, the Gannet and skuas occur in the southeastern North Sea in considerable numbers only during stormy weather or even gales (e.g. BRUNCKHORST & MORITZ 1980, CAMPHUYSEN & VAN DIJK 1983, KRÜGER & GARTHE 2002, PFEIFER 2003), and no studies have been undertaken during such adverse conditions. This points to another shortcoming: the behaviour of seabirds at wind farms during periods of strong winds, which usually occur together with rain and strong waves, both of which reduce visibility. To date, nearly all results available from seabird studies at wind farms have been obtained during calm weather (CHRISTENSEN *et al*. 2003). However, some species fly more easily and more often in windy situations, as has been demonstrated for the Fulmar (FURNESS & BRYANT 1996).

Most surveys of seabird distribution at wind farms have been conducted from fast-travelling aircraft, from which the activities of seabirds could not be recorded in detail. Ship-based surveys are better suited for ascertaining what seabirds really do when they stay inside wind farms, as they allow detailed observation of foraging behaviour (SCHWEMMER & GARTHE 2005). A related question is whether and to which extent seabirds make use of the recently developed hard bottom fauna on the foundations and scour protection of the turbines, but also of the possibly increased fish stocks.

Furthermore, future studies at offshore wind farms should include large-scale monitoring of relevant prey species, which so far has been done only in the study at the Tunø Knob wind farm. This would give further insight into the habitat quality of wind farms and could help explain observed seabird distribution.

However, the major gap in knowledge is that the behaviour of individual seabirds at sea and their interactive processes are quite unkown. Further studies will inevitably have to address the general biology of seabirds, i.e. their food and habitat requirements when living at sea, but also movements within their offshore habitats. The goal must be an understanding of density effects, which is the only possible approach to assessing the impact on population dynamics. With this information, it would be much easier to determine species-specific threshold levels to be used in environmental impact assessments, not only with respect to offshore wind farms, but also when looking at other impacts from human activities. Another factor acting on the population dynamics of seabirds, direct mortality from collision, still needs much more attention. Unfortunately, an applicable method is still in its infancy (DESHOLM 2003).

7 Conclusions

According to the results of the seabird studies at operating offshore wind farms, it would appear that the species living in German waters behave differently when confronted with wind farms. There are several species, which actively avoid offshore turbines, including at least two species listed in Annex I of the EU Birds Directive (Red-throated Diver and Black-throated Diver), and two more species, the Common Scoter and the Velvet Scoter, of which high proportions of the biogeographic population overwinter in German waters (GARTHE 2003). In addition, the lack of avoidance behaviour in other species basically brings them into risk of collision. This also applies to Annex I species (Little Gull and four species of tern). In some other species, the construction of turbines at sea will probably cause no major problems, at least in terms of habitat loss or habitat fragmentation.

Unless possible effects of habituation are understood well, the precautionary principle should be applied when assessing possible impacts of wind farms. Moreover, since wind farms and other technical impacts already exist or are planned along many of the flyways of the respective species, replacement habitats are not always available. Therefore, cumulative effects must be considered as well, because several smaller effects would add up to impacts on entire populations. However, much better knowledge of density effects at sea is urgently required to permit an appropriate assessment of such impacts on population size. Therefore, apart from studies of effects taking place directly at the wind farms, much more basic investigation into processes acting within overwintering seabird communities as well as the individual behaviour of seabirds at sea are strongly recommended.

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APPENDIX I

Systematic list of species mentioned in this report (English name – scientific name – German name)

Red-throated Diver – *Gavia stellata* – Sterntaucher
Black-throated Diver – *Gavia arctica* – Prachttaucher
Red-necked Grebe – *Podiceps grisegena* – Rothalstaucher
Great Crested Grebe – *Podiceps cristatus* – Haubentaucher
Slavonian Grebe – *Podiceps auritus* – Ohrentaucher
(Northern) Fulmar – *Fulmarus glacialis* – Eissturmvogel
Sooty Shearwater – *Puffinus griseus* – Dunkler Sturmtaucher
Storm Petrel – *Hydrobates pelagicus* – Sturmschwalbe
Leach's Storm-petrel – *Oceanodrom leucorhoa* – Wellenläufer
(Northern) Gannet – *Morus bassanus* – Basstölpel
(Great) Cormorant – *Phalacrocorax carbo* – Kormoran
(European) Shag – *Phalacrocorax aristotelis* – Krähenscharbe
Pink-footed Goose – *Anser brachyrhynchus* – Kurzschnabelgans
Snow Goose – *Anser caerulescens* – Schneegans
Barnacle Goose – *Branta leucopsis* - Weißwangengans
Brent Goose – *Branta bernicla* – Ringelgans
Shelduck – *Tadorna tadorna* - Brandgans
Gadwall – *Anas strepera* – Schnatterente
(Eurasian) Teal – *Anas crecca* - Krickente
Mallard – *Anas platyrhynchos* – Stockente
(Northern) Shoveler – *Anas clypeata* – Löffelente
Pochard – *Aythya ferina* – Tafelente
Tufted Duck – *Aythya fuligula* – Reiherente
Greater Scaup – *Aythya marila* – Bergente
(Common) Eider – *Somateria mollissima* – Eiderente
Long-tailed Duck – *Clangula hyemalis* – Eisente
Common Scoter – *Melanitta nigra* – Trauerente
Velvet Scoter – *Melanitta fusca* – Samtente
Red-breasted Merganser – *Mergus serrator* – Mittelsäger
(Northern) Lapwing – *Vanellus vanellus* – Kiebitz
Red Knot – *Calidris canutus* – Knutt
Pomarine Skua – *Stercorarius pomarinus* – Spatelraubmöwe
Arctic Skua – *Stercorarius parasiticus* – Schmarotzerraubmöwe
Great Skua – *Catharacta skua* – Skua
Little Gull – *Larus minutus* – Zwergmöwe
Black-headed Gull – *Larus ridibundus* – Lachmöwe
Common Gull – *Larus canus* – Sturmmöwe
Lesser Black-backed Gull – *Larus fuscus* – Heringsmöwe
Herring Gull – *Larus argentatus* – Silbermöwe
Great Black-backed Gull – *Larus marinus* – Mantelmöwe
Sabine's Gull – *Xema sabini* – Schwalbenmöwe
(Black-legged) Kittiwake – *Rissa tridactyla* – Dreizehenmöwe
Caspian Tern – *Sterna caspia* – Raubseeschwalbe
Sandwich Tern – *Sterna sandvicensis* – Brandseeschwalbe
Little Tern – *Sterna albifrons* - Zwergseeschwalbe
Common Tern – *Sterna hirundo* – Flussseeschwalbe
Arctic Tern – *Sterna paradisaea* – Küstenseeschwalbe
Black Tern – *Chlidonias niger* – Trauerseeschwalbe
(Common) Guillemot – *Uria aalge* – Trottellumme
Razorbill – *Alca torda* – Tordalk
Black Guillemot – *Cepphus grylle* – Gryllteiste
Little Auk – *Alle alle* – Krabbentaucher
Puffin – *Fratercula arctica* – Papageitaucher